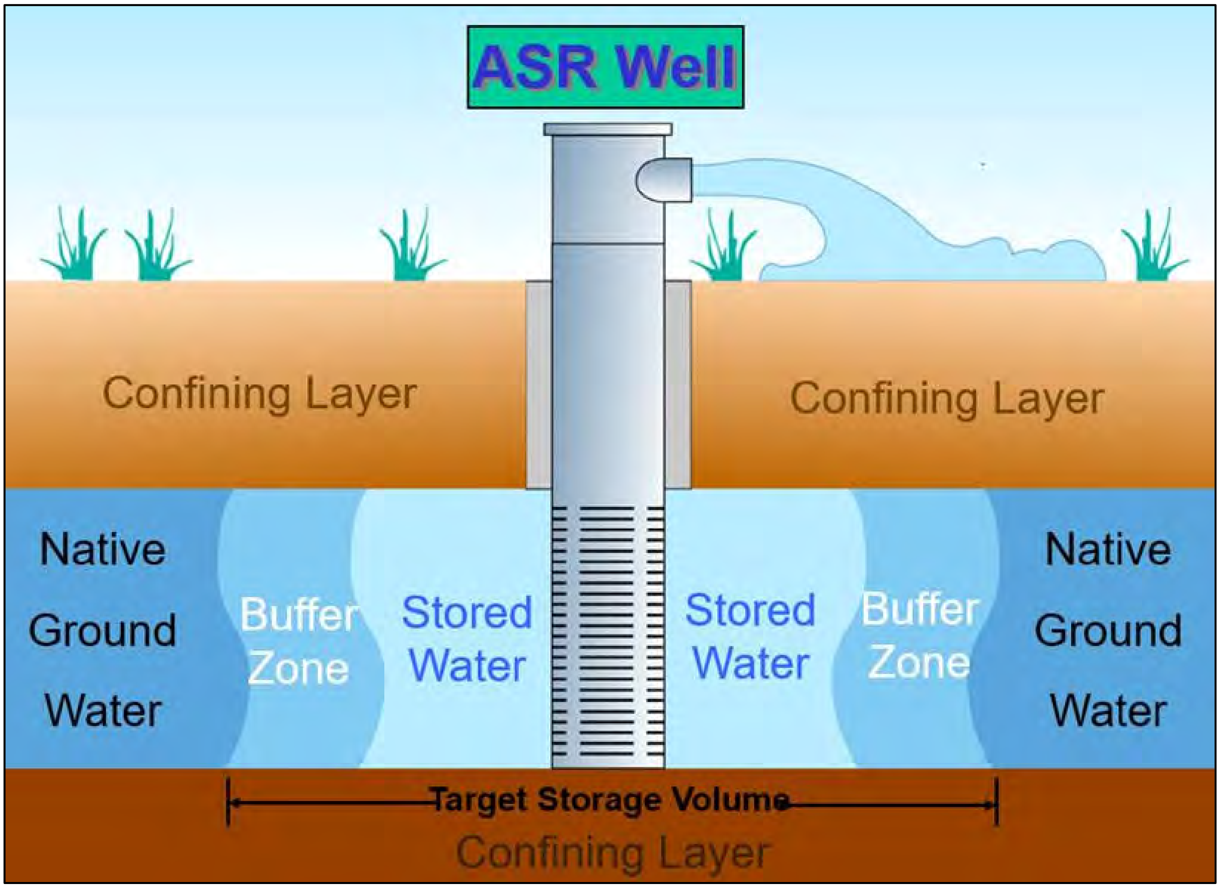
2021 Aquifer Storage and Recovery Science Plan

Appendices



Final

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APPENDIX A:

CHRONOLOGY OF SFWMD ASR AND SUBSURFACE STORAGE STUDIES, PUBLICATIONS, AND MILESTONES

Appendix A Chronology of SFWMD ASR and Subsurface Storage Studies, Publications, and Milestones

(projects and investigations funded wholly by the SFWMD or in cooperation with other Water Management Districts, the USACE, the USGS, the Florida Geological Survey, and/or consultants)

1986 SFWMD construction and operation of the L63N (Taylor Creek) ASR system, utilizing an aquifer exemption for recharge and storage without disinfection

1999 ASR "Issue Team" Report (formed by the South Florida Ecosystem Restoration Working Group); designating 7 main questions regarding the use of ASR technology

1999 Publication of the Yellow Book, including the use of up to 333 ASR wells; included construction of pilot projects

2001 Publication of National Academy of Science critique of the draft CERP ASR Pilot Project Project Management Plans

2001 Construction of ASR/exploratory wells at Port Mayaca, Moore Haven, Berry Groves (C-43), Kissimmee River, and the Hillsboro Canal

2002 Publication of National Academy of Science critique of the draft CERP ASR Regional Study PMP

2002 USGS report: "Inventory and review of aquifer storage and recovery in southern Florida"

2003 Consultant's report: "Analysis of available oil field seismic reflection data to assess its usefulness in deducing regional south Florida geology"

2003 USGS analysis of sequence stratigraphy of cores from the Floridan Aquifer System to determine if predictive patterns of favorable storage zones can be estimated from existing well data

2003 Consultant's report: "Water quality treatment technology pilot investigation to determine optimal processes for surface water for recharge"

2004 Consultant's report: "Survival of fecal indicator bacteria, bacteriophage and protozoa in Florida's surface and groundwater"

2004 USACE report: "Lineament Analysis, South Florida ASR Regional Study" (Unpublished)

2004 Environmental Impact Statement and Pilot Project Design Report for CERP ASR Pilot Projects at Lake Okeechobee, Hillsboro Canal, and C-43 (Berry Groves)

2004	USACE report: “Water Quality Changes During Cycle Testing at Existing ASR Systems”
2005	USGS report: “Synthesis of Regional Hydrogeological Framework of the Floridan Aquifer”
2005	USACE report: “A Scientific Evaluation of Pressure Induced Constraints and Changes within the Floridan Aquifer System and the Hawthorn Group”
2005	USGS report: “Characterization of Native Microbial Communities in Waters Targeted for ASR”
2005	Consultant’s report: “Screening-Level Investigation of the Ecotoxic Effects of Recovered Water on Receiving Waters using Pilot Project Recovered Water – Phase 1”
2005	Hillsboro Aquifer Storage and Recovery Pilot Project, construction plans and specifications
2005	Kissimmee River Aquifer Storage and Recovery Pilot Project, construction plans and specs
2006	USACE report: “Geochemical Models of Water Quality Changes During ASR Cycle Tests, Phase 1: Models Using Existing Data”
2006	USACE report: “Development of an ASR Site Selection Suitability Index in Support of CERP”
2006	USACE report: “Groundwater Numerical Model Development Support and Data Collection Report”
2006	USACE report: “Bench-Scale Groundwater Flow Modeling for the ASR Regional Study”
2006	SFWMD construction and testing of FAS wells in Allapattah, Berry Groves, S-65A, S-65C, LaBelle, Clewiston, the L-8 Canal, and Port Mayaca to supplement and expand the regional FAS monitoring network
2006	USGS Report: “Hydrology and Aquifer Storage and Recovery Performance in the Upper Floridan Aquifer, Southern Florida”
2006	Consultant’s report: “Conversion of OKF-100 monitoring well”
2007	Consultant’s report: “Lake Okeechobee Marine Seismic Geophysical Investigation”
2007	Consultant’s report: “ASR Arsenic Surrogate Model”
2007	Consultant’s report: “Feasibility Assessment of Deep Well Injection to Assist in Management of Surface Water Releases from Lake Okeechobee to Estuaries”
2007	Consultant’s report: “Analysis and Interpretation of Cross-well Seismic and Well Logs for Estimating Lateral Porosity and Permeability Variations in the Inter-well Region at Port Mayaca, Florida”

2007 Consultant’s report: “CERP ASR Baseline Environmental Monitoring Summary Report”

2007 Consultant’s report: “Construction of an exploratory ASR test well at the Seminole Tribe Brighton Reservation”

2007 USGS report: “An Assessment of the Potential Effects of ASR on Mercury Cycling in South Florida”

2007 Consultant’s report: “Phase 2 Report – Ecotoxic Effects of Recovered ASR Water, Mobile Bioconcentration Lab, Mesocosm Methods Evaluation, and Conceptual Ecological Model Development for the ASR Regional Study”

2007 FGS report: “Geochemical and Mineralogic Characterization of Potential ASR Storage Zones in the FAS”

2007 Port Mayaca Aquifer Storage and Recovery Pilot Site, construction plans and specifications

2007 Consultant’s report: “MF-37 Dual-Zone Monitoring Well Conversion at Port Mayaca”

2007 Consultant’s report: “Installation of MW-10 (350 ft Storage Zone Monitor Well at KRASR)”

2007 Consultant’s report: “Modification and Testing of ASR Test Well LAB-PW at the Labelle ASR Test Site”

2007 Consultant’s report: Installation of surficial aquifer monitoring wells at Kissimmee River and Port Mayaca ASR pilot projects”

2007 Consultant’s report: “Rehabilitation and testing of the ASR test well at the L-2 Canal site, near Clewiston, FL”

2008 SFWMD construction of an exploratory test well and evaluation of a 10-well ASR system at Paradise Run

2008 SFWMD report: “2008 ASR Program Interim Report”

2008 USGS report: “Synthesis of the Hydrogeologic Framework of the FAS and Delineation of the Avon Park Permeable Zone in Central and Southeast Florida”

2008 Consultant’s report: “Induced rock fracturing laboratory testing” data report

2009 Initiation of cycle testing at the Kissimmee and Hillsboro ASR pilot systems

2009 Consultant’s report: Strategies to minimize arsenic mobilization during aquifer storage and recovery cycle testing – a desktop analysis”

2010 Florida Geologic Survey report: “Geochemical, Mineralogic and Petrographic Characterization of Rocks Comprising the upper FAS in south Florida”

2010	Consultant’s report: “Construction of proximal monitor well MW-18, Kissimmee River ASR Pilot Site, FL”
2010	Consultant’s report: “Construction of distal monitor well MW-19, Kissimmee River ASR Pilot Site, Florida”
2011	USACE report: “Final Groundwater Model Calibration Report – ASR Regional Modeling Study”
2011	Consultant’s report: “Rehabilitation of ASR well EXKR-1 at Kissimmee River ASR Pilot Site, Florida”
2012	Consultant’s report: “CERP ASR Lake Okeechobee Submerged Aquatic Vegetation Model: Enhancement and Application”
2012	Publication: “Hydraulic fracturing of the Floridan Aquifer from Aquifer Storage and Recovery operations”
2013	Completion of cycle testing at the Kissimmee and Hillsboro ASR pilot systems
2013	Publication of “Final Technical Data Report – CERP ASR Pilot Projects at Lake Okeechobee (Kissimmee) and the Hillsboro Canal”
2013	Consultant’s report: “Everglades Landscape Sulfate Dynamics: Final Summary Evaluation of CERP ASR Alternatives”
2013	USACE report: “Regional ASR Groundwater Model Production Scenario Report”
2013	USACE report: “Local Scale Modeling Report for the Kissimmee River ASR Pilot Site”
2013	Publication: “Arsenic control during aquifer storage recovery cycle tests in the Floridan Aquifer”
2014	USGS report: “Survival of Bacterial Indicators and the Functional Diversity of Native Microbial Communities in the FAS, south Florida”
2014	USGS report: “Hydrogeologic framework and geologic structure of the Floridan Aquifer System and Intermediate Confining Unit is the Lake Okeechobee area, Florida”
2015	Publication of “Final Technical Data Report – ASR Regional Study”
2019	USGS report: “Microbial Inactivation and Nutrient Cycling in Aquifer Zones Targeted for ASR”
2019	Consultant’s report: “Application of High Definition 2D and 3D Seismic Tests for Characterization of the Floridan Aquifer System in the Lake Okeechobee Area”
2020	USGS report (pending): “Nutrient Removal and Uptake by Native Planktonic and Biofilm Bacteria Communities within an Anerobic Aquifer”

APPENDIX B:
AQUIFER STORAGE AND RECOVERY PEER REVIEW PANEL FINAL REPORT

Aquifer Storage and Recovery Peer Review Panel

Final Report

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Submitted to the South Florida Water Management District

November 12, 2020

Contents

Executive Summary

Successful application of aquifer storage and recovery (ASR) as part of the Comprehensive Everglades Restoration Plan relies on a scientific review feedback loop that has been maintained since the initial phase of restoration planning. The South Florida Water Management District (SFWMD) continues this practice through inception of the ASR Peer Review Panel (PRP). The panel has been asked to review recent accomplishments, plans and activities related to ASR as described in recent reports, and especially in context of recommendations made by the 2015 National Research Council review. Additional information was provided to the PRP during a July 2020 public workshop, where the SFWMD ASR team briefed the panel on current and planned ASR activities. The panel subsequently collaborated to develop the report herein, which outlines comments, suggestions and recommendations offered for consideration to the SFWMD ASR team as that team develops an ASR Science Plan.

Feedback offered in this report is thematically framed on research targeting multiple scales, operational and project management considerations. Some recommendations relate to cost-benefit analysis of approaches that have either been undertaken or are under consideration. For example, the PRP recommends evaluating regional permeability distribution and wellfield-scale fluid migration through a cost-benefit analysis of 2D and 3D seismic surveys relative to detailed sequence stratigraphic analysis. At the wellfield scale, this includes assessment of potential benefits from cross-borehole tomography and flow-zone analysis. This is not to imply the outcome should be one technique or the other, as a hybrid approach may be the best path forward.

Another multiscale recommendation relates to the need track hydrologic model uncertainty from regional to wellfield scales. Related to local-scale modeling, the PRP promotes a different parameterization approach that may be better suited for semiconfined aquifer systems. Moreover, with the potential for fluid movement during ASR to be affected by complex karst-related porosity systems, advanced surface geophysical analyses and additional borehole geophysical and imagining analyses methods are suggested.

Comments related to well and wellfield design emphasize considerations of variably dense fluids (i.e., salinity contrasts), and geometric placement of wells to leverage use of groundwater flow gradients to potentially improve recovery efficiencies. Operational recommendations also relate to future wellfield geometries, and the PRP suggests ongoing consideration of ASR-hybrid systems such as co-located application of interaquifer transfer, bank filtration or deep-well injection. Suggestions are also made in reference to pumping sequences, well-screen maintenance and potential tidal pressure influences. The PRP agrees that application of the practice of target storage volume (TSV) is appropriate for brackish native groundwater storage zones; however, the technique may not yield operational benefits in freshwater aquifers. Strategic use of TSV may also address some water-quality and biofouling concerns.

Multiple suggestions and recommendations are made by the PRP related to water quality. Several unknowns exist regarding spatial and temporal water quality concerns and processes. As the scientific understanding this complex and dynamic restoration advances, so will the emergence of new unknowns that require robust and adaptive approaches. During recharge, recovery and outfall events, time-series water quality analyses should be used to determine if mitigation of water quality issues in the aquifer or downstream is needed. Broad spectrum hydrogeochemical analyses are also recommended, especially during the early phases of all new installations as the behavior and influence of dissolved constituents on the ecosystem are not well understood for all constituents. The PRP specifically highlights concerns about arsenic, dissolved sulfate, total mercury, molybdenum, uranium, radium and gross-alpha activity. The PRP also offers suggestions about pre- and post-treatment options.

The ongoing work by the US Geological Survey on nutrient reduction and by the US Army Corps of Engineers on aquifer geochemistry should continue; however, more research is needed to improve understanding of the ecological and ecotoxicological impacts of discharging ASR recovered water to the Everglades wetlands, canals, Lake Okeechobee and downstream areas. Long-term studies of ecosystem response in the Everglades to additional nutrients and other constituents indicate a cascade of responses with soil properties being an important sink/source of nutrients and metals. The PRP suggests the SFWMD ASR team include a plan to characterize the current soil and vegetative conditions in receiving wetland restoration areas co-located with the ASR wells.

The SFWMD ASR team utilizes several contractors and each needs to be fully aware of all program elements. An increased effort to integrate and synthesize data and research would allow a clear explanation of a cohesive set of results and conclusions and increase the transparency and credibility of the science being accomplished. In addition, coordination with the activities of the Central Florida Water Initiative is recommended, and periodic CERP ASR technical workshops are recommended to help improve communications and task integration among scientists. Task integration will also benefit from development and implementation of a comprehensive information management plan. Such a plan will ensure both internal and external access to relevant data over both the short and long term, facilitate data analyses and syntheses across multiple data types and sources, buffer against the potential turnover of key personnel, and increase transparency and communication to stakeholders as the CERP is implemented and evaluated.

The SFWMD ASR team is to be complemented on its implementation of adaptive management and continued process improvement. Past efforts to monitor recommendations, progress and responses historically took the form of an “ASR report card”. The PRP recommends development of a similarly clear tracking method to represent how NRC 2015 Report recommendations, as well as those offered herein, are addressed.

The current SFMWD ASR team consists mainly of hydrogeologists and one microbial ecologist. The PRP recommends the team include additional scientists/experts in the fields of ecology (periphyton), ecotoxicology, as well as soil or wetland science, monitoring plan design, and karst geoscience. Broadening the team’s scientific scope will increase confidence that the SFWMD is considering all scientific aspects and maximizing uncertainty reduction related to ASR operations and the environment. Furthermore, the panel recommends addition of a microbiologist to serve on the PRP.

The PRP recommends that a comprehensive Science Plan be developed related to their proposed ASR research activities, testing and operations. This plan should include research and monitoring for ecological and potential ecotoxicological impacts resulting from the release of recovered water to the restored wetland areas, canals or Lake Okeechobee.

Developing and implementing a comprehensive ASR science plan is not trivial, and adequate time and resources should be made available. The SFWMD ASR team is planning an incremental, phased approach going forward, and the PRP agrees with such a strategy. In summary, the PRP has concerns, suggestions, and recommendations for the SFWMD ASR team as described herein; however, in agreement with the 2015 NRC report, no fatal flaws were identified. While there is much additional work to be done, there is enough information to move forward with partial implementation of ASR using an adaptive strategy to monitor new well clusters in an operational capacity and change timing/volume of recharge and recovery as needed to optimize operational and ecological benefits.

Introduction

The application of aquifer storage and recovery (ASR) to support water management goals within the Comprehensive Everglades Restoration Plan (CERP) was first proposed in 1996 by the Governor's Commission for a Sustainable South Florida. Specifically, the commission recommended, "ASR technology should be investigated to determine its feasibility at a regional scale." Since that time, dozens of studies have been conducted or initiated by the South Florida Water Management District (SFWMD), the US Army Corps of Engineers, and multiple partners with the goal of successful, sustained, and environmentally sound implementation of ASR within CERP. Across more than two decades that followed, planning, research and pilot study implementation has continued with the benefit of external scientific review. Examples include the 1999 ASR Issue Team, multiple reports of the National Academy of Sciences Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE), and in 2015, the Review of the Everglades Aquifer Storage and Recovery Regional Study by the National Research Council (NRC).

In 2020, the South Florida Water Management District (SFWMD) assembled an ASR Peer Review Panel (PRP) of experts to prepare their thoughts, ideas, or suggestions on the CERP ASR plans. This review was to include an assessment of any remaining questions or concerns about ASR such as those identified in the 2015 NRC report. The report herein outlines the findings of the PRP based on review of documents provided by the SFWMD ASR team as well as presentations made by the SFWMD ASR team and others during a public workshop on July 22 and 23, 2020.

In addition to the 2015 NRC report, the PRP reviewed the 2008 CERP ASR Interim Report, the 2013 CERP ASR Pilot Project Technical Data Report, and the 2014 CERP ASR Regional Study Final Report. These documents summarize historical construction, operations, testing and modeling. The presentations on July 22, 2020 included summaries of historical ASR testing activities along with the results of more recently conducted microbial-water-rock experiments and some ecotoxicity testing. A presentation made on July 23, 2020 consisted of 30 slides with one entitled "Lake Okeechobee Watershed Project (LOWRP) Recommended Plan" that outlined planned activities of the SFWMD ASR team going forward.

The SFWMD ASR team consists of experienced scientists who have conducted important hydrogeologic site investigations, geophysical research, hydrogeological modeling, laboratory testing and pilot testing of ASR sites near Lake Okeechobee. This team has significantly advanced knowledge of the Floridan aquifer system in South Florida.

The PRP compliments the authors of these reports and the presenters at the workshop on their thorough and highly professional work. The presentations represent an incredible diversity of topics and the PRP appreciates the extensive briefings. All of the panel's questions were answered and the presenters displayed a thorough understanding of their science and the project. It is apparent that the District and their colleagues have been pro-active and sincere in their undertaking of the recommendations of the 2015 NRC report.

In terms of the charge given to the PRP, it is noteworthy that the PRP was neither presented with a written plan of how the SFWMD team is moving forward with its ASR operations nor how the District team explicitly plans to address the uncertainties identified by the 2015 NRC report. This observation, which was reinforced by public comment during the workshop, underscores an overarching recommendation by the PRP that a comprehensive Science Plan be developed related to their proposed ASR operations, including research and monitoring for ecological and potential ecotoxicological impacts resulting from the release of recovered water to the restored wetland areas, canals or Lake Okeechobee. In addition to the 2015 NRC report, the PRP findings herein provide a foundation for development of the Science Plan.

The 2015 NRC report stated there were no fatal flaws in the 2014 Florida ASR Regional Study Technical Data Report; however, it also stated that "Although current uncertainties are too great to justify near-term implementation of ASR at a large scale in the Everglades, opportunities exist to target future phased implementation of ASR in a way that addresses critical uncertainties while providing some early restoration benefits."

The high-priority actions identified in the 2015 NRC report are reiterated here:

Operations to Maximize Recovery and Reduce Water Quality Impacts are recommended by establishing a freshwater buffer zone, possibly through the use of well pairs or clusters, which could have implications for the ecotoxicity of the recovered water and arsenic mobilization and attenuation.

Ecotoxicology and Ecological Risk Assessment of ASR operations on the Everglades particularly during recovery operations under dry, low-flow conditions, including the possible impacts of additional calcium and hardness on soft-water areas of the Everglades, are needed.

Understanding Phosphorus Reduction Potential in terms of long-term rates and extents of subsurface phosphorus removal under various aquifer conditions is needed.

Disinfection studies are needed to develop appropriate pre-treatment strategies without hindering subsurface biogeochemical processes that attenuate dissolved arsenic. Additional studies are needed on a wide suite of pathogens to understand their survival in groundwater and the level of disinfection necessary to protect human health.

Cost and Performance of ASR Compared to Alternatives analysis, including a cost-benefit assessment for water storage alternatives and performance uncertainties, is needed so that decisions can be made about continued support of ASR. The comparative costs for STAs, reservoirs, and funding the right to flood agricultural lands should be compared to ASR.

Several additional or more specific recommendations exist within the 2015 NRC report.

The following comments, concerns, and suggestions by the PRP are organized by subject. In some cases, these subjects overlap. Items that include more than one subject heading are cross-referenced to foster discoverability. There is no implied significance to the order of these comments.

Regional scale characterization

Rock fracturing analysis

The rock fracturing analysis indicates that it should not be a problem in the normal operation of the regional ASR system. Results of this analysis seem conservative, especially above the Upper Florida Aquifer (UFA). There are improvements that could be realized in the analysis that would likely assist in evaluating the risk of unexpected movement of injected water. First, the principle stress produced in a horizonal-bed aquifer in the horizontal plane would produce horizontal fractures with high apertures at the borehole interface, not vertical fractures. Second, to keep the fractures open a proppant (e.g., quartz sand) would have to be injected under high pressure. When the applied stress is terminated (pumps are shut down), the vertical load is likely to cause annealing of the fractures both at the large scale and the micro-scale. The only way to induce significant vertical fracturing would be to drill a horizontal offset well, common in petroleum and natural gas development. In addition, the relatively finer-grained and less consolidated sediments overlying the UFA are likely to resist fracturing. The physical response would be minor compaction along the boundary with the UFA. (see also Wellfield Scale – Seismic Monitoring).

Permeability distribution

The PRP has a concern regarding the application of sequence stratigraphic analysis to site future ASR wells or clusters of wells. While the analysis is useful in understanding the general changes in facies with a timeframe, it is not always useful in terms of understanding the distribution of permeability, which is scale dependent. A carbonate platform like Florida tends to exhibit a high degree of variability on a scale of a few kilometers. Use of sequence stratigraphic data from individual wells for the purpose of a regional analysis to optimize ASR wellfield locations would have limited practicality. The number of wells required to do a useful analysis is far greater than proposed. Moreover, the usefulness of individual wells becomes more important when detailed high-resolution seismic reflection profiling data are obtained within a regional grid. This is the common procedure used in the petroleum industry when doing resource evaluations. Cost-benefit of sequence stratigraphic analysis relative to seismic surveys should be evaluated in context of 1) regional permeability distributions and 2) wellfield-scale potential fluid migration. In fact a 2020 SFWMD-funded 2D and 3D seismic study showed significant promise as such as tool, as has US Geological Survey seismic work in the Broward and Miami-Dade areas (Cunningham and Walker, 2009; Cunningham, 2015; Cunningham and others, 2017; Missimer and Maliva, 2004). The use of geologic and geophysical logs to "ground truth" the seismic reflection data is necessary, because there are multiple possible interpretations of these data.

Hydrologic modeling

The SFWMD ASR team appears aware of the challenges of working with multi-scale groundwater models. Scales relate to both spatial and temporal and may include large flux in water volumes over short periods. Bracketing extreme conditions in context of climate change, such as extreme drought or rainfall over extended periods, at all scales in all aquifers will be important as these possible future conditions will impact regional groundwater withdrawals and managed recharge activities. Equally important, tracking model uncertainty at all scales should be routine to inform the planning and adaptive management process.

A more specific modeling observation relates to impacts of surficial aquifer system (SAS) heads on deeper aquifers. The modeling of the FAS did not include the SAS, which in most cases is not a major issue. However, the head in the SAS is important because it impacts the heads in all of the underlying aquifers. In several of the USGS coastal plain MODFLOW models (e.g., the 17-layer model in North Carolina), the model sensitivity showed that the head in the uppermost aquifer (surficial or unconfined) was a dominant force in controlled heads in the deeper aquifers. Therefore, including heads in the SAS under extreme drought or rainfall conditions is recommended while modeling the FAS.

Wellfield-scale characterization

Hydrogeological parameters and modeling

For local scale modeling in the clustered ASR sites, the PRP recommends not to use the Jacob aquifer-test method results because in a semicofined system, this method yields higher than real transmissivity values and lower than real storativity values. The Hantush-Jacob values should be used with the leakance being a critical parameter. The analysis of the aquifer test data could also be done using a computer-generated match using MODFLOW and the head data from the tested aquifer and those above and below it.

There is a significant potential role for applied geophysics regarding aquifer property characterization, especially at the wellfield scale. For example, 2D and 3D seismic surveys can inform knowledge of storage zone integrity through identification of “collapse zones” that may be pathways for injectate to migrate vertically. These potential pathways, if present, could jeopardize the effectiveness of the ASR wells (see also Regional Scale Characterization – Permeability Distribution). Borehole geophysics such as vertical seismic profiles, porosity-type logs, and ground-truthing through acquisition and hydrogeologic study of cores would help inform the seismic surveys and allow for improved post-processing to characterize subsurface properties in relation to ASR. Aquifer performance test data could then be used to validate interpretive seismic results. Changes in water temperature could be used to ascertain whether these interpreted collapse zones are allowing upward fluid movement.

Borehole data and core analysis

Extensive permeable zones commonly occur along unconformities and epikarst horizons. An experienced karst geoscientist should be included in the research team as the wells are cored and logged (e.g., borehole geophysics and downhole imaging). This will assist in understanding the injection zones and mineral phases coating sediment and rock surfaces, the latter which may inform understanding of geochemical interactions.

Elsewhere in this report, the PRP recommends re-evaluation of the application of sequence stratigraphic analysis at the regional and wellfield scales. Understanding transgressive and regressive cycles of sea level is interesting from a historical geology perspective; however, we view the relevance of this aspect of sequence stratigraphy to be nominal for ASR operations. The design of a seismic stratigraphic study should be to identify erosion/epikarst zones, karst features, faulting and folding of target strata because of their effects on porosity and hydraulic conductivity and integrity of an ASR injectate “bubble.”

We also suggest aquifer performance tests for anisotropy, flow zone analysis (maybe with packer testing), as well as cross-well tomography to depict permeability away from the injection wells. Testing should be done in a way to understand aquifer heterogeneity and anisotropy and potential for fractures. Also, we suggest the SFWMD ASR team explore various resistivity testing techniques (e.g., time domain) to characterize fluid movement in storage zones (with salinity contrast between native and injected water) before, during and after cycle testing as these results can be useful in defining the extent of the freshwater buffer zone during operations. An ASR-resistivity study completed for the Florida Geological Survey that employed Controlled Source Audio-Frequency Magnetotelluric (CSAMT) profiling and Transient Electromagnetic (TEM) sounding at a Manatee County ASR site serves as an indication of the potential benefits of this approach. Care must be taken when using this technique because it can only detect large contrasts in water density (e.g., 500 vs. 5,000 mg/L of TDS).

Seismic Monitoring

Following the regional characterization of rock fracturing, minimal concern exists regarding fracturing through the Hawthorn Group sediments owing to their modulus of elasticity; however, fracturing of the more brittle carbonate strata below the Hawthorn Group is more of a concern. Fracturing could either increase the efficiency of injection or develop pathways for injectate migration and reduction of recovery efficiency. To evaluate local-scale fracturing during ASR, and as validation of previous fracture modeling, installation of a few, selected, high-sensitivity seismic geophones could provide a fracture monitoring strategy. The geophones would also provide data if collapse events occur.

Hillsboro ASR aquifer testing

We recommend repeating the aquifer test at the Hillsboro site. The time increment from the transducer system should be set at 30 second instead of 15 minutes. Based on the log-log plot, there was also some variation in the pumping rate during the test and some influence of tidal loading in the later part of the test. The tidal fluctuations can be removed from the time-drawdown curve using a harmonic analysis based on a local ocean tide gage. Since this is a site for multiple ASR wells, it is very important to obtain the most accurate data possible in terms of hydraulic coefficients.

Well and wellfield design

ASR well construction

In ASR systems that use steel casings in which freshwater is injected into a saline aquifer (e.g., Avon Park High Permeability Zone [APPZ]) and a bounding higher aquifer contains saline water, will require cathodic corrosion protection or use of an alternative casing material. Fiberglass reinforced PVC could be used or epoxy-coated steel could be used. However, the welds in the epoxy-coated steel would have to be coated during casing installation (not easy).

The APPZ tends to have a high transmissivity and a greater density of “channel” pores compared to the upper Florida Aquifer System wells. To improve recovery efficiency, the ASR wells utilizing this storage zone may require the placement of a one-way flow value within the open hole. During the injection phase, the freshwater would enter the entire thickness of the open hole. During recovery, the value would close and water would be pumped only from the upper part of the aquifer above the valve.

ASR Multi-well Geometry

The geometry of ASR well clusters has a significant impact on the potential recovery of stored water. One of the more effective geometries is the alignment of ASR in a linear mode in the down-gradient direction. This orientation may diverge from patterns of surface water bodies. In a gradient-oriented wellfield configuration, injected water is commonly captured at the terminus of the line before it can escape the effective capture radius of the system. This issue becomes more important as the natural flow gradient becomes greater. This alignment is particularly attractive in the case of continued injection during multiple or consecutive years of high-water conditions without annual recovery when some of the injected water could escape recapture as it moves with regional flow.

Geometric ASR well arrangements that use either triangles, double lines, or grids have the tendency to trap native water between wells, thereby inducing mixing within the ASR storage zone. When operating a complex multi-well ASR system, it may be necessary to fully flush the ASR aquifer or zone between the first two wells, in the case of a triangle, before injection in the third well begins. This avoids the mixing issue. This concept expands on typical TSV practices to improve recovery efficiency (see also Operational Considerations - Target Storage Volume). The trapped water issue becomes even more complex when using double lines or a grid. If the ASR storage zone has low Total Dissolved Solids (TDS), there is no problem, however, but as the salinity in the ASR aquifer increases the geometry problem becomes more acute. The trapped water issue can tend to greatly reduce the recovery efficiency.

In addition to well configurations as new ASR wellfields are conceptualized, the PRP encourages consideration of hybrid approaches including one or more of the following: bank filtration, aquifer-storage-transfer-recovery (ASTR; recharge and recovery not using same wells), inter-aquifer transfer, wetland pre-treatment, and surface reservoirs. Hybrid approaches are advancing worldwide. A technical workshop focusing on emerging wellfield configurations and operational strategies would inform future decisions).

Operational considerations

Injection pressure and air entrainment

During the injection cycle, nearly all ASR wells exhibit an increase in injection pressure, even in potable water systems with no particulate material. Most ASR systems used a one- or two-hour back-pumping procedure during every week of operation. The back-pumping procedure tends to re-establish the initial lower wellhead pressure. This pressure buildup is not caused by particulate accumulation, but it is caused by air entrainment. This procedure could also help control particulate accumulation, which would reduce the frequency of acid cleaning of the ASR wells. Also, it is very important to minimize any air entry into the aquifer during the injection cycle. This should not be a problem due to the location of the air release value and the pressure in the well that is above the wellhead at the start of a pumping cycle, but the well and pump designers should take this into consideration to assure minimization of air input. The highest concentration of air in the recharged water tends to occur at the beginning of pumping. This first injection water could be allowed to discharge via a value for a period of 10 minutes before full injection begins.

Passive screen maintenance

The Kissimmee Rover and Hillsboro ASR test sites both use a passive screen intake system, which can be difficult to maintain due to clogging by particulates, including organic material and biofilm. In marine intake systems used for desalination plants, an air-burst cleaning system that can be remotely operated and provides effective cleaning a minimal cost (used at the Kissimmee site).

Injection pressure and tides

In the ASR wells located proximal to the coast, the impact of ocean tides can cause fluctuations in the wellhead pressure, which could cause pumping-rate fluctuations based on the back pressure. Use of a programmed variable frequency drive on the pumps can be used to maintain a constant flow rate under variable head conditions, such as during tidal head fluctuations.

ASR well clusters – pumping sequence

The operation of well clusters is a good concept but requires special operational management. If a three-well cluster is used, only two wells can be initially used on the first injection cycle, because if all three are used, a column of saline water (if present) may be trapped between the wells and causes extensive mixing and very poor recover. The third well should be pumped only after the injection zone in that well is flushed on the native water. This is not an issue where the aquifer water is close to freshwater, but in brackish-water systems it is a major issue (see also ASR Multi-well Geometry).

Deep well injection – flood mitigation

There are concerns about loss of water from being recovered. Past studies of possible recovery of water from long-term operating boulder zone injection wells showed poor results. Design modifications could be made to allow higher recoveries from these wells. The SFWMD ASR team should evaluate pros and cons of deep ASR wells based on surface water hydrologic modeling of extreme events.

Target Storage Volume (TSV)

The concept of TSV is most applicable to ASR systems that operate on an annual schedule to meet peak demand in public utility systems. Also, it is a key factor in storage aquifers that contain brackish water because it increases the annual operational efficiency. Operational efficiency is commonly defined to include all water injected with a comparison to the water recovered to the goal TDS, including the water used to create the TSV. As it applies to the North Lake Okeechobee ASR well systems, if the target aquifer is essentially freshwater, the use of TSV is not essential. These wells will always have a high recovery efficiency because they exhibit the “blended storage” concept. In the ASR wells located to the east of Lake Okeechobee or other areas where brackish water occurs in the aquifer storage zone, TSV is important, particularly if annual cycles of injection and recovery are anticipated (one injection and recovery period each year). TSV is only effective if the storage aquifer rock contains predominantly intergranular porosity. Where the transmissivity is very high and associated with channel pores (e.g., dual porosity), TSV does not provide a clear operational advantage. The recovery efficiency will tend to remain low. In addition, as the salinity in the storage aquifer increases, the necessary TSV quantity rises because more water needs to be displaced to prevent upward migration during rest/storage cycles. Moreover, in the case of moderate to high salinity native groundwaters, injection of more water than recovered is a common practice in order to create a “buffer zone” between the low- and high-quality water. Management of the volume and rate of growth of the buffer zone could assist in improvement of fouling issues, nitrogen and arsenic mobilization and transformation, and recovery efficiency.

Geochemical considerations

Water Quality

The SFWMD ASR team understands that aquifer hydrogeology is site specific, as are water-rock interactions within the Floridan aquifer system in both the UFA and APPZ during ASR operations. As such, it is imperative that the ASR plan going forward include a detailed description of water quality monitoring at each and every ASR location during all phases of the ASR operation, including time-series monitoring. The PRP recommends that serial samples of the injected water be collected with time to identify any temporal water-quality variations that might offer insight as to optimal times or conditions for water injection.

Another water-quality aspect relates to mixing at the intake/outfall, which in some cases is apparently the same structure. Has consideration been given to such issues as separating the intakes and outfalls to target waters with different chemical properties, such as redox potentials? Has any consideration been given to trying to induce stratification or mixing to improve ecological and/or chemical issues (see also Downstream effects of recovered ASR waters)?

Water-rock interactions during ASR have focused on processes controlling a limited number of mobilized constituents. Several metals besides arsenic, however, are mobilized during ASR, and while the concentrations do not exceed drinking water standards, their environmental effects are largely unknown. See, for example, the discussion of molybdenum (Recovered ASR Waters). For all water quality analyses, the PRP suggests that broad-spectrum hydrogeochemical analytical packages be utilized. These are cost-efficient multi-method, multi-element analytical packages that provide robust information about constituents that may not be known concerns today. As scientific understanding continues, especially in the areas of ecotoxicology, data within an expanded analyzed parameter list may become useful.

We understand that a sampling of 5 municipal wells open to the FAS had low concentrations of total mercury (USACE and SFWMD, 2014), however, lithogeochemical analyses of Floridan aquifer system carbonates in south Florida often have total mercury concentrations exceeding 10 ppm (Arthur et al., 2007). This constituent is not routinely part of ASR monitoring programs. The PRP has a concern that non-methylated Hg may be introduced into downstream waters and recommends that recovered waters be analyzed for total mercury as well as sulfate due to its connection with mercury methylation (Orem et al., 2011; see also Geochemical Considerations – Pre and post water treatment).

In many cases, there exist pre- and post-treatment options to minimize adverse effects of mobilized constituents. Understanding what is present, in what concentrations, and under what physiochemical conditions will well serve the restoration process in the long run.

Pre and post water treatment

In hydrogeological settings where arsenic is mobilized during ASR activities, the mechanisms of mobilization are understood well enough to employ pre-treatment mitigation measures. The PRP recommends that the SFWMD ASR team consider pre-treatment redox control of injected waters as it has been found to be effective in reducing arsenic concentrations (e.g., the Bradenton ASR deoxygenation demonstration study). Redox control alternatives include use of reducing agents, membranes, catalytic oxygen removal and degasification. The cost of such measures should be carefully analyzed to ascertain feasibility.

Based on results of ASR monitoring plans at each well and wellfield, a post-treatment or action plan should be developed if the recovered water has high concentrations of arsenic, gross alpha activity, uranium, radium or other constituents of concern.

Results from previous studies are encouraging in that methyl mercury concentrations are low in the FAS and in recovered ASR waters (USACE and SFWMD, 2014). However, microbial sulfate reduction under anoxic conditions has been found to enhance mercury methylation, the most toxic form of mercury which bioaccumulates in the food chain (Gilmour, 2011). Sulfate loading can enhance methylmercury production in the Everglades (Orem et al., 2011). As sulfate concentrations have been found to be higher in recovered ASR waters we recommend further monitoring of sulfate in recovered waters as well as investigation of the effect of this added sulfate to the receiving wetlands, canals, and Lake Okeechobee in relation to methyl mercury production in water, soils, and biota in those areas. The potential need for post-treatment or dilution of high concentrations of sulfate in the recovered water should be considered because of its reactivity with mercury species in the Everglades.

Phosphorus removal during aquifer storage

The bioclogging column studies proposed by Dr. Lisle of the US Geological Survey are a good step towards addressing the potential for determining phosphorus reduction. We recommend that in addition to those bulleted items on slide 57 to include geochemical modeling (PHREEQC and/or others) to assess the potential for phosphorus reduction and calcium carbonate dissolution/precipitation. We understand that the proposed testing is to be completed on cores and columns of Floridan aquifer material collected from the exploratory borings from the UFA, including the APPZ. We suggest that similar testing for the water quality and microbial analyses be conducted during the injection, storage and recovery phases of all ASR operations.

We agree that phosphorus removal during storage is likely caused by advective dilution, bacterial consumption and most likely by adsorption. The high potential for phosphorus to adsorb onto limestone has been demonstrated in laboratory tests (Price et al., 2010) and in shallow injection wells in the Florida Keys (Corbett et al., 2000). The precipitation of apatite is a not anticipated to be a significant process based on the kinetics of the aquifer environment. Also, be aware that phosphorus can easily desorb from the bedrock with even small increases of chloride associated with seawater intrusion (Flower et al., 2017), so monitoring of phosphorus with chloride concentrations during recovery is recommended.

Another potential source of information are the multiple reports produced by the Florida Geological Survey that assess water-rock interactions at various ASR sites across Florida. While the focus of these studies was mobility of arsenic, uranium, molybdenum, antimony, vanadium, etc. as observed in bench-scale, batch-reactor studies and at the field scale, phosphorous data in the reports may assist understanding of sorption/desorption processes under varying oxidation states in the aquifer during ASR.

The PRP is impressed by the US Geological Survey work (John Lisle) on microorganism die-off and fate of nutrients. As noted during the July 22-23, 2020 presentations, many questions remain. Paramount among them are: 1) understanding the mechanism for nutrient attenuation, and 2) the sustainability of die-off and attenuation at the wellfield and well-lifetime scale. Short term tests indicate that microbial communities in the aquifer may respond to the input of surface water by increased growth and assimilation of phosphorus (Lisle, 2020). Would this community within a well cluster reach an asymptote in its growth and lose capacity over time as rock space as a substrate becomes limiting? Regardless of the results of planned research in this regard, we recommend long-term monitoring of nutrients during cycle testing and operational cycling. Dr. Lisle's work should be continued as planned with the purpose of addressing the 2015 NRC uncertainties related to water quality, nutrient reduction potential and pathogens.

The PRP is equally impressed with Dr. June Mirecki's continued geochemical work on behalf of the US Army Corps of Engineers. Her work on the geochemical processes taking place in the ASR process is central to understanding of mobilization and/or fixations of chemicals of concern. Her work should continue to be supported, including the recommended isotopic fractionation studies. We are concerned about the few number of samples that were collected with Dr. Mirecki's work and recommend that a future ASR plan include significantly more water chemistry measurements.

Non-Borehole Ecological/Biological Considerations

Recovered ASR Waters

Bench-scale and field scale water-rock interactions studies of ASR cycling indicate metals mobilization can occur. Although mechanisms for arsenic mobilization are generally understood, less understood are processes leading to mobility of molybdenum (e.g., Fischler and others, 2015). Molybdenum (Mo) is an essential micronutrient for nitrogen (N) assimilation due to its role in N_2 fixation and nitrate reduction. [Molybdenum enrichment in cores from deep basin sediments in the Baltic Sea suggests periods of increased cyanobacteria growth and deposition of Mo rich algal remnants. These periods of cyanobacteria dominance in the basin likely correlated to periods of higher runoff when the basin was enriched with Mo and other nutrients (Andrén and Vallius, 2001). Other studies have found evidence of Mo limitation of nitrogen assimilation in freshwater and the possibility that Mo enrichment can increase growth of various forms of periphytic and planktonic cyanobacteria (Glass et al., 2010 and 2012). Two considerations for increased Mo mobilization in ASR are whether recovered water leads to a significant increase in Mo in receiving waters and whether receiving waters are in a Mo limited condition in which enhanced Mo could lead to enhanced growth of cyanobacteria

Biomass Modeling - Given the issues with algae in the lake and discharges to the Caloosahatchee and St. Lucie canals, have there been any attempts to determine the benefits of the ASR program to the biomass generated by algae? We realize that the effects of nutrient loading on algae have been studied, but has there been any attempt to correlate the biomass to the nutrient load under different ASR scenarios?

Also related to monitoring recovered ASR waters, routine determination of isotopic ratios of nitrogen, arsenic, oxygen, hydrogen, and sulfur measurements over time should assist in understanding the microbial processes responsible for fixation and mobilization.

Downstream effects of recovered ASR waters

Toxicity and Bioaccumulation Studies – There have been thorough studies of the effects of the recovered ASR water on certain organisms, including mussels (filter feeders?) and water fleas. These studies have considered nutrients, arsenic, and mercury. Members of the PRP are concerned that more was not said about bioaccumulation in higher trophic-level organisms.

During the July meetings, it was difficult for the PRP to determine if the ecological and ecotoxicological testing presented in the Module 3 presentation was from the 2013 Final Technical Data Report – ASR Regional Study or has been conducted since then. The presentation lacked in expertise and the periphyton study was particularly brief in description. We suggest the SFWMD ASR team retain a periphyton expert.

More research is needed into the ecological and ecotoxicological impacts of discharging ASR recovered water to the Everglades wetlands, canals, Lake Okeechobee and downstream areas. Long-term studies of ecosystem response in the Everglades to additional nutrients and other constituents indicate a cascade of responses with often soil properties being an important sink/source of nutrients and metals. We suggest the SFWMD ASR team include a plan to characterize the current soil and vegetative conditions in the two wetland restoration areas co-located with the ASR wells. At a minimum soil nutrient and trace metals (including methyl mercury) need to be determined in the wetland areas as baseline conditions before restoration.

The PRP also suggests replicating the bench scale microbial-water-rock experiments being conducted by Dr. Lisle using soil cores collected from the wetland restoration areas and using groundwater from both the UF and APPZ as well as ASR recovered water (when available).

Concerns also exist regarding the timing of discharges to the ecosystem, which will be driven by what volume of recharge and recovery is realized and how that can work with the operating schedule of Lake Okeechobee. The PRP favors a population-level approach to modelling the impacts on fish populations and communities as described in Suter et al. (2005) in the 2015 NRC review. The primary avenues for impacts to fish at operational ASR facilities are thermal alterations to receiving waters and impingement/entrainment of early life stages of various species.

A warm plume in winter and or a cool plume in summer may serve to alter the spawning timing of some species in the vicinity of recovered water discharge. Table 8-7 of the CERP ASR Regional Study Technical Data Report (October 2014) offers a qualitative risk associated with these effects but no mitigation strategy. ASR review should explore quantified risks and mitigation strategies, which is something to consider is when discharge of recovered water is likely to occur. Most likely it would occur during low flows that may occur during the spring spawning period. Warm highly oxygenated water being released in the winter is likely to attract species like Blue Tilapia into the area and displace some of the cool season spawners like Largemouth Bass and Black Crappie. Quantifying likely outcomes based possible plume sizes and relative impact on system level recruitment may be warranted. Tempering recovered water for temperature in addition to ensuring good oxygenation may be a desirable mitigation strategy if thermal effects are deemed too detrimental.

Impingement and entrainment can be mitigated, as noted in the section 10.6 of the CERP Final Technical Data Report for the Kissimmee River ASR pilot project (December 2013) by intake design as well as timing of withdrawals. This aspect offers an opportunity for adaptive management by monitoring for the presence of vulnerable organisms during recovery operation and considering adapting withdrawal regimes if needed. It is worth noting that withdrawal will generally occur during elevated warm season flows which may make the risk to winter/spring spawners such as Black Crappie.

The regional study also noted that the oxygenated recovery water could attract fish during low ambient oxygen conditions and pose a kill risk if there was sudden withdrawal of the oxygenated recovery water. This risk should be low at sites like the Kissimmee ASR if the recovery water is being discharged during low-flow augmentation. Low oxygen in the lower Kissimmee River and many canals typically occurs during high stages when recharge/withdrawal activities would most likely be occurring as opposed to discharge of recovered water. We recommend having a site-specific monitoring protocol in place for this possibility.

During the July 20-21, 2020 workshop, a comment was made about Paradise Run ASR and its attenuation feature: recovered ASR water differs in color, conductivity, and other physical parameters from water that would naturally inundate the floodplain of the Kissimmee River. The recovered ASR water having less color and higher conductivity than normal Kissimmee River surface water could alter the type and amount of submerged and emergent plants that will grow in the Paradise Run wetland. This site would be an excellent case to monitor the water passing through the wetland for chemical and physical changes and also monitor the biota from the from periphyton to fish. It might also be worth considering passing raw C-38 water through the feature either as a blend with recovery water or during recharge periods when C-38 is high (this may already be proposed). We suggest clarification of goals of co-located wetland features in terms of the desired objective outcomes. It may not be possible re-create a replica of pre-C38 riparian wetlands but those features may have a great ecological benefit by providing wetland habitat and modifying the recovery water prior to re-release back to Lake Okeechobee.

Project Design, Management and Implementation

CFWI considerations

It is recommended that additional ASR facilities north of Lake Okeechobee along the Kissimmee River be included in planning and modeling efforts. The water entering the lake largely comes from the Kissimmee and there might be advantages to incorporation of ASR in the lake management plan in terms of early interception relative to the lake and providing water for the Central Florida Water Initiative (CFWI). Coordination with CFWI throughout this CERP process is important, especially in terms of shared science/data, compatible methodologies and forecasting. The SFWMD ASR team also needs to consider the compounding benefits of other projects that affect water levels and quality in Lake Okeechobee and downstream. For example, the ASR programs associated with the CFWI, especially in the Kissimmee drainage affect water supply to Lake Okeechobee and should inform the ASR program in terms of problems, issues, and consequences of program efforts.

The proposed ASR operations involve co-location with two wetland restoration areas that may also act as water storage and treatment areas. A reduction in water flows to the estuaries from Lake Okeechobee is important not only for salinity in the estuaries but also for the discharge of nutrients and algae present in high concentrations in the Lake. There could be added benefit of the ASR operations in reducing phosphorus concentrations from surface waters of Lake Okeechobee as demonstrated by Lisle (2020). We recommend that a benefit analysis and improved performance of water storage options including ASR operations needs to include an analysis for the potential reduction in nutrients, both for nitrogen species and phosphorus. Specifically, we are interested in understanding the benefits of the ASR project in terms of nutrient removal from the Everglades watershed versus the loss of water from the watershed that occurs from ASR testing and operations. Furthermore, a cost benefit analysis should include the life cycle costs of the ASR operations.

Regulatory considerations

ASR wells are classified as class V injection wells under the FDEP and EPA Underground Injection Control (UIC) rules. Therefore, the definition of an underground source of drinking water (USDW) is any groundwater that has a concentration of 10,000 mg/L or less. Under UIC rules, any water injected into a USDW requires that it meet all drinking water standards. This includes bacteria and a large number of other parameters.

There are two potential strategies to meet these rules. The first is to treat the recharge water to meet all primary drinking standards and request exemptions for any secondary standard exceedances. This is a current direction the SFWMD and the USACOE are taking. Another approach would be to reclassify parts of the Floridan Aquifer System (with buffers) to sole use as an ASR storage and recoverable aquifer (with an aquifer exemption as defined by the EPA) and set appropriate standards that may exceed certain drinking water quality standards. Since the bacteria injected into the aquifer tend to die off rapidly and most of the arsenic and other regulated substances remain in the aquifer, the only water quality standards that would have to be met are those at the point of discharge back into the natural system. The "sole use" designation could save very large amounts of capital and operating expenditures over the long term and would not pose any environmental risks.

Tracking progress

The SFWMD ASR team is to be complemented on its implementation of adaptive management and continued process improvement. Inception of the ASR PRP is just one example of continuous feedback. Efforts to monitor how early recommendations from similar committees (see Introduction) were addressed took on the form of an "ASR report card" (Chapter 10, Table 2 of the 2008 Interim Report). The PRP recommends development of a similar report card to represent progress on NAS 2015 Report recommendations as well as those offered herein. This method of tracking and visualizing progress will serve useful not only to project managers but also to stakeholders. Descriptions of status details, anticipated timelines, links to reports, principal contractors, and points of contact could be included to improve communication and transparency.

During the July 22-23, 2020 presentations, it became clear that different ASR wells or wellfields are associated with different programmatic and research goals. As CERP moves forward and more wellfields and wells are planned, coordination of efforts and use of incoming data will become more important in terms of cost-effectiveness and making decisions about whether to continue certain activities. Similar to the aforementioned report card concept, we recommend a method of tracking planned research/data collection activities at each site, and for each well, to identify the timing/duration and anticipated data availability such that critical decision points can be identified that will inform future decisions. Use of a flow chart-like diagram showing how the different projects would benefit each other and potential communication channels would also improve communications and efficiency. This concept is expanded in the next two sections.

Benefits of Integration

These following suggestions all underscore a recommendation to continue thinking about how best to manage the very long-term process of CERP and the role of ASR in that process. These suggestions are adapted from the findings of a multi-phased, five-year review of the Edwards Aquifer Habitat Conservation Plan (EAHCP; NRC, 2015b).

A broad spectrum of ASR-related monitoring, modeling, individual experiments and field studies is underway as part of a larger overall science plan yet to be developed by the SFWMD. This multifaceted approach has advantages in being flexible and efficient because the various small projects can be modified and staffed by relatively few people and new projects can be added relatively quickly. However, without careful attention to integration and coordination standards across the entire project, inconsistencies in methods and analyses among the individual studies can occur, key elements of study can be omitted, and observational data may not be collected in a manner that best informs overall development, integration and evaluation of projects into a coherent program.

Because the SFWMD ASR team contracts with outside groups to conduct much of the research and monitoring, and each of the contractors may not be fully aware with all program elements, it is particularly important that special emphasis be placed on careful integration of the overall program. Increased effort to integrate and synthesize data and research would enable the clear explanation of a cohesive set of results and conclusions that would increase the transparency and credibility of the science being accomplished. Without clear attention to project integration, there is danger that the CERP ASR efforts might result in several separate projects that do not combine seamlessly into the overall science program. The following are examples of the benefits of a project coordination and integration program:

1. To what degree are water quality and biological monitoring programs integrated? Are sampling sites co-located? In addition, biological monitoring of various species of interest and could benefit from a broader focus on the biological communities in which these species are embedded and the multiple drivers that can influence these biological communities.
2. What is the degree of integration between the hydrogeologic modeling and research efforts? Is there a direct opportunity for groundwater modeling studies to inform the research plans?
3. Effects of climate change could be investigated by looking at long-term hydrologic data trends and incorporating them into the models, which would be helpful in developing adaptive management plans. Lack of coordination between the research efforts and the modeling team could delay improvements to the hydrologic modeling efforts. More formal coordination of the hydrogeologic research with the modeling efforts could be implemented without adding layers of review that might slow the research process.

Acknowledging that these recommendations significantly draw from the NRC (2015b), the ASR PRP offers the following steps that can be taken to enhance science/data:

1. Where possible, consider additional plans to integrate ASR and biological goals into overall conceptual models, including hydrological, climate, and biological community components. Such models can guide the development of quantitative modeling of sub-components, identify gaps in understanding, and provide context for understanding the responses of particular species of interest. This approach could be integrated with and cross-referenced to the more focused conceptual models on key species population dynamics.
2. Develop a unified data/information management system so that data are easily available to and transferable between all project teams (see Data and Information Management below).
3. Convene an annual or biennial science meeting to discuss results, discover gaps in understanding and help plan future studies and monitoring activities. Such a meeting should include all project and contract scientists, other university and agency scientists who might be interested in becoming involved in future studies, and various stakeholder groups. These meetings can provide excellent forums to discuss results to date and provide transparency in identifying future research, monitoring, and modeling needs.

Data and Information Management

Research activities related to ASR and groundwater modeling are data-intensive, including hydrological, meteorological, chemical, and biological data collected at a variety of spatial and temporal frequencies and extents. Users and providers of this data may include a diverse set of individuals and groups from academia, non-governmental organizations, commercial institutions, and municipal, state, and federal agencies. Rich sets of legacy data on multiple aspects of the Floridan aquifer system have been collected by numerous groups. Ongoing data collection as part of specific short-term studies or long-term monitoring is planned or under way. The hydrological and ecological modeling that forms a core part of the CERP will produce large amounts of model output. This section is also adapted from the review of the EAHCP (NRC, 2015b).

The data emanating from these various activities need to be organized, quality assured, maintained, and curated. Furthermore, the data must be accessible, discoverable, reviewable, and useable by individuals or groups, ideally within and outside of the CERP set of stakeholders. The PRP strongly recommends that the SFWMD ASR team develop a comprehensive information management plan. Such a plan would ensure both internal and external access to relevant data over both the short and long term, facilitate data analyses and syntheses across multiple data types and sources, buffer against the potential turnover of key personnel, and increase transparency and communication to stakeholders as the CERP is implemented and evaluated. In short, a well-planned and implemented information management system will make all aspects of the CERP, including ASR more likely to succeed.

The plan should include multiple aspects of information management such as:
- definition of data types, standardization of analytes (e.g., consistent reporting of dissolved nitrogen) and formats ranging from raw data to metadata; what types of data are available and how are they characterized and organized;
- explicit data management plan, from the method of collecting and initially transferring data from the field into digital form, to follow-up data flow consisting of (but not limited to) quality control, analysis, synthesis and dissemination;
- agreements about which data, and types, will be centrally housed and which will be distributed among individual stakeholders;
- maintenance of database integrity including quality assurance and short- and long-term curation, archival and data back-up plans;
- description of the data access and sharing policy;
- description of limitations and disclaimers on data use;
- creation of an accessible environment for the retrieval of information;
- facilitation of linkages among diverse data sets;
- documentation of metadata for data interpretation and analysis;

and
- analysis of information management staffing needs.

Developing and implementing a comprehensive plan is not trivial, and adequate time and resources should be made available. Full-time staffing by trained information managers will likely be required throughout the life of the project. Other complex, data-intensive projects such as the Long-Term Ecological Research Network, the Consortium of Universities for the Advancement of Hydrological Sciences, Inc., and the Ecological Society of America have developed functional information management and data registry systems that might serve as models for this purpose.

Overarching Issues

The 2015 NRC review of the project stressed the need to develop concepts and consider their ramifications in terms of risk. The validity of these tasks hinges on an understanding of the sampling, analytical, and analysis phases of a project. In many cases, the project reports have done an excellent job of explaining uncertainties. However, stakeholder comments, the NRC, and the public review comments demonstrate a continuing need to explain, at all levels, the uncertainties associated with the individual projects and overall outcomes of the ASR project.

Another aspect of monitoring uncertainty throughout this process relates to the complex modeling being undertaken. Some models are designed to be upscaled or coupled. In all instances and at all scales, uncertainty, including cumulative uncertainty should be determined, represented and communicated to the fullest extent possible alongside models, whether they relate to groundwater flow, ecotoxicology or risk assessment.

There are two aspects of team expertise that need be addressed. On the planning and research side, the current SFMWD ASR team consists mainly of hydrogeologists and one microbial ecologist. We suggest the team include additional scientists/experts in the fields of ecology (periphyton), ecotoxicology, as well as soil and wetland science. This will increase confidence that the SFWMD is considering all scientific aspects and maximizing uncertainty reduction related to ASR operations and the environment. On the review side and in relation to the ASR PRP, we recommend addition of a microbiologist.

In Closing

The SFWMD ASR team is planning an incremental, phased approach going forward, and we agree with such a strategy. ASR operations along the northern shores of Lake Okeechobee will be beneficial in being able to intercept flows before they enter the lake. The SFWMD ASR team seems to have a good understanding of the hydrogeology of the Floridan Aquifer in the northern area, but also understands that hydrogeology is very site specific and can have a significant impact on the function and success of ASR operations. Furthermore, investigating clustering of ASR wells could be helpful in increasing the extent of the freshwater buffer zone in the aquifer and reducing arsenic mobilization. We support investigation of both the UFA and APPZ - the lithogeochemistry, mineralogy, hydrogeochemistry and microbiology both aquifers, and the potential for hydraulic interaction between the aquifers. The use of continuous seismic reflection profiling cannot define areas of aquifer interconnection in the absence of core and water quality data. Similarly, the exploratory drilling plan seems reasonable and collection of continuous core is important for understanding geologic conditions including lithology, mineralogy, strength analysis, and presence of fractures and water bearing zones. To prove the existent of collapse features that suggest the development of vertical conduits for groundwater flow, collapse breccias would have to be found in the deep cores to support this interpretation. If these structures are folds, rather that collapse features, no vertical conduits would occur (Missimer and Maliva, 2004).

Initial testing was done on single wells at 5 mgd and there will need to be systematic site-specific monitoring of well clusters as they are implemented. To a large extent, we feel that ASR science has been worked out to the greatest extent regarding the feasibility and implementation of ASR in the greater CERP framework.

In summary, the PRP has concerns, suggestions, and recommendations for the SFWMD ASR team as described herein. While there is much additional work to be done, there is enough information to move forward with some implementation of ASR using an adaptive strategy to monitor new well clusters in an operational capacity and change timing/volume of recharge and recovery as needed to optimize operational and ecological benefits.

References

Andrén, T.U., and H. Vallius. 2001. Molybdenum in sediments of the central Baltic Sea as an indicator for algal blooms. Baltica. 14. 123-130.

Arthur, J.D., Fischler, C., Dabous, A.A., Budd, D.A., and Katz, B.G., 2007. Geochemical and mineralogical characterization of potential aquifer storage and recovery storage zones in the Floridan Aquifer System, Comprehensive Everglades Restoration Plan. Draft final report prepared for the SFWMD dated 17 July 2007, 150 pages plus appendices.

Corbett, D.R., Kump, L., Dillon, K., Burnett, W. and Chanton, J., 2000. Fate of wastewater-borne nutrients under low discharge conditions in the subsurface of the Florida Keys, USA. Marine Chemistry, 69(1-2), pp.99-115.

Cunningham, K.J., 2015. Seismic-sequence stratigraphy and geologic structure of the Floridan aquifer system near "boulder zone" deep wells in Miami-Dade County, Florida. US Geological Survey Scientific Investigations Report 2015-5013.

Cunningham, K.J., and C. Walker, 2009. Seismic-sag structural systems in Tertiary carbonate rocks beneath southeastern Florida, USA: Evidence for hypogenic speleogenesis? In A. Klimchouk and D. Ford (Eds.), Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins, Ukrainian Institute of Speleology and Karstology, Special Paper 1, pp. 151-158.

Cunningham, K.J, J.W. Kluesner, R.L. Westcott, E. Robinson, C. Walker, and S.A. Khan, 2017. Sequence stratigraphy, seismic stratigraphy, and seismic structures of the lower intermediate confining unit and most of the Floridan aquifer system, Broward County, Florida. U.S. Geological Survey Scientific Investigations Report 2017-5109, 71 p., 21 plates.

Fischler, C., Hansard, P., Ladle, M., and Burdette, C., 2015, A review of selected Florida Aquifer Storage and Recovery (ASR) sites and their geochemical characteristics, Florida geological Survey Report of Investigation 112, 216 p.

Flower, H., Rains, M., Lewis, D., Zhang, J.Z. and Price, R., 2017. Saltwater intrusion as potential driver of phosphorus release from limestone bedrock in a coastal aquifer. Estuarine, Coastal and Shelf Science, 184, pp.166-176.

Gilmour CC, Elias DA, Kucken AM, Brown SD, Palumbo AV, Schadt CW, Wall JD (2011) Sulfate-reducing bacterium Desulfovibrio desulfuricans ND132 and a model for understanding bacterial mercury methylation. Appl Environ Microbiol 77:3938–3951

Glass, J.B., Axler, R.P., Sudeep, C., and C.R. Goldman. 2012. Molybdenum limitation of microbial nitrogen assimilation in aquatic ecosystems and pure cultures. Frontiers in Microbiology. (3)331. 1-11.

Glass, J.B., Wolfe-Simon, F., Elser, J.J., and A.D. Anber. 2010. Molybdenum-nitrogen co-limitation in freshwater and coastal heterocyctous cyanobacteria. Limnology and Oceanography. 55(2)667-676.

Lisle, J.T. 2020. Nutrient removal and uptake by native planktonic and biofilm bacterial communities in an anaerobic aquifer. Frontiers in Microbiology, 11:1765.

Missimer, T. M., and Maliva, R. G., 2004, Tectonically-induced fracturing, folding, and groundwater flow in South Florida: Gulf Coast Association of Geological Societies Transactions, v. 54, P. 443-459.

Orem W, Gilmour C, Axelrad D, Krabbenhoft D, Scheidt D, Kalla P, McCormick P, Gabriel M, Aiken G (2011) Sulfur in the South Florida ecosystem: distribution, sources, biogeochemistry, impacts and management for restoration. Crit Rev Environ Sci Technol 41:2

Price, R.M., Savabi, M.R., Jolicoeur, J.L. and Roy, S., 2010. Adsorption and desorption of phosphate on limestone in experiments simulating seawater intrusion. Applied Geochemistry, 25(7), pp.1085-1091.

Suter, G.W., Norton S.B., and A Fairbrother. 2005. Individuals versus organisms versus populations in the definition of ecological assessment endpoints. Integrated Environmental Assessment and Management. 1(4) 397-400.

National Research Council, 2001, Aquifer Storage and Recovery in the Comprehensive Everglades Restoration Plan: A Critique of the Pilot Projects and Related Plans for ASR in the Lake Okeechobee and Western Hillsboro Areas. Committee on the Restoration of the Greater Everglades Ecosystem: The National Academies Press, Washington, DC, 74 p., https://doi.org/10.17226/10061.

National Research Council, 2015a, Review of the Everglades Aquifer Storage and Recovery Regional Study. Washington, DC: The National Academies Press, 68 p. https://doi.org/10.17226/21724.

National Research Council, 2015b, Review of the Edwards Aquifer Habitat Conservation Plan: Report 1. Washington, DC: The National Academies Press. https://doi.org/10.17226/21699.

USACE and SFWMD, 2008, Interim Aquifer Storage and Recovery Interim Report 2008. Comprehensive Storage Restoration Plan.

USACE and SFWMD, 2013, Central and Southern Florida Project Comprehensive Everglades Restoration Plan: Final Technical Data Report, Comprehensive Everglades Restoration Plan Aquifer Storage and Recovery Pilot Project.

USACE and SFWMD, 2014, Central and Southern Florida Project Comprehensive Everglades Restoration Plan: Final Technical Data Report, Aquifer Storage and Recovery Regional Study.

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Dr. Jon Arthur, P.G., is the State Geologist of Florida and Director of the Florida Geological Survey, a division of the Florida Department of Environmental Protection. He is a Fellow of the Geological Society of America, and recipient of the John T. Galey, Sr. Memorial Public Service Award from the American Institute of Professional Geologists and the Florida Governor's Environmental Education Award. Jon has served as president of the Association of American State Geologists and the Florida Association of Professional Geologists, and has served on four National Academy of Sciences, Engineering and Medicine (NASEM) committees related to aquifer recharge and environmental restoration. He recently completed service on the American Geosciences Institute Board of Directors, and currently serves on the NASEM Water Science Technology Board. Jon has given congressional briefings and testimony, keynotes, and invited technical presentations, including international workshops on a broad range of topics including karst geohazards, water-rock interactions, and geologic data preservation. Dr. Arthur's research interests include hydrogeochemistry and aquifer vulnerability, with special interest in geoscience policy, public engagement, and application of geosciences to address societal and environmental concerns. Jon received his BS with Honors and PhD from Florida State University.

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Reid Hyle is a project leader for a Freshwater Fisheries Research field office of the FWC Fish and Wildlife Research Institute. He oversees long term monitoring of fish populations and fisheries in the upper St. Johns River and a project on the restored sections of the Kissimmee River that is investigating the response of fish populations to the restoration and hydrologic management. He also serves as the Florida representative to the Atlantic States Marine Fisheries Commission (ASMFC) Shad and River Herring Technical Committee which provides technical guidance for fishery management plans and stock assessments for anadromous shad and herring along the Atlantic Coast. His primary expertise is in fish population dynamics and fish ecology. He received his B.S. in Fishery Science from Virginia Tech and M.S. in Marine Science from the College of William and Mary Virginia Institute of Marine Science. He has 16 years of experience with fishery research and monitoring in the Florida peninsula.

Thomas M. Missimer

Dr. Thomas Missimer, P.G. is an eminent scholar in hydrology and Director of the Emergent Technologies Institute in the U. A. Whitaker College of Engineering at Florida Gulf Coast University. He is a fellow of the Geological Society of America and the winner of several international awards in technical communication. He is the author or co-author of 11 books (one book on aquifer storage and recovery), more than 120 peer-reviewed journal papers, 47 book chapters, and over 300 other publications including conference papers and abstracts. He practiced as a consultant for 35 years and founded three companies that specialized in providing services in the fields of hydrogeology, geology, and various subdisiplines in geological engineering. Tom served as the permanent Chairman of the Technical Advisory Committee for the Governor's Commission for a Sustainable South Florida Technical Advisory Committee (1995-1999) during the time leading up to the adoption of CERP. He was visiting professor of hydrogeology at the King Abdullah University of Science and Technology in Saudi Arabia (2011-2014), where he did research in desalination intake design (subsurface) and arid lands hydrology. He has advised thesis research work as Committee Chair for two PhD students and nine MS students. Tom received his B.A. in geology from Franklin & Marshall College, his M.S in geology from Florida State University, and his Ph.D. in marine geology and geophysics from the University of Miami. He has 47 years of experience as a hydrogeologist.

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Dr. René M. Price, P.G., is a Professor and former chair of the Department of Earth and Environment at Florida International University. Dr. Price is a chemical hydrogeologist who has conducted numerous hydrogeochemical investigations in the Everglades and in carbonate environments around the world. Her research interests include groundwater and surface water interactions, ecohydrology, karst hydrogeology, seawater intrusion and sea level rise. She supervised and published with a Ph.D. student in the fate and transport of deep injection water into the Boulder Zone in Miami-Dade County. She has served as a science advisor on several Everglades Restoration science advisory boards, including the National Research Council review of the Everglades Aquifer Storage and Recovery Regional Study and more recently serves as a member of the Technical Advisory Committee to the Florida Keys National Marine Sanctuary Water Quality Protection Program. Dr. Price holds a B.S. in geology from Rensselaer Polytechnic Institute, an M.S. in Environmental Sciences from the University of Virginia, and a Ph.D. in Marine Geology and Geophysics from the University of Miami.

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Dr. Sam B. Upchurch, P.G., is retired after 20 years of service as Professor and Chair of Geology at the University of South Florida and almost 20 years as a Principal of two international consulting firms. His expertise is in geochemistry, statistics and monitoring strategy, stratigraphy, Florida geology, and karst science. Dr. Upchurch has published on geochemical processes during ASR and provided numerous reports dealing with geochemical processes in ASR and UIC waste-disposal wells in central and south Florida. He is the senior author of the recently published Karst Systems of Florida (Springer International, 2019).

APPENDIX C:
LOWRP ASR WELLS: L-63N MIT EVALUATION REPORT

SFWMD Lake Okeechobee Watershed Restoration Project (LOWRP) Aquifer Storage and Recovery (ASR) Wells

L-63N MIT Evaluation Report

May 22, 2020

Prepared for:

South Florida Water Management District
(SFWMD)

Prepared by:

Stantec

Revision	Description	Author		Quality Check		Independent Review	
1		Nycole Sharma	NS	Rick Cowles	RC	Neil Johnson	NJ
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L-63N MIT EVALUATION REPORT

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Abbreviations

ASR	Aquifer Storage Recovery
Bpl	Below pad level
CTVSL	Color Television Survey Log
Ft	Feet
Ft^2/d	Foot squared per day
Gpm	Gallons per minute
Gpm/ft dd	Gallons per minute per foot drawdown
MGD	Million gallons per day
MIT	Mechanical integrity testing
PVC	Polyvinyl chloride
SFWMD	South Florida Water Management District
TDS	Total Dissolved Solids
YBI	Youngquist Brothers Inc.
%	percent

1.0 INTRODUCTION

The South Florida Water Management District (SFWMD) has recently selected Stantec Consulting Services Inc. (Stantec) to provide as needed hydrogeologic and engineering services for the mechanical integrity testing (MIT) of the L-63N (LKOKEE-ASR) Aquifer Storage and Recovery (ASR) Well in Okeechobee, FL (**Figure 1**). This technical memorandum includes a review of the initial and final Color Television Survey Log (CTVSL), casing brush cleaning, XY caliper logging, casing pressure test, and step-rate pumping test. The Contractor was Youngquist Brothers, Inc. (YBI). This memorandum provides a review of the mechanical integrity testing activities conducted on the L-63N ASR Well.

Figure 1. Location of the L-63N ASR Well in Okeechobee, Florida.

2.0 SUMMARY OF REHABILITATION ACTIVITIES PER THE SCOPE OF SERVICES

SFWMD is assessing the conditions the L-63N ASR Well to determine if the casing is sound and if the formation is plugged. This work began with an initial CTVSL followed by the clearing of the open hole of a lost XY caliper tool with cable, lost polyvinyl chloride (PVC) drop pipe, fill and rust. This was be followed by a pressure test on the 24-inch diameter steel casing to confirm its integrity. Once it was confirmed that the casing was sound, a step-rate pumping test was conducted to determine general well capacity, which was followed by the reassembly of the wellhead and site restoration activities.

Stantec observed major activities and prepared daily forms while on site. Stantec and YBI daily logs are presented in **Appendices A** and **B,** respectively. Weekly construction summaries are included in **Appendix C**.

2.1 INITIAL COLOR TELEVISION SURVEY LOG

Mobilizing activities began Tuesday, January 21, 2020, and concluded on Friday, February 7, 2020. Due to the L-63N ASR Well having artesian flow, a riser header was temporarily installed on the wellhead to allow the CTVSL activities without the utilization of salt kill that may alter the video quality. When necessary, YBI utilized City water via a local hydrant to improve water clarity.

On January 30, 2020, a CTVSL was conducted by YBI on the L-63N ASR Well to investigate the condition of the 24-inch diameter steel injection casing and open hole injection interval, as well as determine the depth of the lost XY caliper tool. On the first video run, YBI video logged with a LED light bulb that did not produce sufficient light to clearly view the casing and borehole walls, and the lost cable from the caliper tool. However, the cable was observed at 1,570 feet (ft) below pad level (bpl). At the end of the first run, the side view CTVSL was conducted from the blockage at 1,570 ft bpl. For the second run, YBI switched to a halogen lightbulb, which produced good lighting from the top of casing to the blockage at 1,570 ft bpl.

The CTVSL confirmed that the L-63N ASR well borehole was blocked at 1,570 ft bpl with the lost XY Caliper tool and cable, and PVC drop pipe. An accumulation of rust and other sediment was observed on top of the cable that blocked the borehole.

The CTVSL survey indicated that the casing is encrusted with iron nodules and some section of spalling rust. In addition, the open hole interval appeared to have zones of calcium carbonate encrustation. To remove the iron nodules and rust, the casing was brushed prior to redevelopment of the well. A short descriptive summary of the initial CTVSL is provided below and a detailed descriptive summary can be found in **Appendix D**.

From the top of the casing to the bottom of the casing (casing seat at 1,268 ft bpl), the casing wall was covered in iron encrustation and nodules. Encrustation color started out white with a slight metallic sheen, indicating iron, and had a spider-webbed texture from approximately 0 to 300 ft bpl (**Figure 2)**. Below 300 ft bpl, encrustation color varied from a tan to gray to black, indicating that manganese is part of the encrusting material (**Figure 3)**.

Figure 2. Black encrustation at 629 ft bpl.

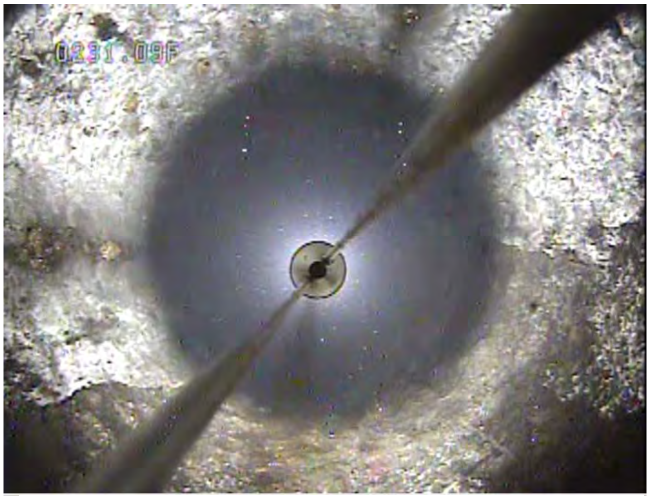


Figure 3. White encrustation at 231 ft bpl.

There were multiple intervals with small to medium iron nodule clusters. These occurred throughout the length of the casing. **Appendix D**, **Screenshot F** shows nodules at approximately 1,057 ft below bpl.

Through some section of the casing, encrustation appears to be thicker and may result in a decrease in the inside diameter of the 24-inch diameter injection casing. **Appendix D**, **Screenshot D** shows the 808 to 810 ft bpl interval with significant encrustation on the casing walls.

Through intervals where the encrustation is thick, spalling, and peeling, it is evident that the casing is peeling off with the encrustation. The spalling and peeling vary in orientation and length. An example of spalling and peeling of the casing wall from 1,000 to 1,010 ft bpl is provided in **Figure 4**.

Figure 4. Spalling and peeling from casing wall at 1,005 ft bpl.

The casing seat at 1,268 ft bpl (**Appendix D**, **Screenshot H**) was identified with the CTVSL and three possible cement windows (located approximately every 120 degrees) were observed (**Appendix D**, **Screenshot I)**. The bottom of the casing was observed at 1,271 ft bpl (**Appendix D**, **Screenshot J)**.

The open hole interval below the bottom of the 24-inch diameter steel injection casing varied in shape from elliptical, to irregular, to gauge (**Appendix D**, **Screenshots P and Q)**.

Other features to note were brecciated borehole intervals (**Appendix D**, **Screenshot O**), and some intervals with cavities. There were sporadic intervals with bacteria growth throughout the entire open hole, such as from 1,541 to 1,544 ft bpl as shown in **Appendix D**, **Screenshot R**.

Immediately above the blockage at 1,570 ft bpl, a large cavernous area began at 1,567 ft bpl, with a partial floor at 1,570 ft bpl (**Figure 5**).

Figure 5. Blockage at 1,570 ft bpl with partial cavern floor.

2.2 FISHING ACTIVITIES

Fishing activities to remove the lost XY caliper tool and cable began February 7, 2020, and most of the lost cable was retrieved from 1,572 ft bpl (**Figure 6**). However, the XY caliper tool was still lodged in the open hole. An interim CTVSL was conducted to see where the XY caliper tool was lodged and to formulate a removal plan. Based on the interim CTVSL, it was determined that the top of the XY caliper tool was lodged at approximately 1,587 ft bpl.

On February 12, 2020, fishing activities resumed with the aid of the CTVSL run simultaneously with the fishing tool. The top of the XY caliper tool was observed at 1,593 ft bpl before the light bulb on the CTVSL blew and YBI lost their video image. YBI believed that the XY caliper tool was hit by the light head, dislodged, and fell to the bottom of the open hole. YBI decided to break up the caliper tool with a rotary bit and remove the tool via the reverse-air drilling method.

Figure 6. Recovered XY caliper tool cable.

2.3 CLEANING OF THE L-63N ASR WELL

With the approval of SFWMD, February 14, 2020, YBI began drilling the XY caliper tool and cleaning out the open hole. YBI initially used a 22-inch diameter drill bit but determined that the bit was too large for the existing open hole diameter and resulted in reaming of the open hole. YBI then switched to a 17.5-inch diameter drill bit, which allowed the bit to be lowered to a depth of approximately 1,400 ft bpl on February 15, 2020.

On Monday, February 17, 2020, YBI drilled through the lost XY caliper tool and PVC drop pipe at the base of the borehole and began developing the well. The bottom of the well was tagged at approximately 1,672 ft bpl and by the end of day the original total depth of 1,700 ft bpl was achieved. Stantec collected pieces of the XY caliper tool and developed material as it was removed from the well (**Figure 7**). Water clarity improved markedly by the end of the initial development process (**Figure 8**).

Tuesday, February 18, 2020, through Wednesday, February 19, 2020, YBI used a steel wire brush to clean the 24-inch diameter steel injection casing of iron encrustation. On Thursday, February 20, 2020, YBI tripped in a 17.5-inch diameter mill tooth drill bit to drill and clear fill out of the open hole of the dislodged rust and other material via the reverse-air drilling method. Approximately 20 feet of debris was removed, and the borehole was opened to 1,700 ft bpl. Stantec collected a few pieces of the XY caliper tool that was removed from the well. On Friday, February 21, 2020, YBI developed the well via the reverse-air method until the discharge water was clear.

Figure 7. Recovered XY caliper tool and PVC drop pipe pieces.

Figure 8. Recovered pieces of XY caliper tool.

2.4 FINAL CTVSL

On Monday, February 24, 2020, YBI completed the final CTVSL and XY caliper log. The final CTVSL confirmed that a majority of the encrustation was removed from the casing walls via steel wire brush cleaning (**Appendix E**, **Screenshot E)**, and most of the welded seams could be observed (**Appendix E**, **Figure F**). Through some intervals, such as from 355 to 390 ft bpl, areas of iron nodule stains can be observed. Continued review of the video log indicated that where some encrustation was removed portions of the casing wall also were removed after cleaning (**Appendix E**, **Screenshot 26**).

At the casing seat depth of 1,268 ft bpl, the three possible cement windows are still visible. From 1,268 to 1,271 ft bpl, the casing appears to be spalling, peeling and missing after the steel wire brush cleaning (**Appendix E**, **Screenshot I**).

The cleaning and clearing, combined with the development, resulted in a clean and clear open hole from 1,268 to 1,700 ft bpl (**Figure 9**). There are no visible pieces of the XY Caliper tool, cable, or PVC drop pipe. A detailed descriptive summary of the final CTVSL can be found in **Appendix E**. The XY caliper log is presented in **Appendix F**.

Figure 9. Clean and clear open hole at 1,568 ft bpl.

2.5 24-INCH DIAMETER CASING PRESSURE TEST

On Friday, February 28, 2020, a pressure test was conducted on the 24-inch diameter steel injection casing. A temporary inflatable packer was set at 1,253 ft bpl. The target pressure for the casing pressure test was 50 pounds per square inch (psi) (**Figure 10**). Overall, the pressure test resulted in a less than 2% decrease in pressure over the hour-long test. The results of the test indicated that the casing can hold pressure with no leaks.

Immediately after the casing pressure test, the temporary inflatable packer was deflated and removed from the L-63N ASR well. Documentation of the pressure test, including the pressure gauge calibration certificate and the signed pressure test log, can be found in **Appendix G**. Once the packer was removed, YBI began setting up for the nine-hour step-rate pumping test.

Figure 10. Calibrated Pressure Gauge at beginning of casing pressure test.

2.6 STEP-RATE PUMPING TEST ON L-63N ASR WELL

The nine-hour step-rate pumping test occurred on Monday, March 23, 2020, after having a previous false-start on Friday, March 20, 2020. After the test began on Friday, March 20, 2020, it was observed that discharge water was eroding the bank of the canal, which resulted in the test being postponed. Additional PVC pipe was added to extend the discharge point further into the canal to bypass the bank, and a floating silt fence was added to minimize turbid water from entering the canal. The step-rate pumping test was postponed till the following Monday to allow for the addition of a second PVC discharge pipe and the installation of a silt fence in the canal (**Figure 11**). Background data collection began on Friday, March 20, 2020.

Figure 11. Discharge pipe set-up to discharge into the canal with silt fence in

The step-rate pumping test consisted of three steps, each with a three-hour duration. The target pump rates for the three steps were 2,200 gallons per minute (gpm), 5,200 gpm, and 7,100 gpm. Water level, temperature, and pressure were logarithmically recorded using two transducers set side-by-side at approximately 18 feet below the top of the concrete well pad. The transducers were calibrated simultaneously by YBI to ensure overall accuracy of readings for both transducers. Each transducer was connected to a computer and readings were recorded by hand from the computer screen approximately every minute for the first 10 minutes, every 5 minutes for the next 20 minutes, every 10 minutes for an hour, and every 15 minutes until the end of the step. The step-rate pumping test hand-recorded data can be found in **Appendix H**. The raw transducer data was electronically submitted to SFWMD. At the conclusion of the step-rate pumping test, transducers recorded 12 hours of recovery data.

SFWMD extracted DBHYDRO water level data from TCRK_GW2 (the lower monitoring zone of the dual zone monitoring well), which is continuously monitoring and recording (this data was also electronically submitted to SFWMD). The monitoring well is approximately 550 feet to the north of the ASR well. **Figure 12** shows the resultant drawdown that was observed in TCRK_GW2. Overall, water levels did not stabilize at the monitoring well during the test and continued to decline at the end of each step. It’s important to note that the time stamp for monitoring well data was not correct so it could not be determined if a delay between the start of the test and the response in the monitoring well water levels was instantaneous of delayed.

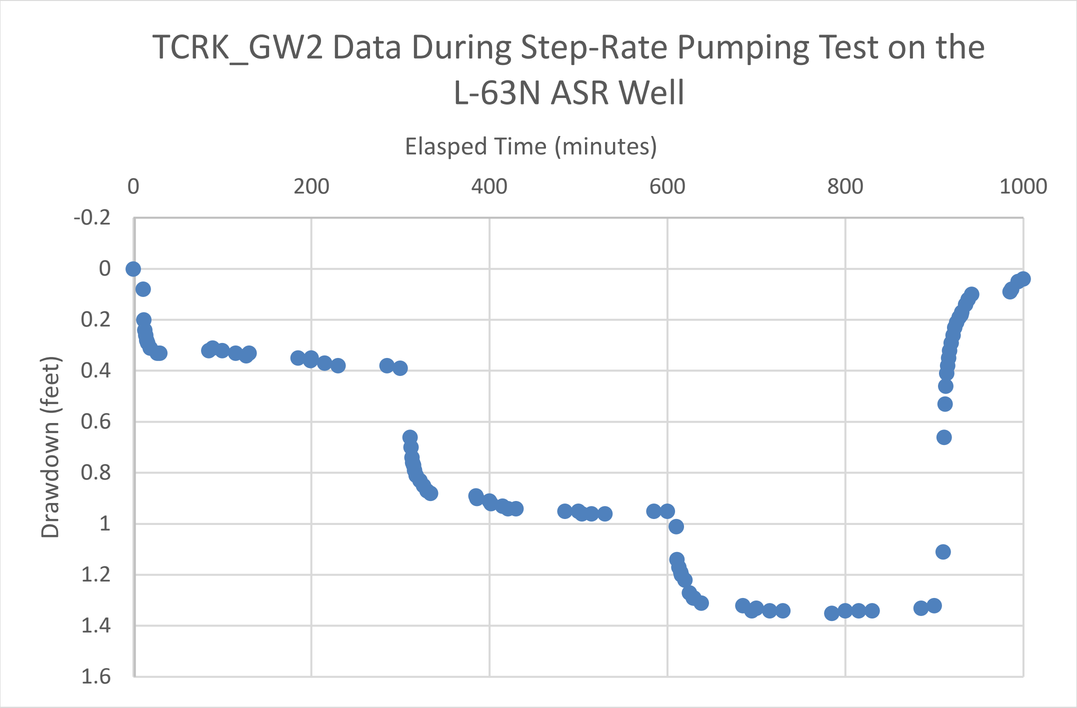


Figure 12. TCRK_GW2 Data During Step-Rate Pumping Test on the L-63N ASR Well showing drawdown.

During each step, field water quality samples were collected every 15 minutes for the first and last half hour and every 30 minutes in between. The water quality samples were measured for total dissolved solids (TDS), pH, temperature, specific conductance, and salinity using a hand-held YSI Professional Plus water quality sampling meter. Turbidity was measured using two Hach 2100Q Turbidimeters to ensure accuracy: one rented by

Stantec from Pine Environmental and one provided by YBI. Graphs for TDS, specific conductance, and salinity were produced to examine trends throughout the test. TDS and specific conductance both showed a slight increase while salinity remained stable. The water quality data in tabular form can be found in **Appendix I,** while the graphs for TDS, specific conductance, pH, temperature, salinity, and turbidity can be found in **Appendix J**.

During the second and third steps, sand content was measured using a Rossum sand tester. Sand content was not measured for the first step because the flow rate was not high enough to fill the pipe. For the second step, the sand test was run 15 minutes after the start of the step and 15 minutes before the end of the step. For the third step, the sand test was run 30 minutes after the start of the step and 15 minutes before the end of the step.

2.6.1 Step-Rate Pumping Test Analysis

The step-rate pumping test data is useful in determining the well efficiency under a variety of pumping conditions, as well as specific capacity and general drawdown conditions in a well. Additionally, the results of the step-rate pumping test establish the baseline pumping conditions of the well. Specific capacities indicate the wells ability to withdraw water per foot of drawdown at a particular pumping rate. This test is used to determine if the desired pumping rate of 10 million gallons per day (MGD) is sustainable. The 10 MGD pumping rate was requested by SFWMD and is also the previous cycle testing target pumping rate (Quiñones-Aponte and et. al., 1996). It is important to note that this was a single well test and that transmissivities derived from this test are estimated and highly effected by borehole plugging. These transmissivities do not represent the actual aquifer transmissivities but rather the transmissive properties of the well under current conditions. However, these data are useful in evaluating the extent of plugging or the decline in well efficiency when compared to the original pumping test data.

The desired pumping rate for the L-63N ASR Well is 10 MGD or 6,944 gpm. Pumping rates were distributed across the maximum discharge of the pump under the operating conditions that existed at the time of the test. The test results indicate a specific capacity of 836.18 gallons per minute per foot drawdown (gpm/ft dd) at an average pumping rate of 2,200 gpm for Step 1, 415.97 gpm/ft dd at an average pumping rate of 5,200 gpm for Step 2, and 347.32 gpm/ft dd at an average pumping rate of 7,100 gpm. Water level trends appeared to stabilize during each step; however, fluctuation in the transducer data did occur. It is not clear why transducer water levels "bounced" during the test; however, it is assumed that pressure waves from the pump may have affected the transducers. A tabular summary of the test data results is presented in **Table 1**. Graphical representations of the step-rate pumping test are presented in **Figure 13**.

Table 1. L-63N ASR Well Step-Rate Pumping Test Results

Test	**Date and Time**	**Step**	**Pump Rate** (gpm)	**Drawdown** (ft)	**Specific Capacity** (gpm/ft dd)
L-63N ASR Well	3/23/2020 0730	1	2,200	2.63	836.18
	3/23/2020 1031	2	5,200	12.50	415.97
	3/23/2020 1330	3	7,100	20.44	347.32

* Static Water Level was 8.083 feet above land surface at the start of the test.

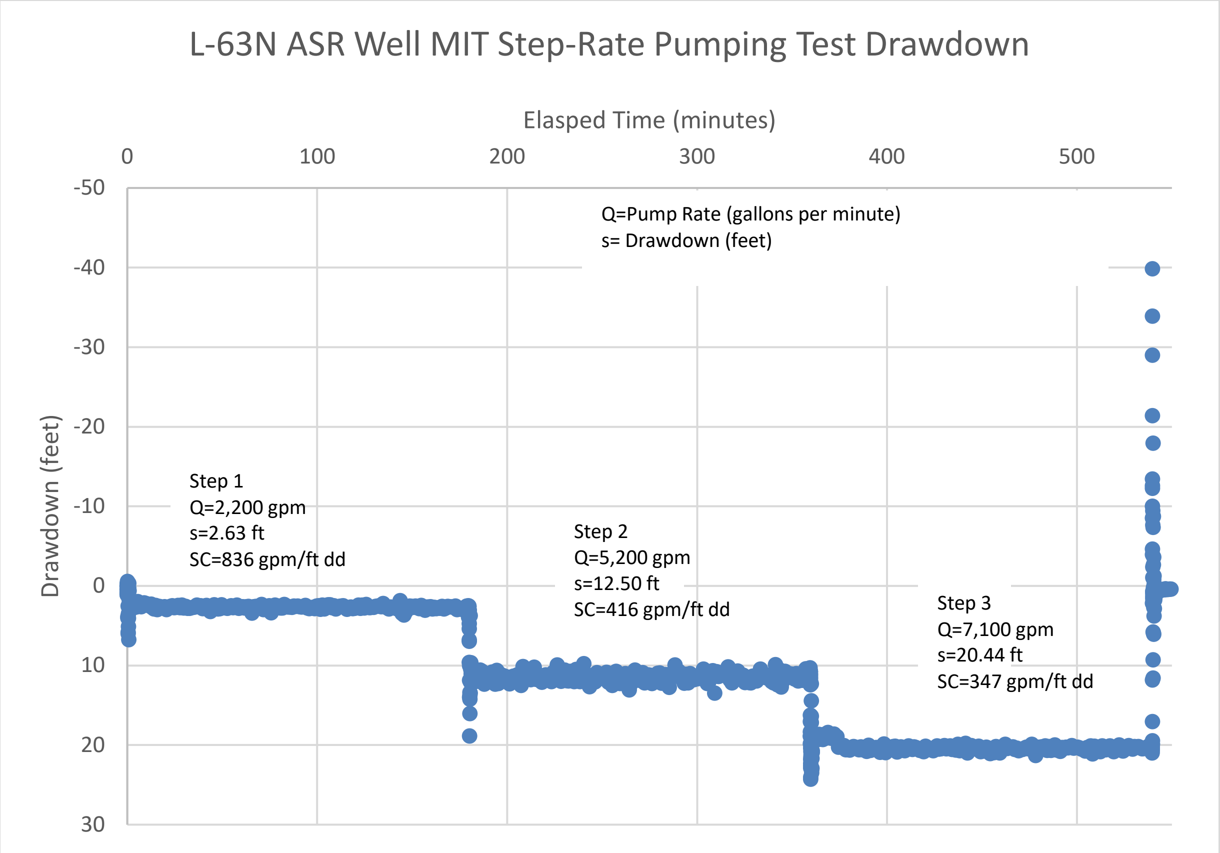


Figure 13. L-63N ASR Well Step-Rate Pumping Test Data

The Bierschenk Method was used to analyze the step-rate pumping test data to determine well efficiencies at specific pumping rates (Driscoll, 1986). **Figure 14** shows graphically the calculated a b-coefficient to determine well efficiency at different pumping rates. Based on this analysis, the well efficiency is approximately 42 percent (%) at 2,200 gpm, 21% at 5,200 gpm, and 17% at 7,100 gpm (**Table 2**).

Table 2. Well Efficiencies for Pumping Rates Completed During Step-Rate Pumping Test

Q Pumping Rate (gpm)	s Drawdown (ft)	s/Q	Formation Loss (Q*b) (ft)	Well Loss (s-Formation Loss) (ft)	Well Efficiency (%)
2,200	2.631	0.0012	1.10	1.53	42
5,200	12.50	0.0024	2.60	9.90	21
7,100	20.44	0.0029	3.55	16.89	17

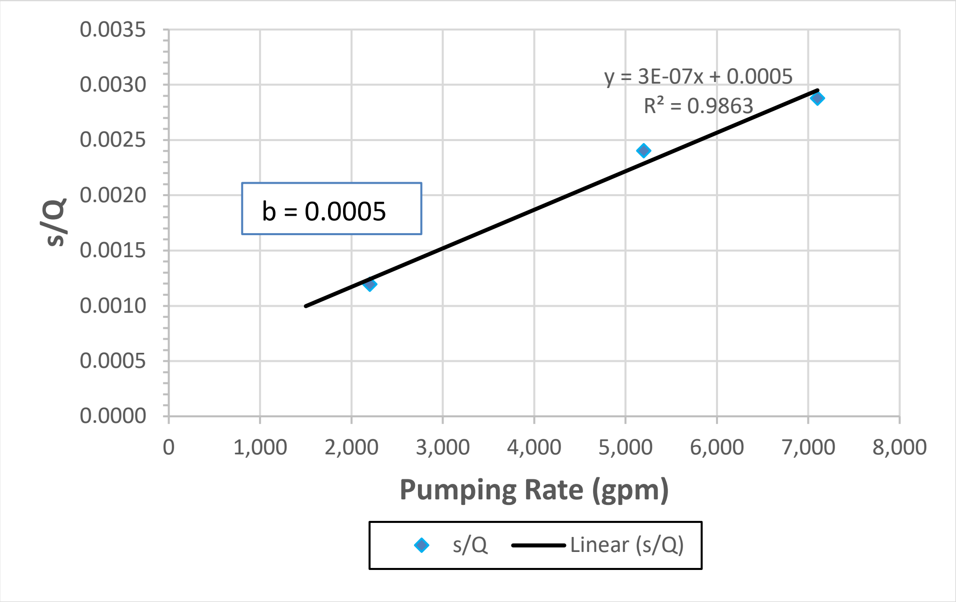


Figure 14. Step-Rate Pumping Test Analysis for Determining a b-Coefficient for Well Efficiencies

Aquifer transmissivity near the pumping well was estimated from the specific capacity data using a derivation of Jacob's empirical non-equilibrium formula for a confined aquifer as presented in Driscoll, 1986. The equation is derived assuming an average well diameter, average duration of pumping and typical values for storage coefficient. The transmissivity in foot squared per day (ft^2/d) for the aquifer can be estimated from the specific capacity by the following empirical equation:

$$Q/s = T \text{ X } 2000$$

where:

Q = yield of the well (gpm)

s = drawdown in the well (feet)

T = transmissivity of the well (ft^2/d)

Utilizing this empirical equation, the estimated transmissivity of the aquifer from the specific capacity testing results indicate a range from 223,549 ft^2/d from the first step to 92,855 ft^2/d from the third step. When well efficiency is taken into account, the estimated aquifer transmissivity ranges from 596,130 to 204,729 ft^2/d.

The step-rate pumping test was also analyzed using AQTESOLV™ (AQTESOLV) for Windows Pro software for aquifer test analysis. Results of the analyses are summarized in **Table 3**. Graphical summaries of AQTESOLV transmissivity curve matchings are presented in **Appendix K**. Five industry standard analytical methods were performed for confined aquifers, Theis (1935)/Hantush (1961), Theis (1935) step-drawdown test, Cooper-Jacob (1946), Papadopulos-Cooper (1967), and Dougherty-Babu (1984). The analyses resulted in an estimated transmissivity of a close range from 228,217 ft^2/d for Cooper-Jacob to a transmissivity of 228,226 ft^2/d for Papadopulos-Cooper. Based on Driscoll, 1986, drawdown data from an observation well are required to calculate the storage coefficient accurately, whereas transmissivities may be calculated based on drawdown data taken from either a pumping well or observation well. As stated by Driscoll, most of the actual pumping tests are constant-rate tests because the storage coefficient is generally more accurate. Storativity cannot be implied from the step-rate pumping test because the aquifer has not stressed enough compared to a constant-rate test. As a result, storage coefficient derived from constant rate tests are more accurate. An estimated confined aquifer coefficient of storage should range from 10^{-5} to 10^{-3} (Driscoll 1986). AQTESOLV was used to estimate storativity from the step-rate pumping test. These storage values fell within a range from 9.02×10^{-4} to 2.88×10^{-4} were used to help estimate transmissivities in AQTESOLV from the step-rate pumping test data.

	Theis (AQTESOLV)	Theis step-drawdown test (AQTESOLV)	Cooper-Jacob (AQTESOLV)	Papadopulos-Cooper (AQTESOLV)	Dougherty-Babu (AQTESOLV)	Empirical Equation (Driscoll, 1986) with well efficiency accounted for
Transmissivity (ft^2/d)	228,225	228,221	228,217	228,226	228,222	596,130 to 204,729
Storativity	2.88×10^{-4}	3.55×10^{-4}	9.02×10^{-4}	3.55×10^{-4}	3.94×10^{-4}	

Table 3. Estimated Transmissivities-First Run AQTESOLV

Jacob, 1946, developed an equation that when turbulent flows exist, the drawdown in a well can be more accurately expressed as the sum of a first-order (laminar) component and a second-order (turbulent) component (Driscoll, 1986):

$$s = BQ + CQ^2$$

Aquifer loss is laminar and well loss is turbulent. Using the Bierschenk method, B, as mentioned above, was 0.0005, while the slope or C was determined to be 3e-7 (3×10^{-7}) as shown in **Figure 13**. Effective well radius is the radial distance from the center of a pumped well, when the theoretical drawdown in the aquifer (laminar aquifer loss) is equivalent to the total aquifer in the well, neglecting the turbulent well loss. Per AQTESOLV, the equation developed by Jacob (1947), accounts for the effective well radius or r_w:

$$s = B(r_w, t)Q + CQ^2$$

Utilizing the maximum drawdown that occurred during the third step, the effective well radius was determined to be 1.498 ft.

In a deeper analysis of well loss, Ramey (1982), defined the aquifer loss coefficient in terms of a dimensionless wellbore skin factor, S_w:

$$S_w = B_2 2\pi T$$

This analysis assumes that turbulent well loss is negligible, and the skin effect is the difference between the total drawdown in the well and the theoretical drawdown in the aquifer (laminar aquifer loss) at the well screen or open borehole. Per Ramey (AQTESOLV) a positive skin indicates permeability reduction at the wellbore.

Ramey (1982) showed the relationship between the nominal well radius and effective well radius is:

$$r^*_w = r_w e^{(-S_w)}$$

With $r_w = .92$ ft and $r^*_w = 1.498$ ft, the S_w is 0.49.

AQTESOLV was utilized to determine if the well losses, including turbulent well loss (C), effective well radius and the wellbore skin factor has an impact of the transmissivity values that were determined previously. The Theis step-drawdown test analysis includes wellbore skin factor (S_w) and well loss (C). Papadopulos-Cooper examines the effective well radius (r^*_w). The Dougherty-Babu includes wellbore skin factor (S_w) and effective well radius (r^*_w). Estimated transmissivity ranged from 212,101 ft^2/d for Theis step-drawdown test to 228,178 ft^2/d for Dougherty-Babu when the wellbore skin factor was considered. Effective well radius had a greater impact to the estimated transmissivity, ranging from 216,463 ft^2/d for Papadopulos-Cooper to 214,696 ft^2/d for Dougherty-Babu. When turbulent well loss was considered, the estimated transmissivity using the Theis step-drawdown test solution resulted in 187,141 ft^2/d. For all the well losses, the coefficient of storage resulted in a closer estimation for a confined aquifer, ranging from 5.01×10^{-4} to 3.94×10^{-4}. These results are shown below in **Table 4**. Graphical summaries of AQTESOLV transmissivity curve matchings are presented in **Appendix K**.

		Theis step-drawdown test (AQTESOLV)	Papadopulos-Cooper (AQTESOLV)	Dougherty-Babu (AQTESOLV)
Wellbore Skin Factor (S_w)	Transmissivity (ft^2/d)	212,101		228,178
	Storativity	3.98×10^{-4}		4.37×10^{-4}
Effective Well Radius (r^*_w)	Transmissivity (ft^2/d)		216,463	214,696
	Storativity		3.94×10^{-4}	4.84×10^{-4}
Turbulent Well Loss (C)	Transmissivity (ft^2/d)	187,141		
	Storativity	5.01×10^{-4}		

Table 4. Estimated Transmissivities-Second Run with Variables

In order to approximate how much of an effect the well losses, including turbulent well loss, effective well radius, and the wellbore skin factor has on the data, Theis step-drawdown test and Dougherty Babu solutions were analyzed once again in AQTESOLV, resulting in the transmissivity and coefficient of storage values presented in **Table 5**. Graphical summaries of AQTESOLV transmissivity curve matchings are presented in **Appendix K**. Dougherty-Babu had the higher transmissivity of 220,020 ft^2/d and Theis step-drawdown test had the lower transmissivity of 200,508 ft^2/d. The coefficient of storage increased to 3.13×10^{-3} for Theis step-drawdown test solution and 3.19×10^{-3} for Dougherty-Babu. These transmissivities appear to be the appropriate transmissivities for the analysis of the step-rate pumping test.

Table 5. Estimated Transmissivities-Third Run with Combined Variables

	Theis step-drawdown test (AQTESOLV)	Dougherty-Babu (AQTESOLV)
Transmissivity (ft^2/d)	200,508	220,020
Storativity	3.13×10^{-3}	3.19×10^{-3}

2.6.2 Comparative Analysis

Based on the report, *Construction and Testing of the Aquifer Storage and Recovery (ASR) Demonstration Project for Lake Okeechobee, Florida* by CH2M Hill (1989), the 24-hour pump test on the L-63N ASR Well had a pump rate of 6,500 gpm. The observed maximum drawdown was 4.06 feet. This resulted in a calculated specific capacity of 1,600 gpm/ft dd. The estimated transmissivity was 620,238 ft^2/d from the Modified Jacob-Recovery solution (CH2M Hill 1989), the storativity was determined to range from 0.00019 (1.9 x 10^{-4}) for the Modified Jacob (Recovery) to 0.00125 (1.25 x 10^{-3}) for the Hantush and Jacob drawdown solution. **Table 6** summarizes the results of the constant rate test and the resultant well efficiency.

Table 6. Well Efficiency for the CH2M Hill 24-hour Pumping Test

Q Pumping Rate (gpm)	s Drawdown (ft)	s/Q	Formation Loss (Q*b) (ft)	Well Loss (s-Formation Loss) (ft)	Well Efficiency (%)
6,500	4.06	0.00062	3.25	0.81	80

The 24-hour pumping test results indicated a well efficiency of 80%, with a transmissivity of approximately 620,238 ft^2/d, and specific capacity of 1,600 gpm/ft dd at 6,500 gpm (CH2M Hill 1989). Since this test was conducted, the well efficiency has dropped to as low as 17% during the last step of the step-rate pumping test. This loss in efficiency also is observed in the decrease in the transmissivity estimated from the step-rate pumping test of approximately 200,508 to 220,020 ft^2/d and the lower specific capacity of approximately 347 gpm/ft, which is nearly an 80% decrease in specific capacity compared to the constant rate test.

3.0 CONCLUSIONS

The lost caliper tool and cable was successfully removed from the borehole at L-63N ASR well and the borehole was cleaned to the total depth. A pressure test indicated that the 24-inch diameter casing can hold 50 psi over a one-hour period, which indicates that the casing has mechanical integrity and does not leak.

The results of the step-rate pumping test indicate that the well can be pumped at 10 MGD; however, the specific capacity of the well has declined by nearly 80% compared to the initial specific capacity calculated from the constant-rate test performed at the time of construction in 1989.

4.0 RECOMMENDATIONS

The L-63N ASR Well is a good producer and was pumped at a discharge rate of 10 MGD during the last step of the test. However, well efficiency has significantly declined since the well was constructed. As a result, it is recommended that the open hole be acidized to remove calcification and bacterial growth that may be plugging the open hole. Acidizing should increase the flow characteristics in the borehole, resulting in higher specific capacity, better well efficiency, and higher desired pump rates.

Although the 24-inch diameter casing passed the pressure test, the video log indicated that significant spalling of the casing had occurred, which has thinned the casing walls. As a result, it is recommended that SFWMD consider lining the 24-inch diameter steel injection casing. The liner can either steel, stainless steel, or FRP and can range in diameter from approximately 16 to 20 inches depending on the desired final capacity of the well. This will prolong the life of the ASR well once cycle testing and operation of the system begins.

5.0 REFERENCES

AQTESOLV, http://www.aqtesolv.com/pumping-tests/step-drawdown-tests.htm, 1998-2020.

CH2M Hill, Construction and Testing of the Aquifer Storage and Recovery (ASR) Demonstration Project for Lake Okeechobee, Florida,1989.

Driscoll, Fletcher G., Groundwater and Wells, 1986.

Quiñones-Aponte, Vicente, Kevin Kotun and Joseph F. Whitley, Analysis of Tests of Subsurface Injection, Storage, and Recovery of Freshwater in the Lower Floridan Aquifer, Okeechobee County, Florida. U.S. Geological Survey Open-File Report 95-765, 1996.

APPENDIX A

Stantec Dailies

Appendix A

A.1 STANTEC DAILIES

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 01/30/2020
0900 - 1600

Sun	Mon	Tue	Wed	Thr	Fri	Sat
				X		

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			x	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			x	**01**

SHIFT SUMMARY

OBSERVER: Cora Summerfield/Stantec and Hannah Rahman/Stantec

START DEPTH: 0 feet bpl

DRILLER: Ross Aanerud/YBI

END DEPTH: 1571 feet bpl

ACTIVITY: Video logging to 1571 feet below pad level (bpl)

SUB CONTRACTORS: None.

FORMATION SAMPLES: None.

WATER SAMPLES: None.

TESTING: None.

TIME	DESCRIPTION
0830	**H. Rahman/Stantec onsite, YBI already onsite.**
0855	**C. Summerfield/Stantec onsite.**
0904	**YBI explains how they will conduct the video log and they start the video log with downhole view.**
0907	**C. Summerfield/Stantec slams finger in geophysical logging truck door. First Aid administered.**
0910	**Video at 28 feet per minute (ft/min).**
0930	**Video increase speed to 30 ft/min.**
0940	**Call with R. Cowles/Stantec.**
0949	**Bottom of casing at 1271 ft bpl. Did a 360-degree side view of the casing. Bottom of casing is uniform. Cement was apparent behind the casing.**
0952	**Switched back to downhole view at 17 ft/min.**
1018	**Reached bottom of borehole – cable and other material visible at bottom of borehole.**
1026	**Began side view up hole video at 10 ft/min.**
1100	**Reached bottom of casing – large iron nodules observed on casing walls.**
1115	**YBI switches to new video.**
1120	**Call with R. Cowles/Stantec.**
1128	**Begin next video.**
1158	**Increased video speed to 20 ft/min.**

Observer's Initials HR/CS

1236 Finished recording video and pulling camera out of the hole.
1242 YBI changed lightbulb on camera from LED to halogen to test if video quality is better.
1258 Second downhole recording begins at 30 ft/min.
1303 Second downhole video much brighter and better quality.
1350 R. Cowles/Stantec onsite.
1354 Video at bottom of borehole – cable and other material easily visible at bottom of borehole.
1450 R. Cowles/Stantec offsite.
1520 C. Summerfield/Stantec and H. Rahman/Stantec offsite for lunch.
1620 C. Summerfield/Stantec and H. Rahman/Stantec onsite.
1622 C. Summerfield/Stantec and H. Rahman/Stantec receive video recordings.
1628 H. Rahman/Stantec offsite.
1630 C. Summerfield/Stantec offsite.

Observer's Initials **HR/CS**

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/07/2020
0900 - 1600

Sun	Mon	Tue	Wed	Thr	Fri	Sat
					X	

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
		X		
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
		X		**02**

SHIFT SUMMARY

OBSERVER: Cora Summerfield/Stantec

START DEPTH:

DRILLER: Ross Aanerud/YBI

END DEPTH:

ACTIVITY: Fishing lost geophysical logging tools, pvc, and cable out of the well

SUB CONTRACTORS: None.

FORMATION SAMPLES: None.

WATER SAMPLES: None.

TESTING: None.

TIME	DESCRIPTION
1010	**C. Summerfield/Stantec onsite, YBI began at 7:30 am and has fishing tool in well.**
1030	**YBI running in hole (RIH) with rod 29. Fishing tool is closed.**
1213	**Rod 72 RIH.**
1243	**Rod 78 RIH to depth of 1564.33 feet below pad level (ft bpl).**
1248	**Fishing tool opened.**
1253	**Fishing tool is in place at 1572.73 ft bpl.**
1254	**Fishing tool is closed.**
1256	**Fishing tool loses pressure as YBI begins to trip out of the hole. YBI resets the fishing tool and does not lose pressure.**
1315	**YBI begins tripping out of the hole.**
1443	**Rod 56 is out of the hole.**

Observer's Initials CS

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/10/2020
0900 - 1600

Sun	Mon	Tue	Wed	Thr	Fri	Sat
	X					

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**03**

SHIFT SUMMARY

OBSERVER: Cora Summerfield/Stantec

START DEPTH:

DRILLER: Ross Aanerud/YBI

END DEPTH:

ACTIVITY: Gopher tortoise trap training and video logging

SUB CONTRACTORS: None.

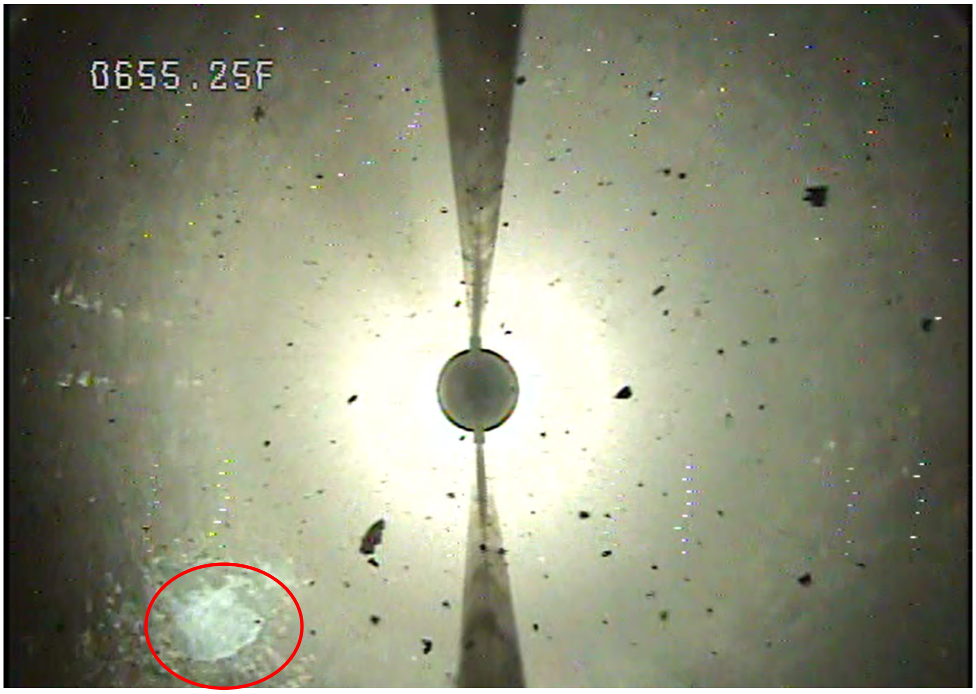
FORMATION SAMPLES: None.

WATER SAMPLES: None.

TESTING: None.

TIME	**DESCRIPTION**
0855	**C. Summerfield/Stantec onsite.**
0900	**H. Andreotta/SFWMD, J. Gent/SFWMD onsite.**
0902	**Begin setting gopher tortoise traps and capture training.**
0935	**Finish setting up traps and capture training**
0938	**Call with R. Cowles/Stantec.**
0940	**YBI begins to run pipe in well to prepare for video logging.**
1005	**C. Summerfield/Stantec offsite.**
1130	**C. Summerfield/Stantec onsite. YBI has 400 feet of pipe in hole to block off salt plug.**
1138	**YBI begins developing well.**
1155	**Geophysical logging truck onsite.**
1320	**Video logging begins.**
1342	**YBI switching from LED to hallogen bulb.**
1407	**YBI restarting video log.**
1430	**Some of the encrustation has flaked off since the previous video exposing the steel casing wall. Images below.**
1507	**Video shows that the obstruction at 1571 feet below pad level (ft bpl) has been cleared. The cable from the lost geophysical logging tool can be seen starting at 1587 ft bpl. The geophysical tool, wires, and caliper arms are visible between 1593-1599 ft bpl. The geophysical tool is lodged against the side of the borehole wall and covered in encrustation. Screenshots of the video log**

	are attached below showing the exposed casing and the lost geophysical tool.
1521	Camera reached a depth of 1599 ft bpl. YBI does not want to go past this point with concern of dislodging the geophysical tool.
1529	YBI begins pulling the camera out of the hole.
1535	Video log completed.
1543	Call with H. Rahman/Stantec.
1559	Call with R. Cowles/Stantec.
1637	Totalizer reading at 1697.4 gallons.
1640	C. Summerfield/Stantec offsite.

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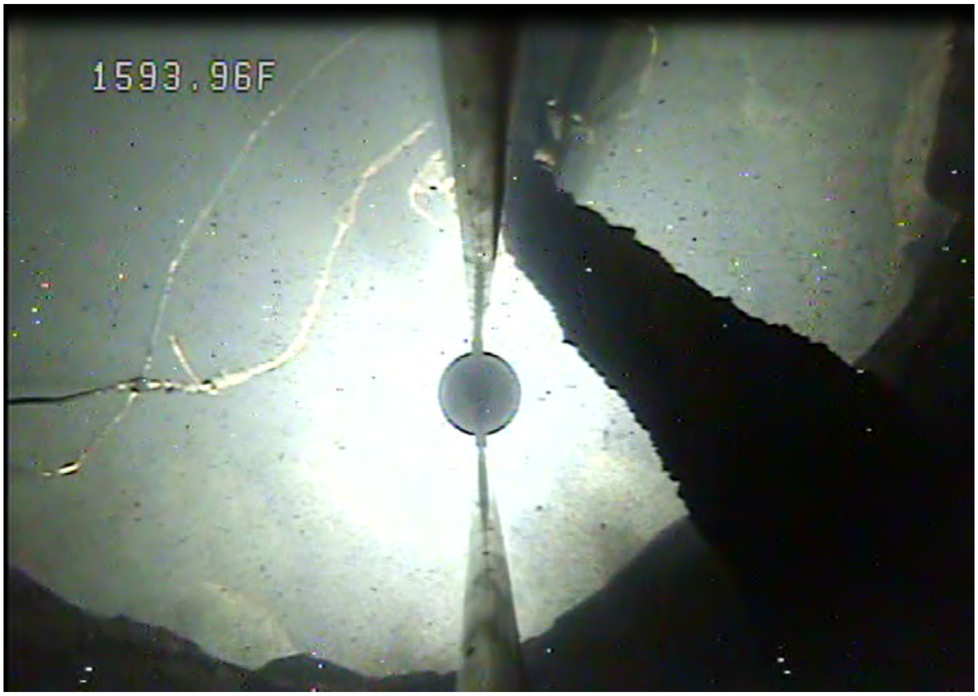

1593.96F

Observer's Initials CS


1596.77F


1598.70F

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/12/2020
1140 - 2000

Sun	Mon	Tue	Wed	Thr	Fri	Sat
			x			

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**04**

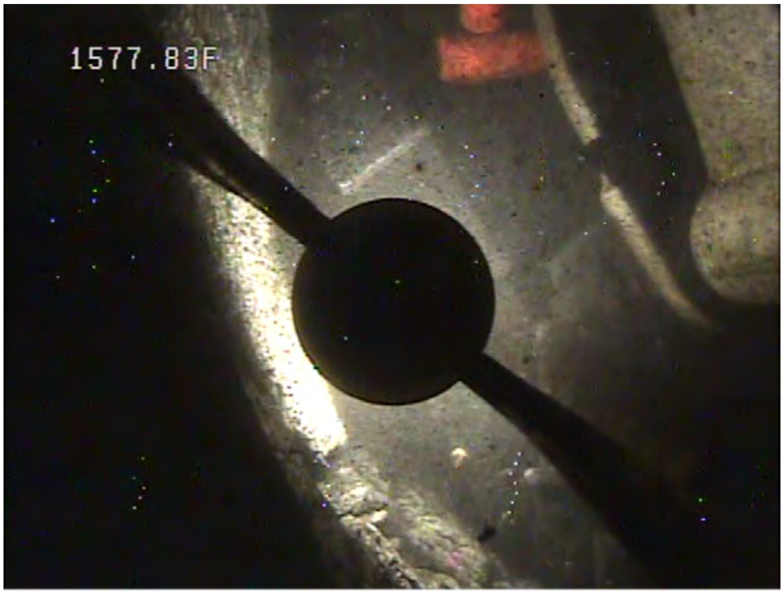
SHIFT SUMMARY

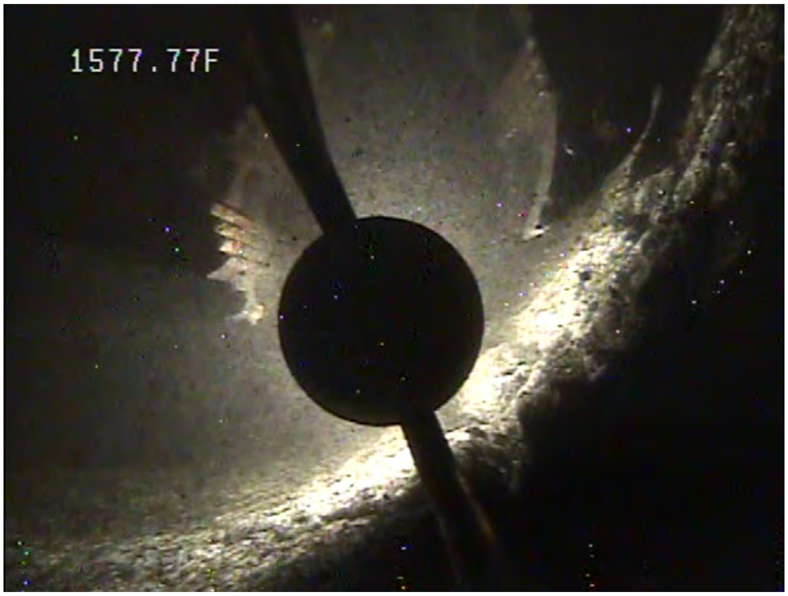
OBSERVER: Hannah Rahman/Stantec
START DEPTH:
DRILLER: Ross Aanerud/YBI
END DEPTH:
ACTIVITY: Fishing for lost XY caliper tool.
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

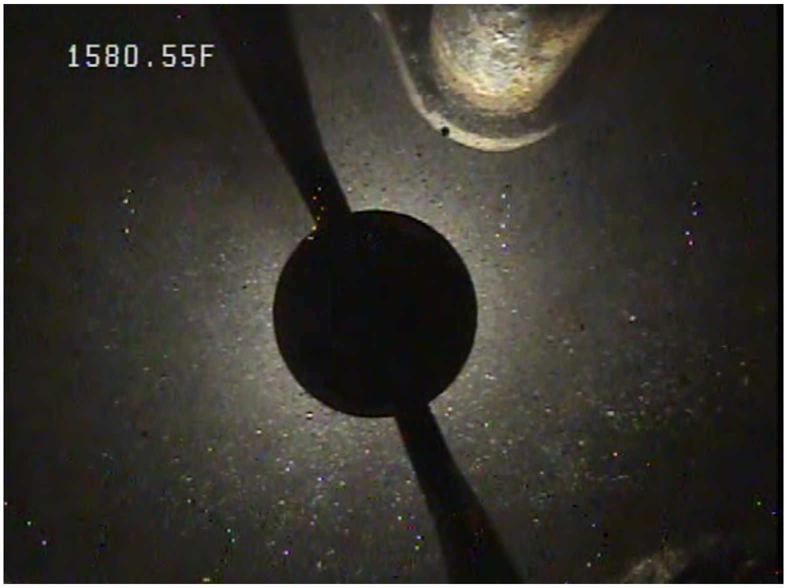
TIME	DESCRIPTION
1140	**H. Rahman/Stantec onsite. YBI onsite since 0830, tripping into hole with drill pipe and fishing tool.**
1205	**Call with R. Cowles/Stantec.**
1210	**H. Rahman/Stantec and YBI offsite.**
1400	**H. Rahman back onsite. YBI already back onsite.**
1403	**R. Cowles onsite.**
1405	**YBI almost finished tripping into hole.**
1419	**YBI logging truck onsite.**
1515	**YBI personnel onsite.**
1521	**Finished tripping into hole with drill pipe and fishing tool. Fishing tool at approximately 1583 feet below pad level (bpl).**
1524	**YBI begins to prepare for fishing out lost caliper tool.**
1550	**R. Cowles getting sample of encrusted cable tool.**
1555	**Received drill pipe tally from R. Aanerud/YBI. See field notebook for pipe tally.**
1612	**Camera set at 0 feet, begin going down hole with video survey tool to find the fishing tool.**
1625	**Camera tool out of hole, need to put on smaller centralizers.**
1639	**R. Cowles/Stantec offsite.**
1653	**Video tool back in hole with smaller centralizers.**
1745	**Top of fishing tool at approximately 1,572 feet bpl.**

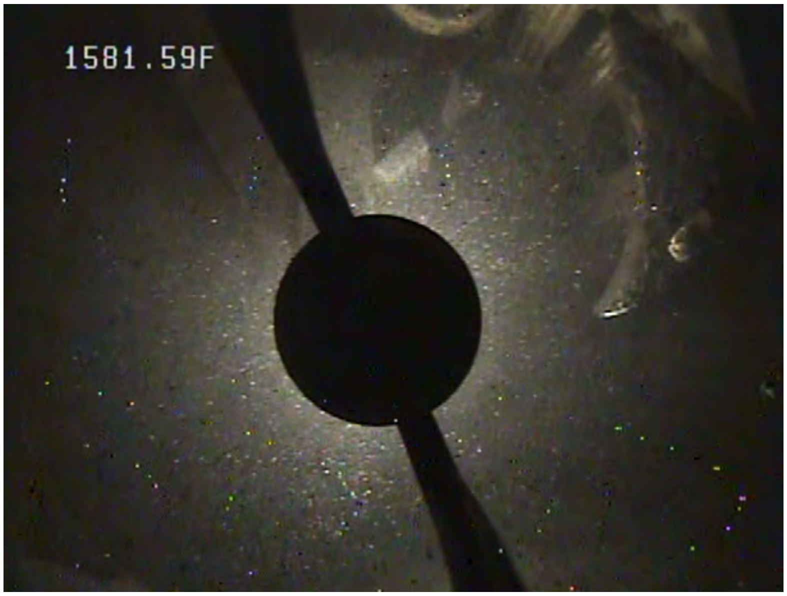
Observer's Initials **HR**

1849	**Light bulb blew and lost visibility of the lost caliper tool.**
1853	**Blindly bringing video tool out of hole.**
1915	**Call with R. Cowles/Stantec.**
1931	**Video tool out of hole.**
2000	**H. Rahman/Stantec and YBI personnel offsite.**

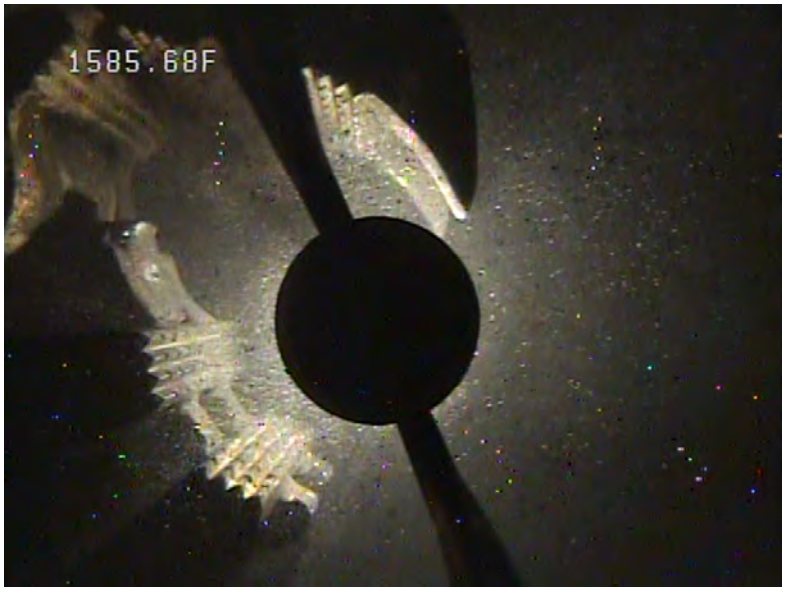








Observer's Initials HR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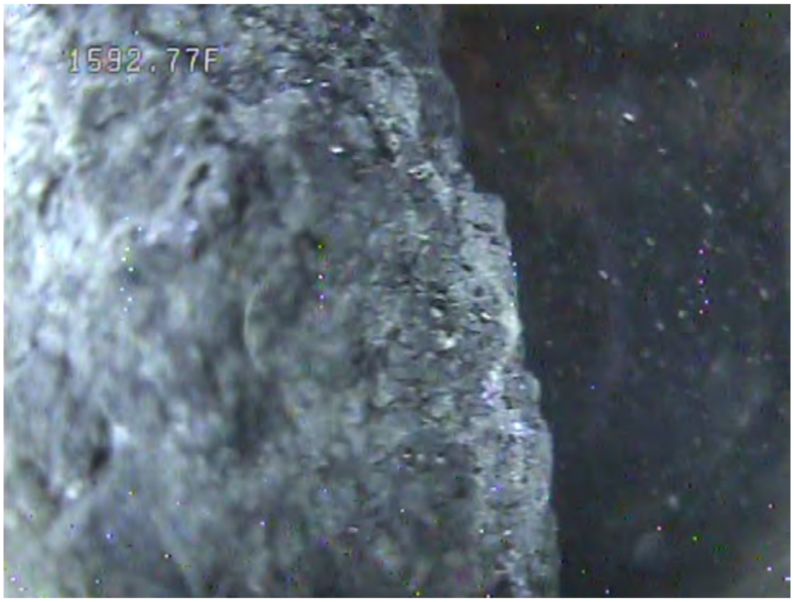


Observer's Initials **HR**


1592.59F


1591.14F

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/14/2020
1100 - 1440

Sun	Mon	Tue	Wed	Thr	Fri	Sat
					x	

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**05**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec
START DEPTH:
DRILLER: Ross Aanerud/YBI
END DEPTH:
ACTIVITY: Drilling/clearing out open hole with 22-inch diameter drill bit.
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
1100	**H. Rahman/Stantec onsite. YBI already onsite.**
1115	**Checked gopher tortoise burrows – no movement.**
1118	**Spoke with R. Aanerud/YBI. They are approximately at 1,270 feet below pad level (bpl) with tremie in preparation of drilling/clearing out open hole via reverse air method.**
1135	**Call with N. Sharma/Stantec.**
1159	**Setting up for reverse air.**
1200	**Begin drilling, rod number 64 on drill string.**
1213	**Kelly down at approximately 1,280 feet bpl.**
1215	**Received drill pipe tally. Refer to field notebook for pipe tally.**
1220	**Stopped drilling. Setting up pump and entire setup for reverse air drilling.**
1255	**Call with N. Sharma/Stantec.**
1338	**Adding bag of salt to open hole.**
1401	**Call with M. Wilson/YBI.**
1403	**Spoke with R. AAnerud/YBI. Fixing valve on equipment so it stops leaking.**
1404	**Call with N. Sharma/Stantec.**
1406	**Call with R. Cowles/Stantec.**
1427	**Call with R. Cowles and N. Sharma/Stantec.**
1420	**YBI is going to trip out of hole with 22-inch diameter bit and trip back in with 17.5-inch diameter drill bit because 22-inch diameter drill bit is getting plugged up.**

Observer's Initials **HR**

1425	**YBI personnel offsite.**
1437	**YBI back onsite.**
1440	**H. Rahman/Stantec offsite.**

Observer's Initials **HR**

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/17/2020
0830 - 1830

Sun	Mon	Tue	Wed	Thr	Fri	Sat
	x					

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**06**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec
START DEPTH: 1,672 feet bpl
DRILLER: Ross Aanerud/YBI
END DEPTH: 1,700 feet bpl
ACTIVITY: Drilling/clearing out open hole with 17.5-inch diameter drill bit.
SUB CONTRACTORS: None.
FORMATION SAMPLES: Collect samples of lost XY caliper tool.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0835	**H. Rahman/Stantec onsite. YBI already onsite.**
0845	**Spoke with R. Aanerud/YBI. They are tripping back into the hole with the 17.5-inch diameter drill bit and are at approximately 1,550 feet below pad level (bpl).**
0900	**H. Andreotta/SFWMD onsite to check gopher tortoise traps. No activity.**
0957	**YBI adding tremie pipe to the hole for reverse air drilling methods.**
1021	**Preparing to begin clearing.**
1024	**Begin clearing. Start depth is 1,630 feet bpl. Rotary = 24 rpm.**
1031	**Kelly down at 1,650 feet bpl. Water has strong odor. YBI is going to purge after each drill rod for 10-15 minutes and will collect cuttings.**
1035	**Per, A. Aanerud/YBI he did not hit anything while clearing, may have felt something closer to 1,650 feet bpl.**
1055	**Setting up to salt kill the well.**
1104	**Adding drill rod.**
1122	**Call with R. Cowles/Stantec.**
1127	**Resume clearing. Rotary = 24 revolutions per minutes (rpm).**
1135	**Per, R. Aanerud/YBI, the drill bit plugged up a little bit. Collecting cuttings, water looks black.**
1210	**Per R. Aanerud/YBI he thinks he hit a void at approximately at 1,662 feet bpl.**

Observer's Initials HR

1227	**R. Aanerud/YBI tagged bottom of the hole (or top of fill) at 1,672.71 feet bpl.**
1245	**Kelly down at 1,670 feet bpl.**
1252	**H. Rahman/Stantec checked gopher tortoise traps. No activity.**
1259	**Water is starting to clear up and hole seems to be getting cleaner.**
1301	**Received drill pipe tally from R. Aanerud/YBI. See field book for drill pipe tally.**
1310	**Setting up to salt kill the well.**
1330	**Resume drilling.**
	Rotary = 32 rpm.
1450	**Per, R. Aanerud/YBI drill bit is still getting plugged up.**
1503	**YBI is going to circulate for about 20 minutes because drill bit is getting plugged up.**
1504	**R. Aanerud/YBI is offsite.**
1506	**H. Rahman/Stantec offsite.**
1539	**H. Rahman/Stantec onsite. R. Aanerud/YBI already back onsite.**
1557	**Kelly down at 1,690 feet bpl.**
1604	**YBI is preparing to add last drill pipe to drill string.**
1619	**H. Rahman/Stantec checked gopher tortoise traps. No activity.**
1621	**Setting up to salt kill the well.**
1638	**Resume drilling.**
	Rotary = 20 rpm.
1710	**R. Aanerud/YBI offsite.**
1747	**R. Aanerud/YBI onsite.**
1751	**Call with R. Cowles/Stantec.**
1802	**Still drilling.**
	Rotary = 12 rpm.
1815	**Reached total depth at 1,700 feet bpl. Stopped drilling.**
1826	**Call with R. Cowles/Stantec.**
1828	**Spoke with R. Aanerud/YBI. They are going to take out tremie pipes. Tomorrow they are going to trip out of the hole and then trip back in the hole to begin brushing the casing.**
1833	**H. Rahman/Stantec offsite.**

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/20/2020
1245 - 1710

Sun	Mon	Tue	Wed	Thr	Fri	Sat
				x		

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**07**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec
START DEPTH: 1,672 feet bpl
DRILLER: Ross Aanerud/YBI
END DEPTH: 1,700 feet bpl
ACTIVITY: Drilling/clearing out open hole with 17.5-inch diameter mill tooth drill bit.
SUB CONTRACTORS: None.
FORMATION SAMPLES: Collect samples of lost XY caliper tool.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
1000	**L-63N MIT progress meeting at Okeechobee field station.**
1227	**Call with R. Aanerud/YBI, they finished tripping into hole and are beginning to set the airline for reverse air methods.**
1246	**H. Rahman/Stantec onsite. YBI already onsite.**
1257	**R. Aanerud/YBI showed me all the sediment in the tanks from development. Approximately six inches of sediment and more in some areas of the tank.**
1259	**YBI begins drilling/clearing.** **Rotary = 22 revolutions per minute (rpm).** **No weight on bit.** **Water has a strong odor and looks like oil.**
1300	**Received polyvinyl (PVC) pipe and XY caliper tool samples from R. Aanerud/YBI.**
1322	**Per R. Aanerud/YBI there is 20 feet of fill from casing brushing. At approximately 1,280 feet below pad level (bpl), they are hitting fill.**
1323	**Water looks to be clearing up.**
1337	**Water is black at 1,690 feet bpl.**
1350	**Kenny/YBI offsite.**
1356	**B. Garrett/SFWMD onsite.**
1400	**Kenny/YBI onsite.**
1415	**Spoke with B. Garrett/SFWMD about tortoise traps.**

Observer's Initials HR

1416	Kelly down at 1,692 feet bpl.
1418	R. Aanerud/YBI is going to circulate for a bit and go back down and clean with drill pipe.
1420	B. Garrett/SFWMD trapped a tortoise.
1429	Water is dark and has an odor.
1501	B. Garrett/SFWMD is offsite.
1445	Kelly back down at 1,692 feet bpl.
1446	YBI continues to circulate.
1522	YBI salt kills the well.
1531	YBI is adding last drill pipe.
1540	Resume drilling. Rotary = 24 rpm No weight on bit.
1546	Water is starting to clear up, but still has an odor.
1550	Water looks like oil and has an odor.
1610	Kelly is down to total depth at 1,700 feet bpl. YBI circulates.
1645	Call with N. Sharma/Stantec.
1646	Water is starting to really clear up, still has a grayish tint to it.
1654	Call with R. Cowles/Stantec.
1657	Talked with R. Aanerud/YBI about plan for tomorrow and next steps. Drill pipe tally did not change with new bit.
1700	Water looks to be significantly clearer.
1706	Checked tortoise traps – no activity.
1710	H. Rahman/Stantec offsite.

Observer's Initials HR

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/24/2020
0930 - 2130

Sun	Mon	Tue	Wed	Thr	Fri	Sat
	x					

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**08**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec
START DEPTH: 1,700 feet bpl
DRILLER: Ross Aanerud/YBI
END DEPTH: 1,700 feet bpl
ACTIVITY: Completing final video survey and XY caliper log.
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0930	**H. Rahman/Stantec onsite. YBI already onsite. G. Cook/SFWMD onsite.**
0942	**YBI logging truck onsite.**
0946	**YBI setting up for final video survey.**
0947	**YBI personnel onsite.**
1017	**YBI putting video survey tool in the hole.**
1022	**Begin video survey.** **Approximately 30 feet/minute.** **Water is flowing about 100 gallons per minute.**
1035	**YBI personnel offsite.**
1059	**YBI personnel back onsite.**
1101	**Reached bottom of casing at 1,268 feet below pad level (bpl).**
1111	**Continue video survey in open hole.** **Approximately 26 feet/minute.**
1127	**Reached total depth of well at 1,700 feet bpl. No XY caliper tool or polyvinyl (PVC) pipe at bottom.**
1130	**Begin recording video survey up hole with 360-degree side view.** **Approximately 14 feet/minute.**
1145	**Slowed down to 12 feet/minute.**
1156	**Quick break.**

Observer's Initials **HR**

1212	**Resume video survey. Approximately 13 feet/minute.**
1222	**Forgot to start recording, now recording. Approximately 12 feet/minute.**
1242	**Call with R. Cowles and N. Sharma/Stantec.**
1424	**Changing out cable on TV.**
1428	**Resume video survey.**
1438	**Call with R. Cowles/Stantec.**
1502	**Video survey tool is back up in the drill pipe at about 24 feet bpl.**
1503	**Complete video survey.**
1510	**Setting up for XY caliper log.**
1538	**Calibrating XY caliper tool.**
1350	**XY caliper tool in hole and running.**
1356	**Greg/SFWMD offsite.**
1600	**YBI recalibrating XY caliper tool.**
1620	**Begin XY caliper log.**
1623	**Call with N. Sharma/Stantec.**
1640	**Reached 1,702 feet bpl, running multiple passes.**
1642	**Coming back up hole with caliper tool at approximately 30 feet per minute.**
1723	**Issues with XY caliper tool not recording correctly. There is a kink in the wireline. YBI is going to try completing the log with a different XY caliper tool.**
1730	**YBI troubleshooting the XY caliper tool issue.**
1735	**H. Rahman/Stantec offsite.**
1810	**H. Rahman/Stantec onsite.**
1820	**YBI calibrating the backup XY caliper tool – issue was not the kink in the wireline.**
1835	**Begin running XY caliper tool.**
1848	**Reached total depth of ~1,700 feet bpl.**
1850	**Completing repeat passes.**
1900	**XY caliper logging up hole.**
1930	**XY caliper log completed.**
1941	**XY caliper tool out of hole.**
1945	**YBI preparing final XY caliper log and video survey.**
2024	**Waiting on approval for the XY caliper log. YBI loggers needed to make some changes and log is sent back for approval.**
2120	**XY caliper log final approval received.**
2125	**Final XY caliper logs sent out via email – hard copies received along with video survey on flash drive.**
2130	**H. Rahman/Stantec offsite.**

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/28/2020
0900 - 1110

Sun	Mon	Tue	Wed	Thr	Fri	Sat
					x	

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
		x		
Wind	Still	Medium	High	
		x		
Humidity	Dry	Moderate	Humid	**Report No.**
		x		**09**

SHIFT SUMMARY

OBSERVER: H. Rahman and N. Sharma/Stantec
START DEPTH: 1,700 feet bpl
DRILLER: Carlos Lopes/YBI
END DEPTH: 1,700 feet bpl
ACTIVITY: Pressure test for 24-inch diameter steel casing to 1,268 feet bpl.
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0850	**H. Rahman and N. Sharma/Stantec onsite. YBI already onsite.**
0855	**Call with R. Cowles/Stantec.**
0900	**YBI lowering pressure from 60 pounds per square inch (psi) to 50 psi. Pressure is set at 51.5 psi.**
0901	**Received pressure gauge calibration sheet.**
0910	**Received tubing tally and packer measurements from YBI – see photolog and field form.**
0921	**Begin pressure test on 24-inch diameter steel casing.**
1009	**Noticed tiny leak in hole connection to middle pressure gauge.**
1021	**Finished pressure test. Pressure test was less than 2% - see field form.**
1025	**Call with R. Cowles/Stantec.**
1022	**Begin pressure bleed off.**
1024	**Complete pressure bleed off – see field form.**
1026	**YBI signed pressure test field observation form. YBI is taking down packer setup for pressure test.**
1031	**Call with R. Cowles/Stantec.**
1108	**H. Rahman and N. Sharma/Stantec offsite.**

Observer's Initials **HR & NS**

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 03/05/2020
0700 - 0830

Sun	Mon	Tue	Wed	Thr	Fri	Sat
				x		

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			x	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
		x		**10**

SHIFT SUMMARY

OBSERVER: H. Rahman & C. Summerfield/Stantec

START DEPTH: 1,700 feet bpl

DRILLER: Carlos Lopes/YBI

END DEPTH: 1,700 feet bpl

ACTIVITY: 12-hour Step-Rate Pumping Test.

SUB CONTRACTORS: None.

FORMATION SAMPLES: None.

WATER SAMPLES: None.

TESTING: None.

TIME	DESCRIPTION
0700	**H. Rahman and C. Summerfield/Stantec onsite. YBI already onsite.**
0720	**Begin setting pump rate for first step at 2,167 gallons per minute (gpm).**
0727	**Spoke to YBI, they said the pump is in high gear.**
0735	**Pump is set at approximately 2,167 gpm.**
0742	**Begin Step 1 of Step-Rate Pumping Test.**
0743	**Computers are logging transducer data. YBI has two transducers sitting one on top of the other.**
0800	**C. Lopes/YBI onsite.**
0805	**R. Cowles/Stantec onsite.**
0810	**Discussed how the pump can't pump at high enough rates, how there isn't enough drawdown, and what to do about discharge water in regard to the canal and discharge pond.**
0820	**R. Cowles/Stantec offsite.**
0830	**H. Rahman and C. Summerfield offsite.**

Observer's Initials HR & CS

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 03/13/2020
0900 - 1015

Sun	Mon	Tue	Wed	Thr	Fri	Sat
					x	

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			x	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
		x		**11**

SHIFT SUMMARY

OBSERVER: H. Rahman/Stantec
START DEPTH: 1,700 feet
DRILLER: Danny Atkisson/YBI
bpl END DEPTH: 1,700 feet bpl
ACTIVITY: Gopher tortoise trap training with SFWMD.
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0845	**H. Rahman/Stantec onsite. YBI and G. Brian/SFWMD already onsite.**
0850	**J. Gent/SFWMD onsite.**
0910	**Begin gopher tortoise training.**
0920	**J. Gent/SFWMD offsite.**
1000	**End of gopher tortoise training.**
1004	**B. Garret/SFWMD offsite.**
1006	**H. Rahman/Stantec offsite.**
1008	**Call with R. Cowles.**
1010	**H. Rahman/Stantec back onsite to take picture of pump setup for the Step-Rate Pumping Test.**
1015	**H. Rahman/offsite.**

Observer's Initials HR

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 03/20/2020
0700 - 1100

Sun	Mon	Tue	Wed	Thr	Fri	Sat
					x	

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	X
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**12**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec and Cora Summerfield/Stantec

START DEPTH:

DRILLER: Danny Atkisson/YBI

END DEPTH:

ACTIVITY: Step-Rate Pumping Test

SUB CONTRACTORS: None.

FORMATION SAMPLES: None.

WATER SAMPLES: None.

TESTING: None.

TIME	**DESCRIPTION**
0640	**H. Rahman/Stantec onsite. YBI already onsite.**
0650	**Call with C. Summerfield/Stantec.**
0705	**H. Rahman/Stantec informed that 7,000 gallons per minute (gpm) pumping rate was sustained for over 3 hours on March 19, 2020 without any issue with drawdown.**
0718	**C. Summerfield/Stantec onsite.**
0725	**R. Cowles/Stantec onsite.**
0730	**Stepped the test from background to Step 1.**
0731	**YBI starting pump.**
0732	**Begin Step 1.**
0734	**Pumping rate at 2,000 gpm. Totalizer at 721.5**
0740	**Water quality sample taken.**
0749	**Pumping rate at 2,400 gpm**
0754	**Pumping rate at 2,400 gpm**
0803	**YBI shutting down test to fix issue with discharge area.**
0845	**R. Cowles/Stantec call with South Florida Water Management District to inform of delay.**
0930	**YBI still working on fixing discharge to the canal but adding another PVC pipe to allow water to discharge further out into the canal as to prevent bank erosion.**
0935	**Transducer not set up correctly and needs adjusting.**

Observer's Initials **HR/CS**

0945	**Connecting the PVC pipe to existing pipe did not work. Discharge water is still hitting the bank of the canal. YBI to see if they can extend further into canal and will need to add silt fence and re-sod the bank after the test.**
0955	**R. Cowles/Stantec calls M. Wilson/YBI.**
1002	**R. Cowles/Stantec calls M. Wilson/YBI. Decision made to postpone testing till Monday, March 23, 2020.**
1015	**R. Cowles/Stantec offsite.**
1040	**YBI shows H. Rahman/Stantec and C. Summerfield/Stantec improved discharge pipe to canal.**
1042	**Call with R. Cowles/Stantec.**
1046	**Call with R. Cowles/Stantec.**
1050	**YBI waiting on silt fence equipment. C. Summerfield/Stantec and H. Rahman/Stantec offsite.**

Observer's Initials **HR/CS**

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 03/23/2020
0700 - 1700

Sun	Mon	Tue	Wed	Thr	Fri	Sat
	X					

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	X
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**13**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec and Cora Summerfield/Stantec
START DEPTH:
DRILLER: Danny Atkisson/YBI
END DEPTH:
ACTIVITY: Step-Rate Pumping Test (totalizer readings in 10,000 gallons).
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0640	**H. Rahman/Stantec onsite. YBI already onsite.**
0700	**R. Cowles/Stantec onsite.**
0702	**D. Atkisson/YBI onsite.**
0715	**C. Summerfield/Stantec onsite. Discharge pipe is extended 40 feet into the canal and silt fence is set up.**
0721	**Totalizer reading taken. Cowles/Stantec informs water quality to be taken 15 minutes after the start of each step, then every 30 minutes, then 15 minutes before the end of each step.**
0730	**Step 1 begins. First step pumping rate at about 2,000 gallons per minute (gpm).**
0731	**Pumping rate at ~2,000 gpm.**
0736	**Pumping rate at ~2,100 gpm.**
0739	**Transducer set at 18 feet below the concrete pad.**
0745	**No sampling port because of new pump.**
0756	**Turbidity meter calibrated.**
0758	**Sampling port for water quality fixed.**
0800	**Water quality sample taken. Refer to field form.**
0822	**Totalizer reading taken. Refer to field form.**
0823	**YBI informs Stantec that the transducer is set 18 feet below the concrete pad, not the land surface. Both transducers were calibrated at the same time, both are equally accurate.**

Observer's Initials **HR/CS**

0827 Per YBI, transducers are set side by side, but one may be sitting slightly higher than the other after being lowered into the well.
0830 Water quality sample taken.
0843 Totalizer reading taken. Refer to field form.
0900 Water quality sample taken. Refer to field form.
0901 Totalizer reading taken. Refer to field form.
0902 Per YBI, there is 40 feet of drop pipe in the well.
0920 B. Verrastro/SFWMD, J. Shaw/SFWMD, and T. Colios/SFWMD onsite.
0921 Totalizer reading taken. Refer to field form.
0930 Water quality sample taken. Refer to field form.
0945 Stantec gave SFWMD the XY caliper log, XY caliper samples, and video log DVD.
0957 Leak in south side of the discharge pipe.
1000 Water quality sample taken. Refer to field form.
1010 Totalizer reading taken. Refer to field form.
1015 Water quality sample taken. Refer to field form.
1021 YBI placed plastic wrap around leak in discharge pipe.
1022 J. Gent/Stantec onsite.
1023 Totalizer reading taken. Refer to field form.
1030 Water quality sample taken. Refer to field form. Step 1 ends and step 2 begins at a pumping rate of 5,000 gpm. YBI steps computer
1031 Pumping rate reading taken. Refer to field form.
1037 Totalizer reading taken. Refer to field form
1045 Water quality sample taken. Refer to field form.
1049 Sand sample taken. Refer to field form.
1052 Totalizer and pump rate recorded. Refer to field form.
1100 Water quality sample taken. See field form.
1112 B. Verrastro/SFWMD, J. Shaw/SFWMD, and T. Colios/SFWMD offsite.
1113 Totalizer and pumping rate recorded. Refer to field form.
1130 Water quality sample taken. Refer to field form.
1135 R. Cowles/Stantec offsite.
1158 R. Cowles/Stantec onsite.
1200 Water quality sample taken. Refer to field form.
1204 B. Verrastro/SFWMD, J. Shaw/SFWMD, and T. Colios/SFWMD onsite.
1205 J. Gent/SFWMD offsite.
1210 Totalizer and pump rate reading taken. Refer to field form.
1230 Water quality sample taken. Refer to field form.
1300 Water quality sample taken. Refer to field form.
1303 Totalizer and pump rate recorded. Refer to field form.
1315 Water quality sample taken, and totalizer and pump rate recorded. Refer to field form.
1330 Water quality sample taken Refer to field form. End of step 2. Step 3 begins with a pumping rate of approximately 7,000 gpm.
1331 Totalizer and pump rate recorded. Refer to field form.
1335 Water quality sample taken. Refer to field form.
1342 Totalizer and pump rate recorded. Refer to field form.
1345 B. Verrastro/SFWMD, J. Shaw/SFWMD, and T. Colios/SFWMD offsite.
1354 Totalizer and pump rate recorded. Refer to field form.
1400 Water quality sample taken. Refer to field form.
1416 Totalizer and pump rate recorded. Refer to field form.
1430 Water quality sample taken. Refer to field form.
1435 R. Cowles/Stantec offsite.
1439 Totalizer and pump rate recorded. Refer to field form.
1500 Water quality sample taken. Refer to field form.
1512 Totalizer and pump rate recorded. Refer to field form.
1530 Water quality sample taken. Refer to field form.
1542 Totalizer and pump rate recorded. Refer to field form.
1600 Water quality sample taken. Refer to field form.
1607 Totalizer and pump rate recorded. Refer to field form.

1615	**Water quality sample taken. Refer to field form.**
1620	**Totalizer and pump rate recorded. Refer to field form.**
1625	**Water quality sample taken. Refer to field form.**
1630	**End of step 3. YBI will email recovery data tomorrow morning.**
1631	**Pump turned off.**
1632	**Totalizer recorded. Refer to field form.**
1635	**YBI begins taking down discharge pipe from canal. YBI downloads step-rate pumping test data to flash drive for Stantec.**
1640	**The pump is a CAT 600-cylinder diesel. Horsepower of the pump is unknown.**
1700	**H. Rahman/Stantec and C. Summerfield/Stantec offsite.**

APPENDIX B

YBI Dailies

Appendix B

B.1 YBI DAILIES

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/20/20
Day of Week:	Monday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	2		Collect materials for site
2	6:30		Mobilize materials / unload materials
6:30	9		Mobilize rig to shop

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud ✓	11.5	No
Kenny Smith ✓	14	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/21/20
Day of Week:	Tuesday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
6:30	11		Mobilize Boomtruck to site
			Set up silt fence / tourtise training
11	5:15		List of materials / Put 6in valve on well
			head / seal wellhead

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud ✓	10.75	No
Kenny Smith ✓	10.75	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/22/20
Day of Week:	Wedensday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7	5:15		Disassemble piping from well head
				(well has 10.6' of head pressure)
				Put up new silt fence
				Unload truck

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR: NAME	HOURS	INJURED YES/NO
Ross Aanerud	✓ 10.25	No
Kenny Smith	✓ 10.25	No
Danny Atkisson	✓ 10.25	No

NIGHT TOUR: NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/23/20
Day of Week:	THURSDAY

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER			
Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
6	1		ROSS & KENNY DRIVE TO YBI SHOP
			AND LOAD MATERIAL ON SEMI FOR
			JOBSITE
6	5:30		DANNY ATKINSON ON SITE UNLOADING
			TRUCKS AND ORGANIZING
			MATERIAL - TRUCK LOAD OF SALT
			DELIVERED TO SITE

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
1	5		ROSS & KENNY SENT OVER TO
			EAST COAST

DRILLING CREW PAYROLL DATA

DAY TOUR: NAME	HOURS	INJURED YES/NO
ROSS ARNERUD	7	NO
KENNY SMITH	7	NO
	16.5	NO

NIGHT TOUR: NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/24/20
Day of Week:	FRIDAY

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	6		UNLOADING TRUCKS & ORGANIZING
			MATERIALS ON JOBSITE

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
			ROSS & KENNY NOT ON SITE TODAY

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
DANNY ATKISSON	11	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/27/20
Day of Week:	Monday

YOUNGQUIST
BROTHERS

LAST CASING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7	12		Collect materials for site, load truck
	12	3		Mobilize to site
6	3	6		Start setting up waterline, unload trailer
		10		Mobilize tractor back to yard, drive back
				to hotel
				(

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Ross Aanerud ✓	11	No
Kenny Smith ✓	15	No
Dennis Hurtado ✓	11	No

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/28/20
Day of Week:	Tuesday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	5:30		Run 4" yellowmine for water line
			Flowers Testing sampled ASR Well
			Pressure test waterline

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Ross Aanerud	✓10.5	No
Kenny Smith	✓10.5	No
Dennis Hurtado	✓10.5	No

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/29/20
Day of Week:	Wedensday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	5:15		Replace ARU with blind flange
			Hook up waterline to well
			Unload / load truck
			Begin pumping down well at 3:45
			Moniter waterline / well
9	10		Check well / Shut off water

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	✓ 10.25	No
Kenny Smith	✓ 11.25	No
Dennis Hurtado	✓ 10.25	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/30/20
Day of Week:	Thursday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	8		Flush well
8	9		Rig up logger
9	3		Run log
3	6		Set up to Kill well / Kill well 3 bags of salt

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud ✓	11	No
Kenny Smith ✓	11	No
Dennis Hurtado 2048 ✓	11	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/31/20
Day of Week:	Friday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7			Disassemble well head, [illegible] bag of salt
			in well 18' below flange, weld
			coupling onto header, put on header,
			seal well
5	7		Mobilize to yard

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	12	No
Kenny Smith	12	No
Dennis Hurtado	12	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/1/20
Day of Week:	Saturday

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	12		Collect materials, load open top pit
12	2:30		Mobilize to site
2:30	3		Unload material
3	5:30		Mobilize back to shop

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	10.5	No
Kenny Smith	10.5	No

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/2/20
Day of Week:	Sunday

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	9		Collect materials/load semis with open tops
9	12		Mobilize to site
12	12:45		~~[illegible]~~ unload material
12:45	3:15		Mobilize back to yard

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	8.25	No
Kenny Smith	8.25	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/3/20
Day of Week:	Monday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER			
Size	**Weight**	**Length**	**Set At**

	DEPTH INTERVAL		**ROTORY TABLE SPEED**	**WEIGHT ON BIT**
	From	**To**		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		**TIME / HR**	**DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS**
FROM	**TO**		
7	6:15		Set settling tanks, set up rig over hole,
			set up catwalk and drill pipe

NIGHT SHIFT

TIME LOG		**TIME / HR**	**DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS**
FROM	**TO**		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		**INJURED YES/NO**
NAME	**HOURS**	
Ross Aanerud	11.25	No
Kenny Smith	11.25	No
Dennis Hurtado	11.25	No

NIGHT TOUR:		**INJURED YES/NO**
NAME	**HOURS**	

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/4/20
Day of Week:	Tuesday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7			Plum together settling tanks / unload
				crane / organise, set up site to begin
		5:30		fishing / seat wellhead
	5	8		Mobilize boom truck to yard

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Ross Aanerud	10.5	No
Kenny Smith	13	No
Dennis Hurtado	10.5	No

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/5/20
Day of Week:	WEDNESDAY

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	**Size**	**Weight**	**Length**	**Set At**

	DEPTH INTERVAL		**ROTORY TABLE SPEED**	**WEIGHT ON BIT**
	From	**To**		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	**TIME LOG**		**TIME / HR**	**DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS**
	FROM	**TO**		
	7	5:30		UNLOAD SETTLING TANK, SET UP TO
				TRIP IN HOLE. ORGANIZE SITE-
				RUN DISCHARGE LINE FROM
				TANKS

NIGHT SHIFT	**TIME LOG**		**TIME / HR**	**DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS**
	FROM	**TO**		

DRILLING CREW PAYROLL DATA

DAY TOUR:		**INJURED YES/NO**
NAME	**HOURS**	
ROSS AANERUD	10.5	NO
KENNY SMITH	10.5	NO
DENNIS HURTADO	10.5	NO

NIGHT TOUR:		**INJURED YES/NO**
NAME	**HOURS**	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/6/20
Day of Week:	THURSDAY

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7			PRESSURE TEST FISHING EQUIPMENT
	3		CLEAN SITE
			(ROSS ATTENDED PROGRESS MEETING)
2:30	5		KENNY DROVE TO SHOP IN FT MYERS
5	5:30		PICKED UP MATERIAL FOR JOBSITE
5:30	8		DROVE BACK TO OKEECHOBEE

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
ROSS AANERUD	8	NO
DENNIS HURTADO	8	NO
KENNY SMITH	13	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/7/20
Day of Week:	FRIDAY

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7	7:30		TOOL UP FISHING TOOL - CLOSE JAWS
	7:30	12:45		TRIP IN FISHING TOOL TO 1570'
	12:45			OPEN JAWS & SET DOWN ONTO CABLE
		1:15		& CLOSE JAWS
	1:15			PULL OUT OF HOLE WITH BUNDLE OF LOGGING
		5:30		CABLE, TAKE APART TOOL. SEAL IN
	5:30	6:30		WELL, CLEAN SITE

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
ROSS AANERUD	11.5	NO
KENNY SMITH	11.5	NO
DENNIS HURTADO	11.5	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/10/20
Day of Week:	Monday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
4:45	5		Collect material
5	7		Mobilize to site
7	10		Regen rig, set traps, finish discharge line
10	11:15		Trip to 400', prep to flush down well
11:15	2		Flush well, rig up logger,
2	4		Run VIDEO (SEE CALIPER TOOL AT 1599' DEPTH)
4	6		TRIP OUT CAMERA Rig down logger, clean up site

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	11	No
[redacted]	[redacted]	No
Dennis Hurtado	11	No
Kenny Smith	13.15	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/11/20
Day of Week:	Tuesday

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7			Pump salt kill down drill pipe, [illegible] /
			pull drill pipe out of hole / replace
			subsaver, get fuel, break down subs
	4		on wire brush, organize site
4	6:15		Mobilize to Lehigh to get 2ND FISHING TOOL
6:15	8		Mobilize to site WITH FISHING TOOL

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	9	No
Kenny Smith	13	No
Dennis Hurtado	7	No

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/12/20
Day of Week:	Wedensday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	8:30		Test tool / tool up and prep to trip in
8:30	3:30		Trip in tool to 1580' TO GRAB CALIPER TOOL
3:30	8		Rig up logger / run down camera / * pull
			camera out of hole / pack up site
		*	(BUMPED CALIPER TOOL & KNOCKED IT DOWN HOLE)
12:30	8 PM		RAFAEL SENT FROM FT MYERS TO
			HELP ROSS IN OKEECHOBEE

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	13	No.
Kenny Smith	13	No
Dennis Hurtado	13	No.
RAFAEL GUTIERREZ	7.5	NO
		7.5

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/13/20
Day of Week:	Thursday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	22"
STRING WT.	
BIT TYPE	BUTTON

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	3		Regen rig / rig down logger / Trip out of hole / Change subsaver
3	6:30		Tool up bit / trip in bit to 73' / Seal up well /

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	11.5	No
Kenny Smith	11.5	No
Dennis Hurtado	11.5	No
Rafael Gutierrez	11.5	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/14/20
Day of Week:	Friday

YOUNGQUIST
BROTHERS

LAST CASING TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTARY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE [illegible]	22"
[illegible]	
BIT TYPE	Button

DAY SHIFT

TIME LOG			
FROM	TO	[illegible]	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	11		Trip into 1272'
11			Trip in Airline/reamed from 1265' to 1293'
			Adjust swivel on tophead/Kill drill pipe/
			Trip airline out of hole Trip out to
	6:30		412'/ seal well
6:30	8:30		Mobilize to shop
8:30	9		Load material

NIGHT SHIFT

TIME LOG			
FROM	TO	[illegible]	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
			22" BIT DRILLING NEW (LARGER HOLE)
			FROM BOTTOM OF CASING DOWN TO
			1293 FEET DEPTH - CALLED RICK COWLES
			& HE AGREED WE COULD SWITCH TO
			17½" BIT

DRILLING CREW PAYROLL DATA

DAY WORK		
NAME	[illegible]	[illegible]
Ross Aanerud	11.5	No
Kenny Smith	14	No
Dennis Hurtado	11.5	No
Rafael Gutierrez	9	No

NIGHT WORK		
NAME	[illegible]	[illegible]

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Sig/Well ID	

YBI Job #	020-10-064
Date:	2/15/20
Day of Week:	Saturday

YOUNGQUIST
BROTHERS

LAST CASING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	17 1/2
STRING WT.	
BIT TYPE	Button

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
4:45	7		Mobilize to site / get fuel for rig
7	9:15		Trip out of hole / breakdown BHA
9:15	9:45		Tool up BHA / Trip into 50'
9:45	10:15		Replace subsaver
10:15			Trip into 1450' / strip header over drill
	3		pipe / put on rubber can / seal well /
3	5:30		Mobilize to shop

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	8.5	No
[illegible]	[illegible]	[illegible]
Dennis Hurtado	8	No
Kenny Smith	12.75	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/10/20
Day of Week:	Monday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
9:45	5		Collect material
5	7		Mobilize to site
7	10		Regen rig, set traps, finish discharge line
10	11:15		Trip to 400', prep to flush down well
11:15	2		Flush well, rig up logger
2	4		Run VIDEO (SEE CALIPER TOOL AT 1599' DEPTH)
4	6		TRIP OUT CAMERA Rig down logger, clean up site

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	11	No
[redacted]	[redacted]	No
Dennis Hurtado	11	No
Kenny Smith	13.15	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/11/20
Day of Week:	Tuesday

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER			
Size	**Weight**	**Length**	**Set At**

	DEPTH INTERVAL		**ROTORY TABLE SPEED**	**WEIGHT ON BIT**
	From	**To**		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		**TIME / HR**	**DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS**
FROM	**TO**		
7			Pump salt Kill down drill pipe, [redacted] /
			pull drill pipe out of hole / replace
			subsaver, get fuel, break down subs
	4		on wire brush, organize site
4	6:15		Mobilize to Lehigh to get 2ND FISHING TOOL
6:15	8		Mobilize to site WITH FISHING TOOL

NIGHT SHIFT

TIME LOG		**TIME / HR**	**DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS**
FROM	**TO**		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		**INJURED YES/NO**
NAME	**HOURS**	
Ross Aanerud	9	No
Kenny Smith	13	No
Dennis Hurtado	7	No

NIGHT TOUR:		**INJURED YES/NO**
NAME	**HOURS**	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/12/20
Day of Week:	Wedensday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	8:30		Test tool / tool up and prep to trip in
8:30	3:30		Trip in tool to 1580' TO GRAB CALIPER TOOL
3:30	8		Rig up logger / run down camera / *pull
			camera out of hole / pack up site
		*	(BUMPED CALIPER TOOL & KNOCKED IT DOWN HOLE)
12:30	8 PM		RAFAEL SENT FROM FT MYERS TO
			HELP ROSS IN OKEECHOBEE

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Acnerud	13	No.
Kenny Smith	13	No
Dennis Hurtado	13	No.
RAFAEL GUTIERREZ	7.5	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/13/20
Day of Week:	Thursday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	22"
STRING WT.	
BIT TYPE	BUTTON

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	3		Regen rig / rig down logger / Trip out of hole / Change subsaver
3	6:30		Tool up bit / trip in bit to 73' / Seal up well /

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	11.5	No
Kenny Smith	11.5	No
Dennis Hurtado	11.5	No
Rafael Gutierrez	11.5	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/14/20
Day of Week:	Friday

YOUNGQUIST BROTHERS

LAST CASTING TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTARY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	22"
[illegible]	
BIT TYPE	Button

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7	11		Trip into 1272'
	11			Trip in Airline/reamed from 1265' to 1293'
				Adjust swivel on tophead / Kill drill pipe/
				Trip airline out of hole Trip out to
		6:30		412' / seal well
	6:30	8:30		Mobilize to shop
	8:30	9		Load material

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
				22" BIT DRILLING NEW (LARGER HOLE)
				FROM BOTTOM OF CASING DOWN TO
				1293 FEET DEPTH - CALLED RICK COWLES
				& HE AGREED WE COULD SWITCH TO
				17½" BIT

DRILLING CREW PAYROLL DATA

DAY SHIFT		
NAME	HOURS	[illegible]
Ross Aanerud	11.5	No
Kenny Smith	14	No
Dennis Hurtado	11.5	No
Rafael Gutierrez	9	No

NIGHT SHIFT		
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/15/20
Day of Week:	Saturday

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER			
Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	17 1/2
STRING WT.	
BIT TYPE	Button

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
4:45	7		Mobilize to site / get fuel for rig
7	9:15		Trip out of hole / breakdown BHA
9:15	9:45		Tool up BHA / Trip into 50'
9:45	10:15		Replace subsaver
10:15			Trip into 1450' / strip header over drill
	3		pipe / put on rubber can / seal well /
3	5:30		Mobilize to shop

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	8.5	No
~~[illegible]~~	~~[illegible]~~	~~[illegible]~~
Dennis Hurtado	8	No
Kenny Smith	12.75	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/24/20
Day of Week:	Monday

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
5	7		Mobilize to site
7	10:15		Pump / Develop well / rig up logger
10:15	3		Run log video
3	8		Run caliper log
8	9:30		Rig down logger / clean site / upload video

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	16.5	No
Kenny Smith	16.5	No
Brad Bennett	13	No
Danny Atkisson	13.5	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/25/20
Day of Week:	Tuesday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7			Kill well w/ 3 bags of salt/ put on new
			24in flange/clean tanker/ Fill tanker, empty
			settling tank / Start emptying other settling
	4:30		tanks / organize site

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	9.5	No
Kenny Smith	9.5	No.
Brad Bennett	9.5	No.
Danny Atkisson	9.5	No.

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/26/20
Day of Week:	Wedensday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7			Rig down rig / pull off of hole / pull
			settling tanks out / Put drill pipe in racks /
			fuel equipment / put crane over hole /
			unload GIW and material / load tank onto
			trailer / Set MIT trailer up on hole /
	6		set up to trip packer into hole

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	10	No
Kenny Smith	12	No
Brad Bennett	11	No
Danny Atkisson	11	No

NIGHT SHIFT

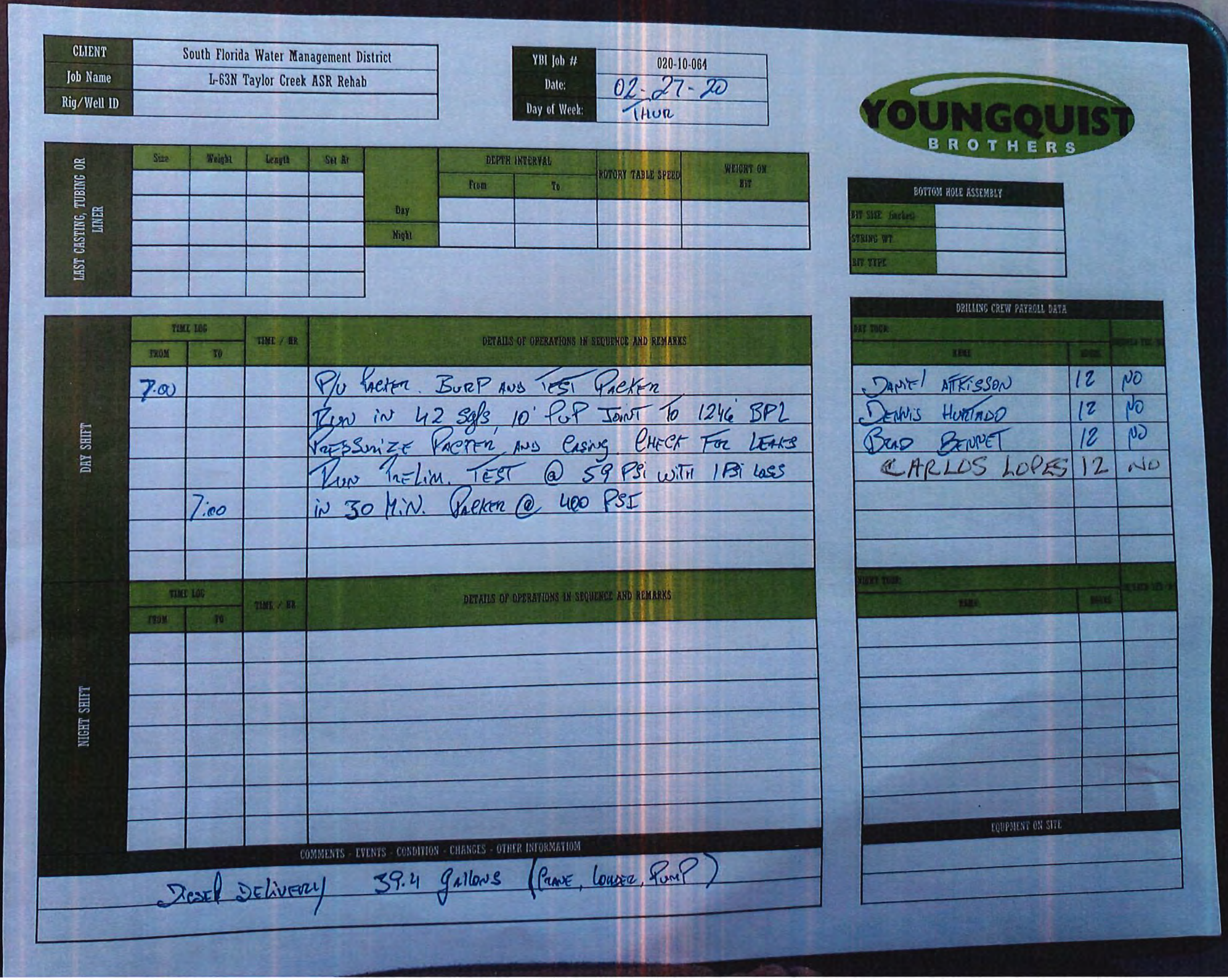
TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
3:30pm	6pm		Drive tanker to pit
6:00	6:30		Empty / clean tanker
6:30	7		Drive tanker to yard

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE



CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	02-27-20
Day of Week:	THUR

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7:00			P/U PACKER. BURP AND TEST PACKER
			RUN IN 42 SGLS, 10' PUP JOINT TO 1246' BPL
			PRESSURIZE PACKER AND CASING. CHECK FOR LEAKS
			RUN PRELIM. TEST @ 59 PSi WITH 1 PSi LOSS
	7:00		IN 30 MIN. PACKER @ 400 PSI

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR

NAME	HOURS	[illegible]
DANIEL ATTKISSON	12	NO
DENNIS HURTADO	12	NO
BRAD BENNET	12	NO
CARLOS LOPES	12	NO

NIGHT TOUR

NAME	HOURS	[illegible]

EQUIPMENT ON SITE

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

DIESEL DELIVERY 39.4 gallons (CRANE, LOADER, PUMP)

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Friday, February 28, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		Safety meeting. Service Crane
	7:30	9:20		Run preliminary test @ 51.5 psi. WOE. Stantec Representatives on site.
	9:20	10:20		run Pressure test @51.5 psi. passed test with 1psi loss
	10:20			Deflate Packer. TOOH. L/D packer and secure well with 24x6 with 6" valve.
				Off load truck with 16"pipe rack and misc. parts for pump test. Move MIT trailer from well area.
				Load up truck with open top tank. Continue rig down and removal of all equipment related to
		7:00		packer testing. Place GIW pump on well pad.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Monday, March 2, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00			Safety meeting. Service equipment
				Continue plumbing 16" pipe to pond area.
				disconnct 8" discharge line and had welder correcting angle of flange. Reeinstall.
				weld 2" coupling on well head plate (still well inlet)
		7:00		Receive 500 gls of diesel fuel. Place diesel tank in work area adjacent to GIW.

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Tuesday, March 3, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		Safety meeting. Service equipment
			Continue to plumb in 16" pipeline. Connect fuel tank to GIW and run motor on idle for 5 min.
			Install 1.5" still well at 80' in depth. Run transducers to 75' BPL, connect computers and ready
	7:00		system to bring well alive.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	6	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Wednesday, March 4, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Service equipment
			replace damaged 8" butterfly valve on discharge side of GIW.
			pump well alive into tanker and haul away.
			flood system and check for leaks. Conduct prelim. Pump test
			GIW cavitating at 5000 GPM, free flow at 1000GPM, pumping steady 4000GPM at idle in low gear
	7:00		close well in for the night.
			Per Mike Wilson, we are waiting for a Permit before stantec allow us to proceed.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

Dennis Hurtado fell off GIW suction rubber pipe where he was sitting on while tightning flange bolts. (40" high fall)

Upon being asked if he was ok, he stated he was "just fine" and there was no problem.

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	10	?
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Thursday, March 5, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		Safety meeting. Service Equipment.
7:30			Pump water to pond. Establish flow rate at iddle speed on Low gear open discharge 4800 GPM.
			pump cavitates at 5000GPM. level @ pond reached max accepted level after 2 hours of pumping
			(552000 gls pumped) Outfall to canal doesn't keep up with GIW. Per Stantec, Ybi is to install an
	3:00		additional pump on pond to pump out to canal and help water levels.
3:00			Per Tim youngquist, kill well and remove suction hose from GIW and inspect impeler and volute.
	7:00		check gear ratio between impeler and transmission RPM.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Friday, March 6, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7:00			Crew on site. Carlos .Trouble shoot GIW impeler and volute via video With Tim Youngquist.
			Inspect well head assembly for possible suction leaks. Fabricate Gasket for 10" pump suction and
			reassemble suction hose with 12" butterfly valve onto well head.
			Tap into 16" yellow mine pipe and install sand sampler. Seal pump shaft and all flanges with
			gel, install vacuum gauge. Ready to bring well alive. Organize equipment for demob. load out.
			Per cameron webster get measurements on well head.
	7:00		New header pipe being worked on at the shop. W.O.O

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
			Per Harvey youngquist and Ravi, Tadano crane is to be removed from site and sent back to
			rock pit.

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Saturday, March 7, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		Safety meeting. Service equipment
	7:30			cntinue to organize demob. Equipment ready to go
				Off load truck with John Deere pump, kelley hoses, loader extension arm, and modified well
				head. Remove spool piece, tee, 6" valve. Install stilling well pipe on new head piece. Cut out 1.5"
				hole doesn't fit in 24" well. Remove all and secure well for the night. Reload header piece and
		7:00		send back to shop.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Monday, March 9, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		safety meeting. Service equipment
	7:30			install John deere pump and run kelley hoses from pond to canal.
				remove well cover. Install 12" sweep header with stilling well. Move GIW to accommodate new
				angle. Install 6" gate valve. Install transducers 18' BPL reprogram computers for new test
				Bring well alive and pump 320000 gls of water. GIW will not pump more than 2800GPM and cav.
				Prime pond pump and flood kelley hoses. No leaks. Head on well at 7'30.
		6:00		shut in transducer read out at 24', drawdown to 21' while running

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	11	
Dennis Hurtado	11	
Brad Bennet	11	
CARLOS LOPES	11	NO

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Tuesday, March 10, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7:00	7:30		safety meeting. Service equipment
7:30			Kill well (1 tank of water, 1/2 bag salt) pull 12" header out . Move GIW pump to new alignment
			install 12" drop pipe header. Discharge pipe too short. Call for welder. Continue to demobe equip.
			to ship out. Make up flange bolts and pump suction. Install transducers 18' BPL . Pump well alive
			. Transducers reading 24' w/ well closed in. Flowing 3750 gpm @970 RPM. Drawdown to 19'
			Manometer tube 7' 5 shut in and 3'1/2 pumping (right on bottom of suction pipe).
	7:00		pumped 200.000 gls water and no improvement. Call Cameron. Secure well for the night.

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Wednesday, March 11, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		afety meeting. Service equipment.
7:30			contact office video chat and trouble shoot with Tim, Harvey,Cameron, Mike
			Prime GIW once again and raise end of 16" discharge line 7' above ground level.
			establisha step pump rate of 450 rpm @3800GPM 7' draw down, 900 rpm @5250gpm,
			1100 rpm between 5250 and 5750 Gpm, 1300 rpm between 5250 and 5750 with 14' drawdown.
			1550 rpm (pump maxed out) no change in GPM or drawdown. Vacuum gauge at -16 to -25 inches
	7:00		continue developing well at 5000gpm. W.O.O. continue demob, site clean up.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

Continue to onitor gopher Tortoise holes twice per day. No presence noted so far.

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Thursday, March 12, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Service equipment.
7:30			W.O.O. Continue demob work. Office decided on changing set up and use 2 pumps.
			load truck to go back to shop. Organize MIT trailer.
	5:00		Kill well to remove well head.

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	10	no
Dennis Hurtado	10	no
Brad Bennet	10	no
CARLOS LOPES	10	NO

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Friday, March 13, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		Safety meeting. Service equipment. Tortoise training.
			Uninstall drop pipe header
			secure well with 24"x 6" flange. Instal 6" gate valve.
			site clean out and repir silt fence. Tortoisee watch in AM and PM. No sightings
	5:00		W.O. new drop pipe header 16"x doble suction.
			CARLOS AT SHOP GATHERING ADDITIONAL
			PUMPS & PIPING, LOADING TRUCKS TO TRANSPORT

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
			MATERIAL TO JOBSITE

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	10	no
Dennis Hurtado	10	no
Brad Bennet	10	no
CARLOS LOPES - SHOP	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Saturday, March 14, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		safety meeting. Service equipment
	7:30			offload 16" drop pipe header with tee and reducer flanges. Adjust GIW-1 in new position
				install stiiling well pipe and run it in hole. Install tee and connect to GIW number one.
				offload second truck with GIW number 2 john deere pump 8"certalock fittings box.
		7:00		secure well for the night
				check tortoise traps twice. No movement.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Sunday, March 15, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Inspect tortoise traps. Service equipment.
7:30	12:00		continue Rigging up new 24"x 16" header and GIW-2

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	5	no
Dennis Hurtado	5	no
Brad Bennet	5	no
CARLOS LOPES	5	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Monday, March 16, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7:00	7:30		safty meeting. Service Equipment.
7:30			continue working on GIW pumps suction lines. Install 16" tee, 16"90, 16"x 12" reducers, 16 valves
			and make up to 12" pump intakes.
			remove kelley hose from John deere pump at canal to facilitate access to water management
			personal. Tortoise traps moved out and no more monitoring required.
	7:00		take 16" discharge spool piece out ad start to work on discharge lines from GIWS.

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Tuesday, March 17, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		safety meeting. Service equipment
	7:30			plumb in discharge lines on GIW's install 2nd john deere pump and plumb in suction and discharge
				bring well alive and test pumps.
				GIW-1 GIW-2 at 798 rpm. Sustained flow at 7250GPM- 26' drawdown. Static @ 7' above pad level.
		7:00		Per Rick (stantec) 7000 GPM will sufice for pump test.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Wednesday, March 18, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Service equipment
7:30			install Second john deere pump suction into pond. Only have capacity to pump 45min. At 7250 gpm
			pondfull. Install 16" tee and 16" valve aiming to canal. Authorization to discharge to canal while
			running pump test was given (rick).
			test system again at 2000, 5000 and 7000. pumps holding steady at 7000GPM.
	7:00		per Rick test is to be started Frid. 20th @ 7:00 am.

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Thursday, March 19, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Service equipment.
7:30			establish flow rates at GIW pumps, (2000, 5000, 7000) Gpm.
			run pre-test @7000 gpm for 3 hours..
	6:00		start background @ 6PM. Ray pierson confirmed computers are running the test.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Daniel Attkisson	11	no
Dennis Hurtado	11	no
Brad Bennet	11	no

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Friday, March 20, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
6:30	7:00		safety meeting service pumps.
7:00			Step computers and start pump test at 2000GPM.
			Pojnd liner ripped by water flowing to canal created washout . Test stopped
			extend 16" flow line with crane so it discharges direct onto canal
	5:00		w.o silt boom to be dekivered on site.

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	10	NO
Dennis Hurtado	10	NO
Brad Bennet	10	NO

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Saturday, March 21, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Service equipment
7:30	12:00		spot crane on canal side. Launch boat and install silt boom in canal.
			Called Rick Cowles and rescheduled the pump test for Momday morning.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Daniel Attkisson	5	NO
Dennis Hurtado	5	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Sunday, March 22, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
3:00	5:00		final check on location prior to testing. Start Background for 12 hours.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	2	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Monday, March 23, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		safety meeting.
				start pump test @ 2000GPM for 3 hours
				step pumping rate to 5000gpm for 3 hours
				step pumping rate to 7000gpm for 3 hours
		6:00		end pumping and step box to recovery. Secure site for the night.

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	11	NO
Dennis Hurtado	11	NO
Brad Bennet	11	NO

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Tuesday, March 24, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Service crane and loader
7:30			stop test download data and W.O approval.
			Stantac approved data and authorized demob. Demob 2 GIW pumps and John deere pumps.
	7:00		load and ship GIW's to yard. Continue to demob water line to pond.

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	NO
Dennis Hurtado	12	NO
Brad Bennet	12	NO

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Wednesday, March 25, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7am	7:30		Safety meeting
			Continue demob. Kill well. Remove pumphead tee and 40 ft suction pipe from well. Bolt final 24"
	7pm		flange with 6" gate valve on top of the well.

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Danny Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Thursday, March 26, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7am			Safety meeting
			Continue demob. Bring well alive. Pump kill into a tanker and haul offsite for disposal
			Plumb 6" flow line with water meter from well to pond. Begin free flowing well to pond.
	7:30		Shut in well overnite.

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Danny Attkisson	12.5	no
Dennis Hurtado	12.5	no
Brad Bennet	12.5	no

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Friday, March 27, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7am	7:30		Safety meeting
				Continue demob. Load trucks and send to shop.
				Free flow water from well to pond. Rate of flow at 1000 gpms
		6:30		Shut in well overnite.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Danny Attkisson	11.5	no
Dennis Hurtado	11.5	no
Brad Bennet	11.5	no
NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Saturday, March 28, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7am	7:30		Safety meeting
			Continue demob. Load trucks and send to shop.
			Remove 6" flow line and meter from well
	5:00		Trackhoe delivered to site for repairs to washouts on Monday

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Danny Attkisson	10	no
Dennis Hurtado	10	no
Brad Bennet	10	no

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Monday, March 30, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7am			Glen and Site crew making repairs on canal bank washouts. Delivered 1 load of ASTM C-33 graded
				sand and 2 loads of fill dirt. Removed loose material from washouts and canal and hauled offsite.
				GFA International ran 4 density tests on new compacted material. (All tests results ranged from
			5pm	93-98% compaction).

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Glen Hughes	10	no
Tim Ayers	10	no
Aaron Cogugar	10	no
Ty Sheppard	10	no
Dennis Hurtado	10	no

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Tusday, March 31, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7am			Completed repairs on canal bank washouts. Prepare for sod in the am. Install fittings above
		5pm	6" valve on new wellhead.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Glen Hughes	10	no
Tim Ayers	10	no
Aaron Cogugar	10	no
Ty Sheppard	10	no
Dennis Hurtado	10	no

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Wednesday, April 1, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7am			Bahaia Sod delivered, laid, and pinned on top of the repaired washouts in the morning. Glen had a
			final walkthru with Stantec and District personell in the afternoon. Reported that everything
		5pm	looked good. Dennis is watering the new sod for now.

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Glen Hughes	10	no
Tim Ayers	10	no
Aaron Cogugar	10	no
Dennis Hurtado	10	no

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Thursday, April 2, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7am			Dennis is watering the sod off and on during the day.
	6pm		Excavator and Loader removed from the site and sent elsewhere

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Dennis Hurtado	11	no

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Friday, April 3, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7am	2pm		Checked site. Watered new sod

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Dennis Hurtado	7	no

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

APPENDIX C

Weekly Construction Summaries

Appendix C

C.1 WEEKLY CONSTRUCTION SUMMARIES

Memo

To:	SFWMD South Florida Water Management District	From:	Rick Cowles Stantec
File:	Lake Okeechobee ASR Project L-63N MIT Weekly Progress Report	Date:	February 18, 2020

Work Completed to Date:

On Tuesday, January 7, 2020, the L-63N Mechanical Integrity Testing Project had a construction kick-off meeting at the South Florida Water Management District (SFWMD) Okeechobee field office with personnel from SFWMD, Stantec and Youngquist Brothers Inc. (YBI) in attendance. Mobilization activities began January 21, 2020, including the installation of an outer silt fence and inner silt fence surrounding the wellhead. SFWMD personnel also hosted a specialized wildlife training for the handling of onsite gopher tortoises for Stantec and YBI personnel. The first progress meeting was held on January 23, 2020, at which time completed tasks and future tasks were discussed. The initial Color Television Survey Log (CTVSL) was conducted by YBI on January 30, 2020, with Stantec personnel providing observation services.

The second progress meeting was held on February 6, 2020. Fishing activities began February 7, 2020, and the lost XY Caliper tool cable was retrieved from 1,572 feet below pad level (bpl), but the XY Caliper tool was still lodged in the open hole. On February 10, 2020, gopher tortoise live bucket trapping training was held onsite for Stantec and YBI personnel, followed by YBI conducting another CTVSL with Stantec observing to see where the XY Caliper tool is lodged and to formulate a removal plan. It was determined that the top of the XY Caliper tool was lodged at approximately 1,587 feet bpl.

February 12, 2020, YBI continued fishing for the XY Caliper tool with aid of the CTVSL run simultaneously. The top of the XY Caliper tool was observed at 1,593 feet bpl before the light bulb on the CTVSL blew and YBI lost their video image. The Contractor believed that the lost caliper tool was bumped and fell to the bottom of the borehole.

With the approval of SFWMD and Stantec, on Friday, February 14, 2020, YBI began cleaning out the open hole. YBI initially used a 22-inch diameter drill bit but determined that the bit was too large for the existing borehole diameter and was resulting in reaming of the borehole. On Friday afternoon, February 14, 2020, YBI then removed the 22-inch diameter bit and switched to a 17.5-inch diameter drill bit, which allowed the bit to be lowered to the bottom to a depth of approximately 1,400 feet on February 15, 2020.

On Monday, February 17, 2020, YBI drilling the lost caliber tool and began developing the well. The bottom of the well was tagged at approximately 1,672 feet and by the end of the day the total depth of the borehole was encountered at 1,700 feet. Stantec was on site during the development process and collected pieces of the caliper tool and developed material as it was removed from the well. Water clarity improved markedly by the end of the initial development process.

The following attachments are included in this weekly summary report:

- Stantec Daily Reports
- Initial CTVSL Log
- Daily Photo Logs
- YBI Daily Reports

Work to be Completed through Next Period

It is anticipated that casing brushing with a steel wire brush will follow development and should begin around February 19, 2020. The casing pressure testing will follow the casing brushing.

Stantec Consulting Services Inc.

Rick Cowles, PG
Senior Hydrogeologist/Senior Associate

Phone: 941-266-3917

Attachment: Attachment

c.	C.C.	Jennifer Gent/SFWMD	(jgent@sfwmd.gov)
		Robert Verrastro/SFWMD	(bverras@sfwmd.gov)
		Neil Johnson/Stantec	(Neil.Johnson@stantec.com)
		Cora Summerfield/Stantec	(cora.summerfield@stantec.com)
		Nycole Sharma/Stantec	(Nycole.sharma@stantec.com)
		Hannah Rahman/Stantec	(hannah.rahman@stantec.com)
		Heath Wintz/Stantec	(Heath.Wintz@stantec.com)
		Jeovanni Ayala-Lugo/Stantec	(jeovanni.ayala-lugo@stantec.com)

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 01/30/2020
0900 - 1600

Sun	Mon	Tue	Wed	Thr	Fri	Sat
				X		

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			x	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			x	**01**

SHIFT SUMMARY

OBSERVER: Cora Summerfield/Stantec and Hannah Rahman/Stantec

START DEPTH:

DRILLER: Ross Aanerud/YBI

END DEPTH:

ACTIVITY: Video logging to 1,571 feet below pad level (bpl)

SUB CONTRACTORS: None.

FORMATION SAMPLES: None.

WATER SAMPLES: None.

TESTING: None.

TIME	DESCRIPTION
0830	**H. Rahman/Stantec onsite, YBI already onsite.**
0855	**C. Summerfield/Stantec onsite.**
0904	**YBI explains how they will conduct the video log and they start the video log with downhole view.**
0907	**C. Summerfield/Stantec slams finger in geophysical logging truck door. First Aid administered.**
0910	**Video at 28 feet per minute (ft/min).**
0930	**Video increase speed to 30 ft/min.**
0940	**Call with R. Cowles/Stantec.**
0949	**Bottom of casing at 1,271 feet below pad level (bpl). Did a 360-degree side view of the casing. Bottom of casing is uniform. Cement was apparent behind the casing.**
0952	**Switched back to downhole view at 17 ft/min.**
1018	**Reached bottom of borehole – cable and other material visible at bottom of borehole.**
1026	**Began side view up hole video at 10 ft/min.**
1100	**Reached bottom of casing – large iron nodules observed on casing walls.**
1115	**YBI switches to new video.**
1120	**Call with R. Cowles/Stantec**
1128	**Begin next video.**
1158	**Increased video speed to 20 ft/min.**

Observer's Initials HR/CS

1236 Finished recording video and pulling camera out of the hole.
1242 YBI changed lightbulb on camera from LED to halogen to test if video quality is better.
1258 Second downhole recording begins at 30 ft/min.
1303 Second downhole video much brighter and better quality.
1350 R. Cowles/Stantec onsite.
1354 Video at bottom of borehole – cable and other material easily visible at bottom of borehole.
1450 R. Cowles/Stantec offsite.
1520 C. Summerfield/Stantec and H. Rahman/Stantec offsite for lunch.
1620 C. Summerfield/Stantec and H. Rahman/Stantec onsite.
1622 C. Summerfield/Stantec and H. Rahman/Stantec receive video recordings.
1628 H. Rahman/Stantec offsite.
1630 C. Summerfield/Stantec offsite.

Observer's Initials HR/CS

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/07/2020
0900 - 1600

Sun	Mon	Tue	Wed	Thr	Fri	Sat
					X	

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
		X		
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
		X		**02**

SHIFT SUMMARY

OBSERVER: Cora Summerfield/Stantec
START DEPTH:
DRILLER: Ross Aanerud/YBI
END DEPTH:
ACTIVITY: Fishing lost geophysical logging tool, pvc, and cable out of the well
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
1010	**C. Summerfield/Stantec onsite, YBI began at 0730 and has fishing tool in well.**
1030	**YBI running in hole (RIH) with rod 29. Fishing tool is closed.**
1213	**Rod 72 RIH.**
1243	**Rod 78 RIH to depth of 1564.33 feet below pad level (ft bpl).**
1248	**Fishing tool opened.**
1253	**Fishing tool is in place at 1572.73 feet bpl**
1254	**Fishing tool is closed.**
1256	**Fishing tool loses pressure as YBI begins to trip out of the hole. YBI resets the fishing tool and does not lose pressure.**
1315	**YBI begins tripping out of the hole.**
1443	**Rod 56 is out of the hole.**
1607	**Rod 18 is out of the hole**
1647	**Rod 9 is out of the hole.**
1701	**Fishing tool is out of the hole. Fishing tool has grabbed a large clump of wire. No geophysical logging tool attached. Hydraulic line to tool beginning to break off.**
1711	**Call with R. Cowles/Stantec.**
1730	**C. Summerfield/Stantec offsite.**

Observer's Initials CS

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/10/2020
0900 - 1600

Sun	Mon	Tue	Wed	Thr	Fri	Sat
	X					

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

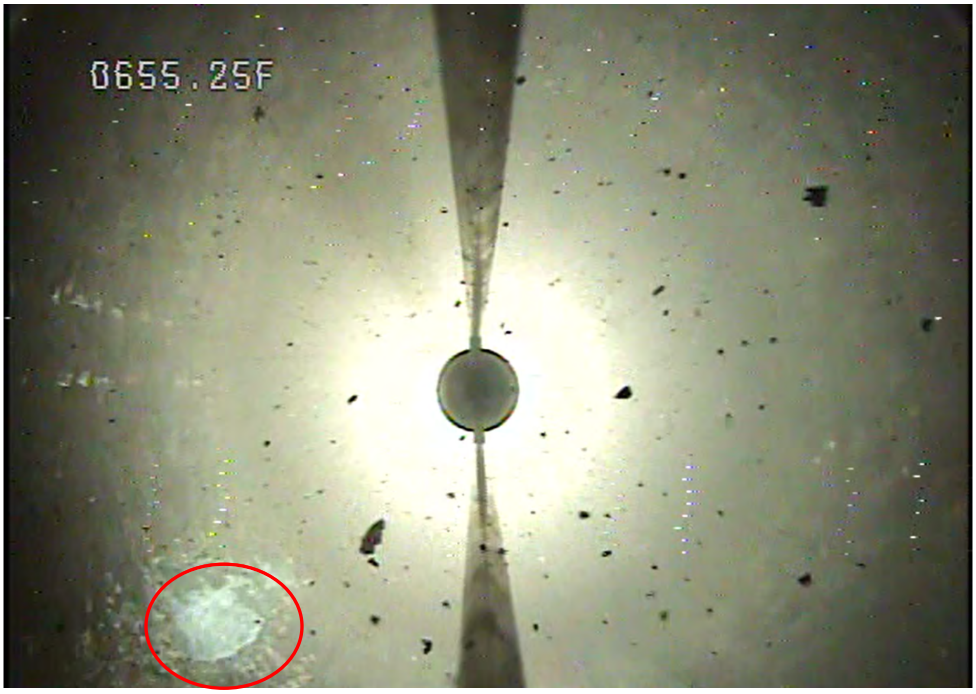
Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**03**

SHIFT SUMMARY

OBSERVER: Cora Summerfield/Stantec
START DEPTH:
DRILLER: Ross Aanerud/YBI
END DEPTH:
ACTIVITY: Gopher tortoise trap training and video logging
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0855	**C. Summerfield/Stantec onsite.**
0900	**H. Andreotta/SFWMD, J. Gent/SFWMD onsite.**
0902	**Begin setting gopher tortoise traps and capture training.**
0935	**Finish setting up traps and capture training.**
0938	**Call with R. Cowles/Stantec.**
0940	**YBI begins to run pipe in well to prepare for video logging.**
1005	**C. Summerfield/Stantec offsite.**
1130	**C. Summerfield/Stantec onsite. YBI has 400 feet of pipe in hole to block off salt plug.**
1138	**YBI begins developing well.**
1155	**Geophysical logging truck onsite.**
1320	**Video logging begins .**
1342	**YBI switching from LED to halogen bulb.**
1407	**YBI restarting video log.**
1430	**Some of the encrustation has flaked off since the previous video exposing the steel casing wall. Images below.**
1507	**Video shows that the obstruction at 1,571 feet below pad level (ft bpl) has been cleared. The cable from the lost geophysical logging tool can be seen starting at 1,587 ft bpl. The geophysical tool, wires, and caliper arms are visible between 1,593-1,599 ft bpl. The geophysical tool is lodged against the side of the borehole wall and covered in encrustation. Screenshots of the**

	video log are attached below showing the exposed casing and the lost geophysical tool.
1521	Camera reached a depth of 1,599 ft bpl. YBI does not want to go past this point with concern of dislodging the geophysical tool.
1529	YBI begins pulling the camera out of the hole.
1535	Video log completed.
1543	Call with H. Rahman/Stantec.
1559	Call with R. Cowles/Stantec.
1637	Totalizer reading at 1,697.4 gallons.
1640	C. Summerfield/Stantec offsite.

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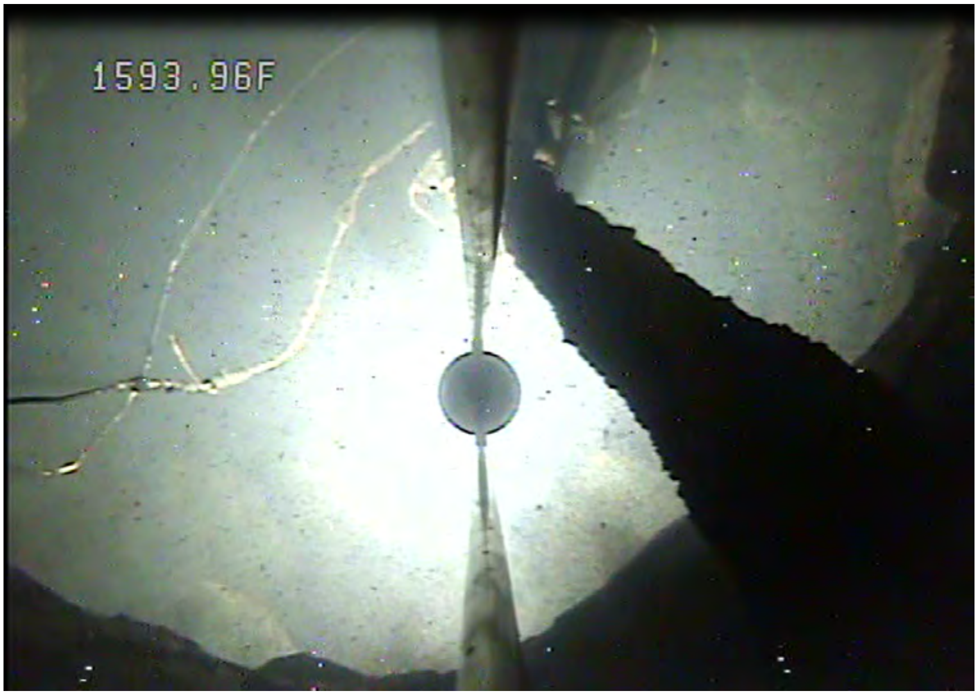
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Observer's Initials CS

Observer's Initials CS

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/12/2020
1140 - 2000

Sun	Mon	Tue	Wed	Thr	Fri	Sat
			x			

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**04**

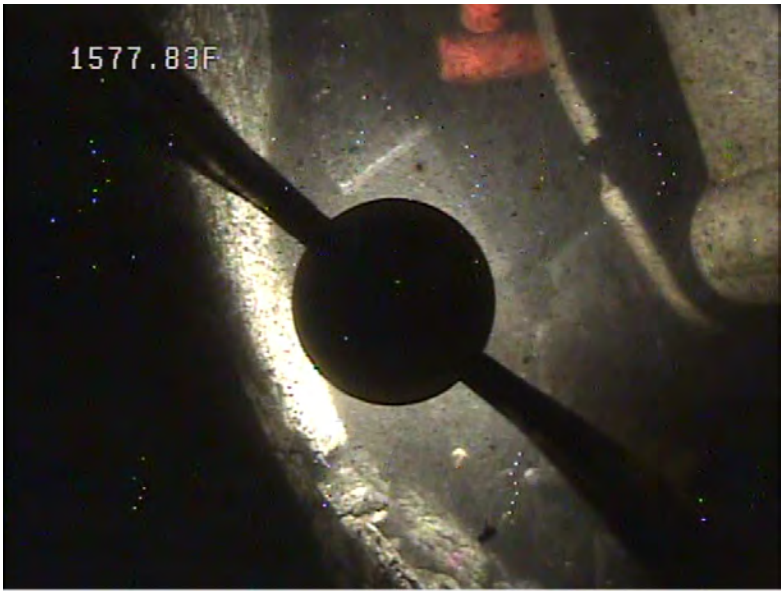
SHIFT SUMMARY

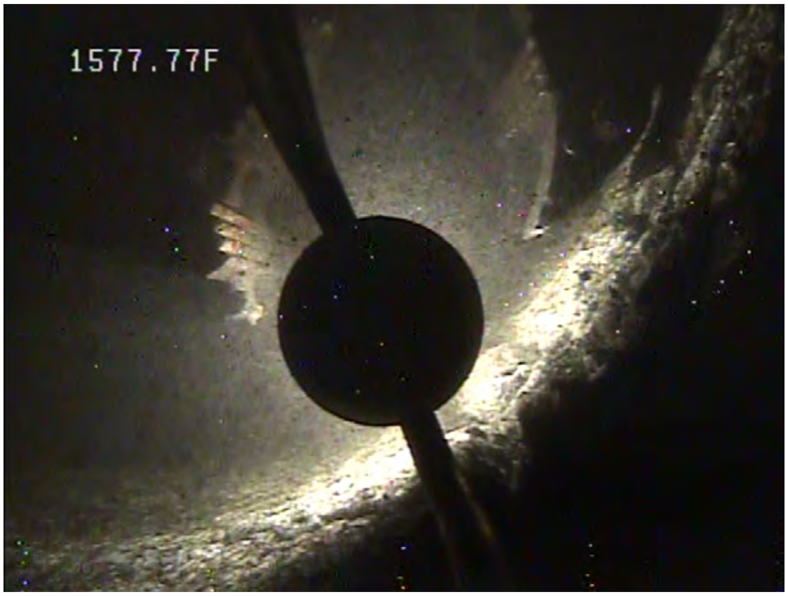
OBSERVER: Hannah Rahman/Stantec
START DEPTH:
DRILLER: Ross Aanerud/YBI
END DEPTH:
ACTIVITY: Fishing for lost caliper tool.
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
1140	**H. Rahman/Stantec onsite. YBI onsite since 0830, tripping into hole with drill pipe and fishing tool.**
1205	**Call with R. Cowles/Stantec.**
1210	**H. Rahman/Stantec and YBI offsite.**
1400	**H. Rahman back onsite. YBI already back onsite.**
1403	**R. Cowles onsite.**
1405	**YBI almost finished tripping into hole.**
1419	**YBI logging truck onsite.**
1515	**YBI personnel onsite.**
1521	**Finished tripping into hole with drill pipe and fishing tool. Fishing tool at approximately 1,583 feet below pad level (bpl).**
1524	**YBI begins to prepare for fishing out lost caliper tool.**
1550	**R. Cowles getting sample of encrusted cable tool.**
1555	**Received drill pipe tally from R. Aanerud/YBI. See field notebook for pipe tally.**
1612	**Camera set at 0 feet, begin going down hole with video survey tool to find the fishing tool.**
1625	**Camera tool out of hole, need to put on smaller centralizers.**
1639	**R. Cowles/Stantec offsite.**
1653	**Video tool back in hole with smaller centralizers.**
1745	**Top of fishing tool at approximately 1,572 feet bpl.**

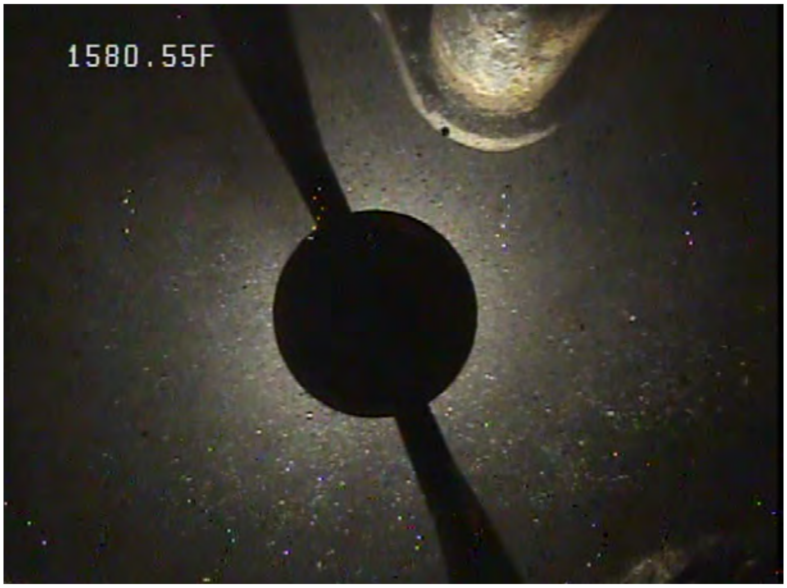
Observer's Initials HS

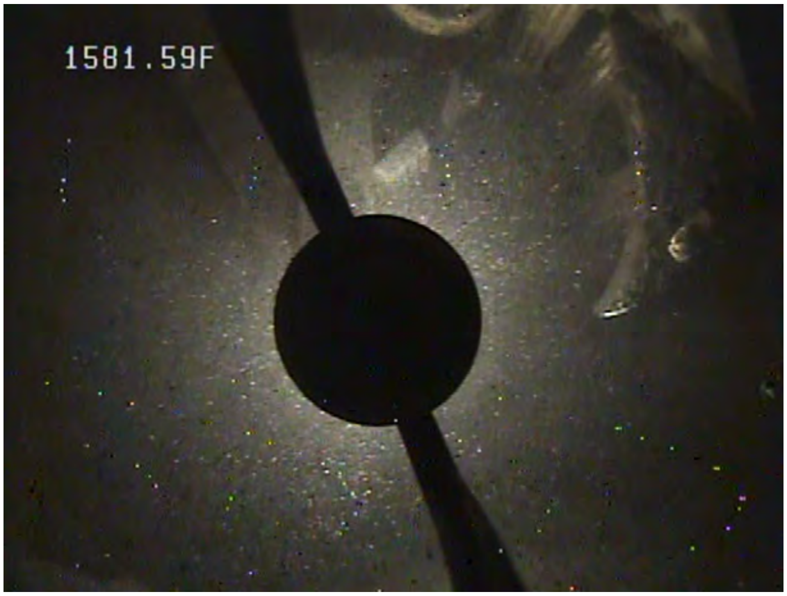
1849	**Light bulb blew and lost visibility of the lost caliper tool.**
1853	**Blindly bringing video tool out of hole.**
1915	**Call with R. Cowles/Stantec.**
1931	**Video tool out of hole.**
2000	**H. Rahman/Stantec and YBI personnel offsite.**



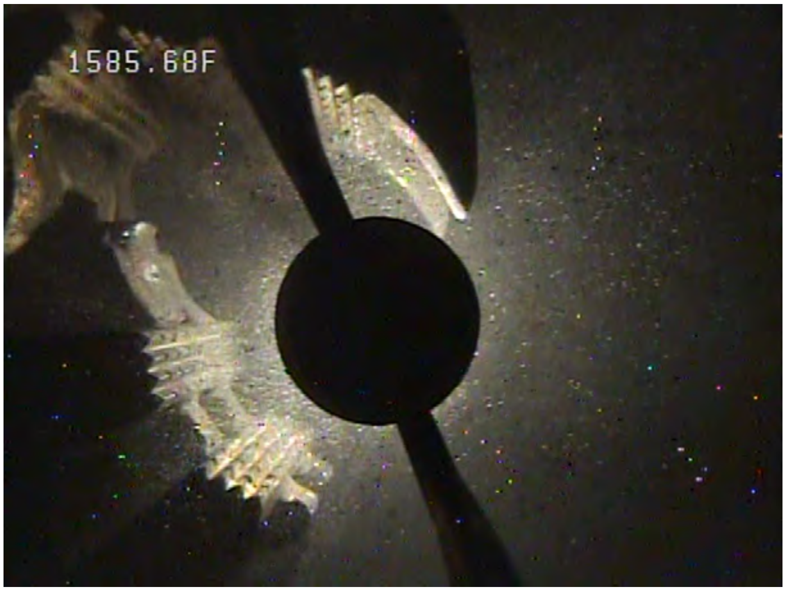


Observer's Initials **HS**

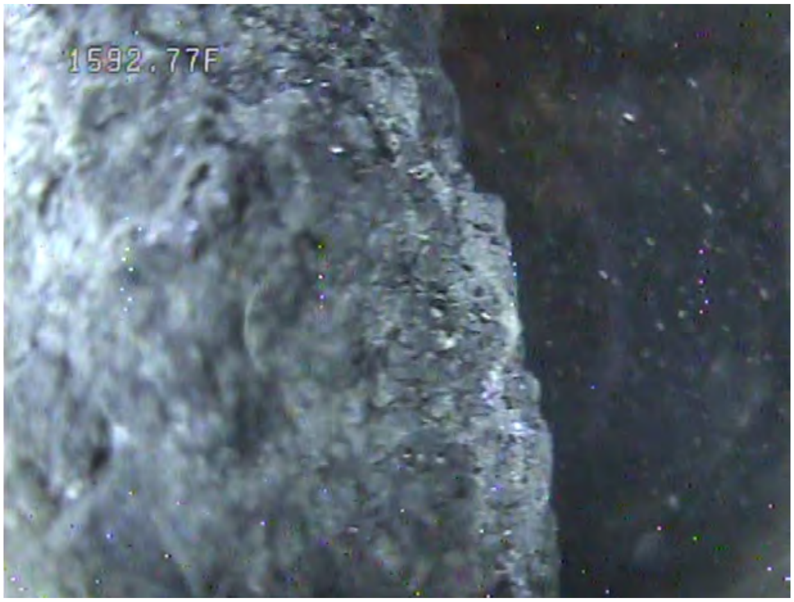




Observer's Initials HS



Observer's Initials HS


1592.77F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L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/17/2020
0830 - 1830

Sun	Mon	Tue	Wed	Thr	Fri	Sat
	x					

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**06**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec
START DEPTH: 1,672 feet bpl
DRILLER: Ross Aanerud/YBI
END DEPTH: 1,700 feet bpl
ACTIVITY: Drilling/clearing out open hole with 17.5-inch diameter drill bit.
SUB CONTRACTORS: None.
FORMATION SAMPLES: Collect samples of lost XY caliper tool.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0835	**H. Rahman/Stantec onsite. YBI already onsite.**
0845	**Spoke with R. Aanerud/YBI. They are tripping back into the hole with the 17.5-inch diameter drill bit and are at approximately 1,550 feet below pad level (bpl).**
0900	**H. Andreotta/SFWMD onsite to check gopher tortoise traps. No activity.**
0957	**YBI adding tremie pipe to the hole for reverse air drilling methods.**
1021	**Preparing to begin clearing.**
1024	**Begin clearing. Start depth is 1,630 feet bpl. Rotary = 24 rpm.**
1031	**Kelly down at 1,650 feet bpl. Water has strong odor. YBI is going to purge after each drill rod for 10-15 minutes and will collect cuttings.**
1035	**Per, A. Aanerud/YBI he did not hit anything while clearing, may have felt something closer to 1,650 feet bpl.**
1055	**Setting up to salt kill the well.**
1104	**Adding drill rod.**
1122	**Call with R. Cowles/Stantec.**
1127	**Resume clearing. Rotary = 24 revolutions per minutes (rpm).**
1135	**Per, R. Aanerud/YBI, the drill bit plugged up a little bit. Collecting cuttings, water looks black.**
1210	**Per R. Aanerud/YBI he thinks he hit a void at approximately at 1,662 feet bpl.**

Observer's Initials HR

1227	**R. Aanerud/YBI tagged bottom of the hole (or top of fill) at 1,672.71 feet bpl.**
1245	**Kelly down at 1,670 feet bpl.**
1252	**H. Rahman/Stantec checked gopher tortoise traps. No activity.**
1259	**Water is starting to clear up and hole seems to be getting cleaner.**
1301	**Received drill pipe tally from R. Aanerud/YBI. See field book for drill pipe tally.**
1310	**Setting up to salt kill the well.**
1330	**Resume drilling.** **Rotary = 32 rpm.**
1450	**Per, R. Aanerud/YBI drill bit is still getting plugged up.**
1503	**YBI is going to circulate for about 20 minutes because drill bit is getting plugged up.**
1504	**R. Aanerud/YBI is offsite.**
1506	**H. Rahman/Stantec offsite.**
1539	**H. Rahman/Stantec onsite. R. Aanerud/YBI already back onsite.**
1557	**Kelly down at 1,690 feet bpl.**
1604	**YBI is preparing to add last drill pipe to drill string.**
1619	**H. Rahman/Stantec checked gopher tortoise traps. No activity.**
1621	**Setting up to salt kill the well.**
1638	**Resume drilling.** **Rotary = 20 rpm.**
1710	**R. Aanerud/YBI offsite.**
1747	**R. Aanerud/YBI onsite.**
1751	**Call with R. Cowles/Stantec.**
1802	**Still drilling.** **Rotary = 12 rpm.**
1815	**Reached total depth at 1,700 feet bpl. Stopped drilling.**
1826	**Call with R. Cowles/Stantec.**
1828	**Spoke with R. Aanerud/YBI. They are going to take out tremie pipes. Tomorrow they are going to trip out of the hole and then trip back in the hole to begin brushing the casing.**
1833	**H. Rahman/Stantec offsite.**

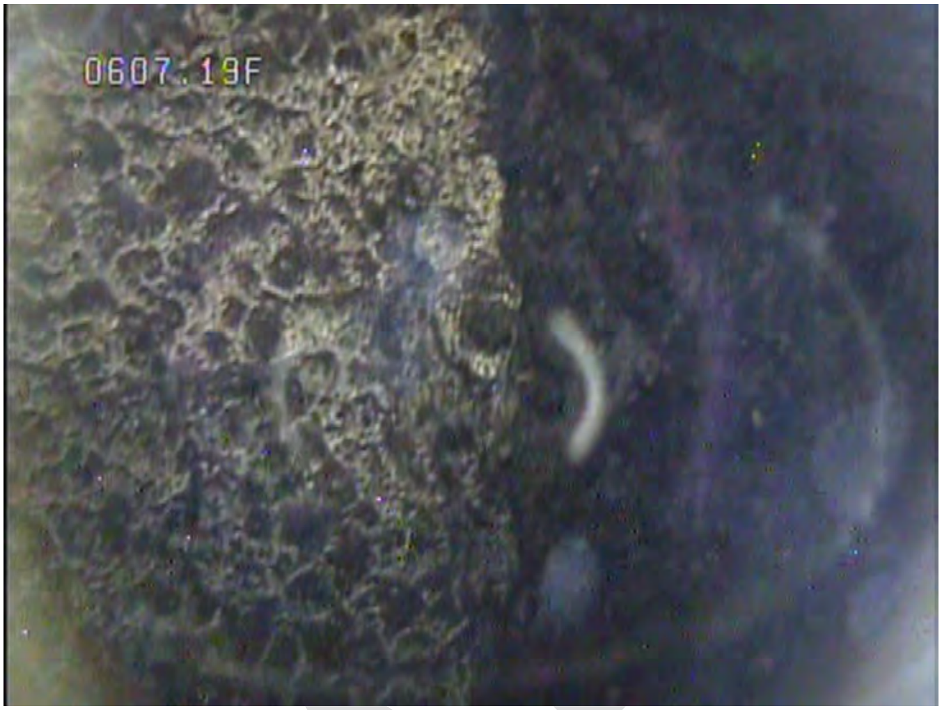
L-63N MIT CTVS Log Description Summary

Interval (feet bpl)	Description
0	Top of encrustation
0-14	Encrustation
14-15	Peeling encrustation or casing (?)
15-34	Encrustation
34-40	Small encrustation nodule clusters (possible crack or encrustation along casing)
40-55	Encrustation
55-56	Small encrustation nodule cluster
55-83	Encrustation with small nodule clusters
83-144	Encrustation appears to be thicker
144-157	Appears to be more nodule clusters on side of encrusted casing wall
157-181	Thicker encrustation
181-230	Small sporadic nodule clusters
230-234	Encrustation or casing (?) peeling off
234-260	Thicker encrustation, nodule clusters
260-262	Crack in casing or encrustation
262-289	Encrustation with small nodule clusters
289-296	Thicker gray encrustation with small nodule clusters
296-301	Holes and tears/cracks in encrustation
301-310	Encrustation with small nodule clusters **approximately 300 feet below pad level (bpl) to top of casing encrustation is whitish in color and resembles blocky nodules (fenced pattern) with a slimy dark brown background color. Less abundant closer to top of casing. Almost none from 0 to 10 feet bpl.*
310-319	Crack in encrustation
319-397	Encrustation with sporadic small nodule clusters
397-406	Crack in encrustation, peeling
406-416	Encrustation with sporadic nodule clusters
416-418	Crack in encrustation
418-427	Encrustation appears thinner with sporadic nodule clusters
427-554	Diameter of casing changes as a result of encrustation **change in encrustation from 495 to 480 feet bpl, possible weld seam at 469 feet bpl*
554-557	Crack in encrustation, appears to be peeling, casing appears irregular
557-569	Encrustation appears slightly thicker, nodule clusters
569-572	Crack in encrustation, appears to be peeling **red piece of something (casing?)*
572-585	Encrustation
585-587	Peeling
587-602	Encrustation with small nodule clusters **583 feet bpl, pieces missing, black nodules*
602-614	Encrustation peeling
614-634	Encrustation with small sporadic nodule clusters **weld seam at 629 feet bpl, pieces missing & potential casing peeling from 610 to 617 feet bpl*
634-637	Peeling
637-678	Encrustation with fewer nodule clusters
678-682	Peeling
682-695	Encrustation with small nodule clusters
695-699	Peeling

699-717	Encrustation
717-719	Large piece of encrustation appears to be peeling
719-755	Encrustation with sporadic nodule clusters
755-757	Peeling
757-773	Encrustation appears thicker, nodule clusters
773-777	Peeling
777-809	Encrustation with more nodule clusters
809-810	Casing diameter seems to change slightly as a result of encrustation
810-950	Encrustation appears thicker with more nodule clusters (large and small)
950-961	Peeling
961-979	Encrustation with sporadic nodule clusters **949 feet bpl possible crack or encrustation of casing and possible crack at 969 feet bpl*
979-981	Large encrustation nodule cluster
981-1,000	Encrustation with larger nodule clusters
1,000-1,027	Encrustation and peeling
1,027-1,081	Encrustation with sporadic nodule clusters **small vertical fracture in casing throughout, well seam at 1,030 feet bpl (?)*
1,081-1,086	Change in casing diameter as a result of encrustation
1,086-1,105	Encrustation appears thicker with larger nodule clusters
1,105-1,150	Encrustation with smaller nodule clusters, sporadic **possible weld seam at 1,111 and 1,030 feet bpl*
1,150-1,155	Change in casing diameter as a result of encrustation
1,155-1,247	Encrustation with smaller nodule clusters, sporadic
1,247-1,249	Large nodule cluster
1,249-1,265	Encrustation with large sporadic clusters
1,265-1,268	Large nodule clusters
1,268-1,269	Three windows in casing filled with encrustation or cement (?)
1,269-1,271	Casing bottom, encrustation to bottom of casing. Cement came down
1,271-1,284	Oblate borehole
1,284-1,292	Irregular and oblate borehole, partial collapse **very dark in borehole*
1,292-1,301	Irregular borehole **very dark in borehole*
1,301-1,307	Irregular borehole with cavities **very dark in borehole*
1,307-1,314	Irregular, oblate borehole with small cavities **bacteria at 1,310 feet bpl, very dark in borehole*
1,314-1,316	Oblate borehole, with large cavity
1,316-1,321	Irregular, oblate borehole with brecciated cavities **possible flow zone in this area*
1,321-1,333	Gauge borehole, vug field, heavily vugged
1,333-1,354	Irregular borehole, small cavities, brecciated along some bedding planes, vuggy **bacteria from 1,333 to 1,334 feet bpl*
1,354-1,355	Slightly irregular borehole, possible bedding (?), sporadic vugs
1,355-1,357	Brecciated borehole
1,357-1,364	Irregular borehole with small fractures and vugs **1,359 feet bpl tiny cavity*
1,364-1,365	Lithology change (?)
1,365-1,378	Gauge borehole, vuggy, vug chains
1,378-1,380	Irregular, brecciated borehole, very vuggy **bacteria at 1,379 feet bpl*
1,380-1,390	Irregular borehole, small cavities, vuggy
1,390-1,405	Irregular borehole, small cavities, brecciated
1,405-1,410	Possible flow zone, video becomes slightly cloudy and wavy
1,410-1,411	Possible lithology change (?)
1,411-1,431	Irregular borehole, brecciated with small cavities and fractures
1,431-1,432	Irregular, oblate borehole, vuggy and brecciated
1,432-1,439	Small cavern, very brecciated, drilling induced fractures (?)

1,439-1,453	Gauge borehole, bedded lithology, vuggy, small fractures
1,453-1,466	Irregular borehole, small fractures, vugs, slightly brecciated
1,466-1,473	Gauge borehole, vuggy, vug chains
1,473-1,475	Irregular, oblate borehole, brecciated, small cavity
1,475-1,477	Irregular borehole, fractures, brecciated
1,477-1,483	Gauge borehole, vuggy, vug chains, brecciated
1,483-1,490	Irregular borehole
1,490-1,499	Gauge borehole **small cavity with vugs at 1,493 feet bpl*
1,499-1,503	Irregular borehole, brecciated
1,503-1,505	Gauge borehole, vuggy
1,505-1,510	Irregular, brecciated borehole, vuggy **fracture swarm (possible thin horizontal cavity) and bacteria from 1,510 -1,507 feet bpl*
1,510-1,541	Gauge borehole, vuggy, small cavities, vug chains
1,541-1,544	Slightly irregular borehole, brecciated, fractures **bacteria at 1,543 feet bpl*
1,544-1,554	Gauge borehole, vuggy, vug fields
1,554-1,560	Possible flow zone in this area **camera centralizer markings at 1,557 feet bpl*
1,560-1,565	Gauge borehole, vuggy, vug fields
1,565-1,567	Irregular borehole, very brecciated
1,567-1,570	Large cavernous room
1,570	Fill blockage, geophysical tools and cable, PVC pipe
Notes:	*CTVSL tool centralizer pattern (120° white lines) throughout casing and borehole. *Water is clear throughout video. *Three windows at bottom of the casing at approximately 1,268 feet bpl. *A 360° view of the bottom of the casing was completed at 1,271 feet bpl. *A side view of the entire borehole and casing was completed. **Description came from the side view portion of the video.*

Screenshots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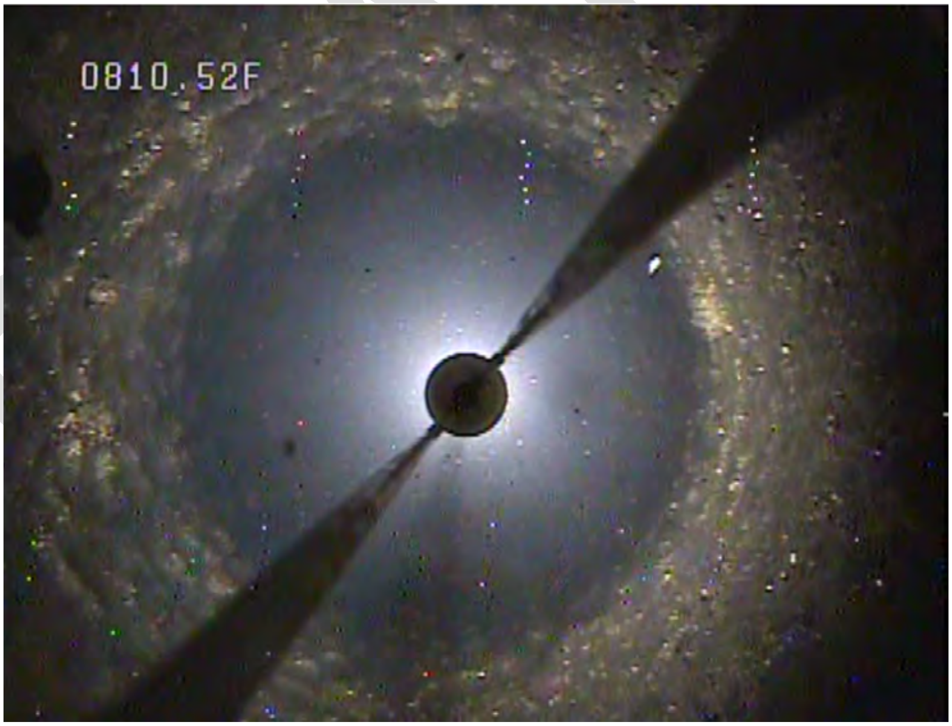
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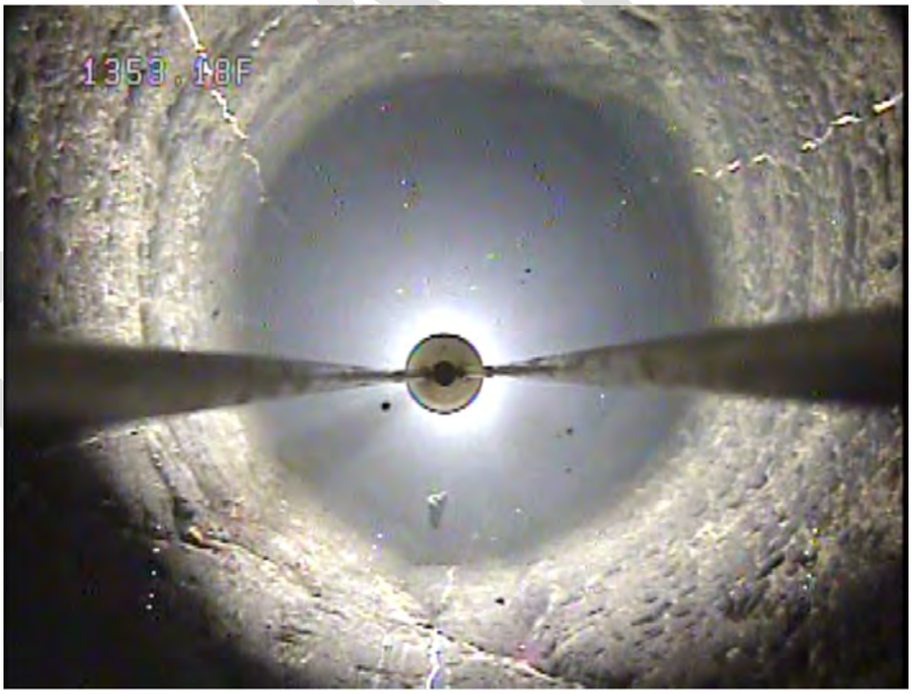
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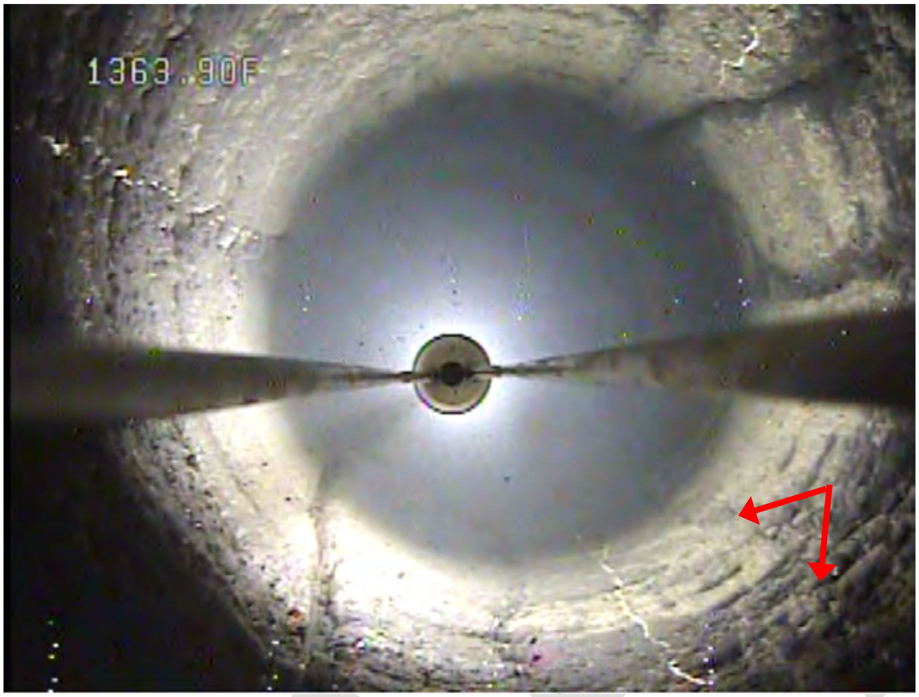
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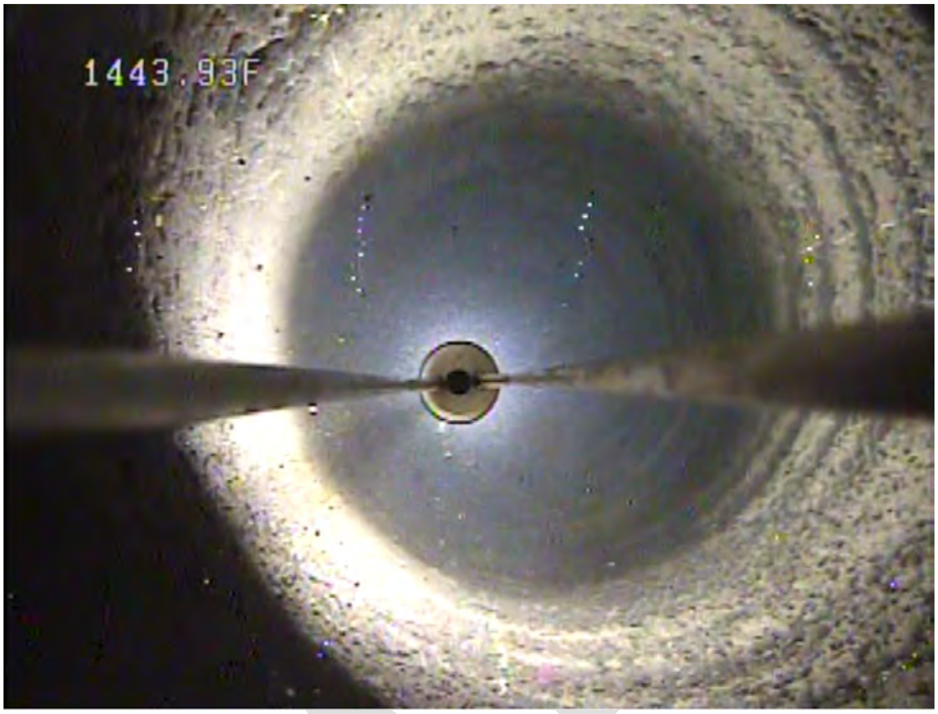
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Stantec

Photographic Log

Client Name: **SFWMD**

Date: **January 30, 2020**

Site Location: **SFWMD L-63N MIT, Okeechobee, FL**

Activity: **L-63N MIT**

Project No. **177311456**

Stantec

Photo No.
1

Date
1/30/2020

Photographer
Hannah Rahman

Description

YBI Geophysical logging truck used to do the video logging.

Photo No.

2

Date

1/30/2020

Photographer

Hannah Rahman

Description

Well at L-63N.

Photo No.
3

Date
1/30/2020

Photographer
Hannah Rahman

Description

Previous rotary pumps.

Photo No.
4

Date
1/30/2020

Photographer
Hannah Rahman

Description

Youngquist Brothers Inc (YBI) installing new bulb to video logger.

Photo No.
5

Date
1/30/2020

Photographer
Hannah Rahman

Description

YBI attaching two steel risers to the wellhead.

Photo No.
6

Date
1/30/2020

Photographer
Hannah Rahman

Description

YBI and Stantec observing the fallen tools, cable, and polyvinyl chloride (PVC) pipe at the bottom of the open hole.

Stantec

Photo No.
7

Date
1/30/2020

Photographer
Hannah Rahman

Description

Pump connected to fire hydrant across the road from the field site for water source.

Stantec

Photo No.
8

Date
1/30/2020

Photographer
Cora Summerfield

Description

Pump connected to fire hydrant running towards canal to go under the bridge and across the field site.

Photo No.
9

Date
1/30/2020

Photographer
Cora Summerfield

Description

Pump running underground to cross a gate and dirt road and then down to the side of the canal.

Stantec

Photographic Log

Client Name: **SFWMD**

Date: **February 7 – 14, 2020**

Site Location: **SFWMD L-63N MIT, Okeechobee, FL**

Activity: **L-63N MIT Video logging**

Project No. **177311456**

Photo No.
1

Date
2/7/2020

Photographer
Cora Summerfield

Description

Cable coming out of L-63N ASR well.

Photo No.
2

Date
2/7/2020

Photographer
Cora Summerfield

Description

Cable pulled out of L-63N ASR well.

Photo No.
3

Date
2/10/2020

Photographer
Cora Summerfield

Description

Gopher tortoise trap set up onsite.

Photo No.
4

Date
2/10/2020

Photographer
Cora Summerfield

Description

Gopher tortoise traps set up onsite.

Photo No.
5

Date
2/10/2020

Photographer
Cora Summerfield

Description

Totalizer onsite at L-63N.

Stantec

Photo No.
6

Date
2/12/2020

Photographer
Hannah Rahman

Description

Encrusted cable from L-63N ASR fished out by Youngquist Brothers Incorporated (YBI).

Photo No.
7

Date
2/12/2020

Photographer
Hannah Rahman

Description

R. Cowles/Stantec taking samples of encrusted cable.

Stantec

Photo No.
8

Date
2/12/2020

Photographer
Hannah Rahman

Description

YBI fishing for lost XY caliper tool.

Stantec

Photo No.
9

Date
2/12/2020

Photographer
Hannah Rahman

Description

YBI fishing for lost XY caliper tool.

Photo No.
10

Date
2/12/2020

Photographer
Hannah Rahman

Description

YBI fishing for lost XY caliper tool.

Photo No.

11

Date

2/12/2020

Photographer

Hannah Rahman

Description

Video survey light bulb blew while fishing for lost XY caliper tool.

Photo No.
12

Date
2/14/2020

Photographer
Hannah Rahman

Description

YBI clearing L-63N open hole via reverse air methods.

Photo No.
13

Date
2/14/2020

Photographer
Hannah Rahman

Description

Drill pipe used by YBI.

Photo No.

14

Date

2/14/2020

Photographer

Hannah Rahman

Description

Fishing tool used by YBI to try and retrieve lost XY caliper tool.

Stantec

Photographic Log

Client Name: **SFWMD**

Date: **February 17 - 21, 2020**

Site Location: **SFWMD L-63N MIT, Okeechobee, FL**

Activity: **L-63N MIT Video logging**

Project No. **177311456**

Photo No.

1

Date

2/17/2020

Photographer

Hannah Rahman

Description

Youngquist Brothers Inc.,(YBI) drilling out fill, tagged fill at 1,672.71 feet below pad level (bpl).

Photo No.
2

Date
2/17/2020

Photographer
Hannah Rahman

Description

Collecting lost XY caliper tool samples while drilling via reverse air methods.

Photo No.
3

Date
2/17/2020

Photographer
Hannah Rahman

Description

Salt kill setup – brings down the artesian head.

Photo No.

4

Date

2/17/2020

Photographer

Hannah Rahman

Description

Discharge water flowing into storage pond.

Photo No.
5

Date
2/17/2020

Photographer
Hannah Rahman

Description

XY caliper tool samples retrieved during drilling.

Stantec

Photo No.

6

Date

2/17/2020

Photographer

Hannah Rahman

Description

Weir setup.

Stantec

Photo No.
7

Date
2/17/2020

Photographer
Hannah Rahman

Description

XY caliper tool samples retrieved during drilling.

Photo No.
8

Date
2/17/2020

Photographer
Hannah Rahman

Description

Discharge water starting to clear up.

Photo No.

9

Date

2/17/2020

Photographer

Hannah Rahman

Description

Discharge water significantly clearing up.

Photo No.
10

Date
2/17/2020

Photographer
Hannah Rahman

Description

Night drilling, YBI hit total depth at 1,700 feet bpl.

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/20/20
Day of Week:	Monday

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	2		Collect materials for site
2	6:30		Mobilize materials / unload materials
6:30	9		Mobilize rig to shop

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud ✓	11.5	No
Kenny Smith ✓	14	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/21/20
Day of Week:	Tuesday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
6:30	11		Mobilize Boomtruck to site
			Set up silt fence / tortise training
11	5:15		List of materials / Put 6in valve on well
			head / seal wellhead

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud ✓	10.75	No
Kenny Smith ✓	10.75	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/22/20
Day of Week:	Wedensday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	5:15		Disassemble piping from well head
			(well has 10.6' of head pressure)
			Put up new silt fence
			Unload truck

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		
NAME	HOURS	INJURED YES/NO
Ross Aanerud	✓10.25	No
Kenny Smith	✓10.25	No
Danny Atkisson	✓10.25	No

NIGHT TOUR:		
NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/23/20
Day of Week:	THURSDAY

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
6	1		ROSS & KENNY DRIVE TO YBI SHOP
			AND LOAD MATERIAL ON SEMI FOR
			JOBSITE
6	5:30		DANNY ATKINSON ON SITE UNLOADING
			TRUCKS AND ORGANIZING
			MATERIAL - TRUCK LOAD OF SALT
			DELIVERED TO SITE

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
1	5		ROSS & KENNY SENT OVER TO
			EAST COAST

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
ROSS AANERUD	7	NO
KENNY SMITH	7	NO
	16.5	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/24/20
Day of Week:	FRIDAY

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	6		UNLOADING TRUCKS & ORGANIZING
			MATERIALS ON JOBSITE

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
DANNY ATKISSON	11	NO

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
			ROSS & KENNY NOT ON SITE TODAY

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/27/20
Day of Week:	Monday

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	7	12		Collect materials for site, load truck
	12	3		Mobilize to site
6	3	[illegible]		Start setting up waterline, unload trailer
		10		Mobilize tractor back to yard, drive back
				to hotel
				(

NIGHT SHIFT	TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud ✓	11	No
Kenny Smith ✓	15	No
Dennis Hurtado ✓	11	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/28/20
Day of Week:	Tuesday

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	5:30		Run 4" yellowmine for water line
			Flowers Testing sampled ASR Well
			Pressure test waterline

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	✓10.5	No
Kenny Smith	✓10.5	No
Dennis Hurtado	✓10.5	No

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/29/20
Day of Week:	Wedensday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	5:15		Replace ARV with blind Flange
			Hook up waterline to well
			Unload / load truck
			Begin pumping down well at 3:45
			Moniter waterline / well
9	10		Check well / Shut off water

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Ross Aanerud	✓10.25	No
Kenny Smith	✓11.25	No
Dennis Hurtado	✓10.25	No

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/30/20
Day of Week:	Thursday

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	8		Flush well
8	9		Rig up logger
9	3		Run log
3	6		Set up to Kill well / Kill well 3 bags
			of salt

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud ✓	11	No
Kenny Smith ✓	11	No
Dennis Hurtado 2048 ✓	11	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	1/31/20
Day of Week:	Friday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7			Disassemble well head, 1 bag of salt in well 18' below flange, weld coupling onto header, put on header, seal well
5	7		Mobilize to yard

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	12	No
Kenny Smith	12	No
Dennis Hurtado	12	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/1/20
Day of Week:	Saturday

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	12		Collect materials, load open top pit
12	2:30		Mobilize to site
2:30	3		Unload material
3	5:30		Mobilize back to shop

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	10.5	No
Kenny Smith	10.5	No

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/2/20
Day of Week:	Sunday

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	9		Collect materials/load semis with open tops
9	12		Mobilize to site
12	12:45		[illegible] unload material
12:45	3:15		Mobilize back to yard

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Ross Aanerud	8.25	No
Kenny Smith	8.25	No

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/13/20
Day of Week:	Monday

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	6:15		Set settling tanks, set up rig over hole,
			set up catwalk and drill pipe

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Ross Aanerud	11.25	No
Kenny Smith	11.25	No
Dennis Hurtado	11.25	No

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/4/20
Day of Week:	Tuesday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7			Plum together settling tanks / unload
			crane / organise, set up site to begin
	5:30		fishing / seat wellhead
5	8		Mobilize boom truck to yard

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		
NAME	HOURS	INJURED YES/NO
Ross Aanerud	10.5	No
Kenny Smith	13	No
Dennis Hurtado	10.5	No

NIGHT TOUR:		
NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/5/20
Day of Week:	WEDNESDAY

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7	5:30		UNLOAD SETTLING TANK, SET UP TO
				TRIP IN HOLE. ORGANIZE SITE -
				RUN DISCHARGE LINE FROM
				TANKS

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
ROSS AANERUD	10.5	NO
KENNY SMITH	10.5	NO
DENNIS HURTADO	10.5	NO

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/6/20
Day of Week:	THURSDAY

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7			PRESSURE TEST FISHING EQUIPMENT
		3		CLEAN SITE
				(ROSS ATTENDED PROGRESS MEETING)
	2:30	5		KENNY DROVE TO SHOP IN FT MYERS
	5	5:30		PICKED UP MATERIAL FOR JOBSITE
	5:30	8		DROVE BACK TO OKEECHOBEE

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
ROSS AANERUD	8	NO
DENNIS HURTADO	8	NO
KENNY SMITH	13	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/7/20
Day of Week:	FRIDAY

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	7:30		TOOL UP FISHING TOOL - CLOSE JAWS
7:30	12:45		TRIP IN FISHING TOOL TO 1570'
12:45			OPEN JAWS & SET DOWN ONTO CABLE
	1:15		& CLOSE JAWS
1:15			PULL OUT OF HOLE WITH BUNDLE OF LOGGING
	5:30		CABLE, TAKE APART TOOL. SEAL IN
5:30	6:30		WELL, CLEAN SITE

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
ROSS AANERUD	11.5	NO
KENNY SMITH	11.5	NO
DENNIS HURTADO	11.5	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

Stantec

Memo

To:	SFWMD South Florida Water Management District	From:	Rick Cowles Stantec
File:	Lake Okeechobee ASR Project L-63N MIT Weekly Progress Report	Date:	February 24, 2020

Work Completed to Date:

On Monday, February 17, 2020, YBI drilled through the lost caliper tool and began developing the well. The bottom of the well was tagged at approximately 1,672 feet and by the end of the day the total depth of the borehole was encountered at 1,700 feet. Stantec was onsite during the development process and collected pieces of the caliper tool and developed material as it was removed from the well. Water clarity improved markedly by the end of the initial development process. Tuesday, February 18, 2020, through Wednesday, February 19, 2020, YBI used a steel wire brush to gently clean the entire the 24-inch diameter injection casing of iron encrustation. On Thursday, February 20, 2020, YBI tripped in a 17.5-inch diameter mill tooth drill bit to drill or clear fill out of the open hole via the reverse air drilling method. Approximately 20 feet of fill from brushing was removed, and the open hole total depth was advanced at 1,700 feet bpl. Stantec was onsite for the development process and collected a few pieces of the caliper tool that was removed from the well. On Friday, February 21, 2020, YBI developed the well until the discharge water was clear via the reverse air drilling method.

The following attachments are included in this weekly summary report:

- Stantec Daily Reports
- Daily Photo Logs
- YBI Daily Reports

Work to be Completed through Next Period

It is anticipated that on Monday, February 24, 2020, the final color television survey log and the XY caliper log will be completed. Geophysical logging will be followed by a casing pressure test later in the week.

Stantec Consulting Services Inc.

Rick Cowles, PG
Senior Hydrogeologist/Senior Associate

Phone: 941-266-3917

Attachment: Attachment

c. C.C.	Jennifer Gent/SFWMD	(jgent@sfwmd.gov)
	Robert Verrastro/SFWMD	(bverras@sfwmd.gov)

Neil Johnson/Stantec	(Neil.Johnson@stantec.com)
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Jeovanni Ayala-Lugo/Stantec	(jeovanni.ayala-lugo@stantec.com)

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/17/2020
0830 - 1830

Sun	Mon	Tue	Wed	Thr	Fri	Sat
	x					

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**06**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec
START DEPTH: 1,672 feet bpl
DRILLER: Ross Aanerud/YBI
END DEPTH: 1,700 feet bpl
ACTIVITY: Drilling/clearing out open hole with 17.5-inch diameter drill bit.
SUB CONTRACTORS: None.
FORMATION SAMPLES: Collect samples of lost XY caliper tool.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0835	**H. Rahman/Stantec onsite. YBI already onsite.**
0845	**Spoke with R. Aanerud/YBI. They are tripping back into the hole with the 17.5-inch diameter drill bit and are at approximately 1,550 feet below pad level (bpl).**
0900	**H. Andreotta/SFWMD onsite to check gopher tortoise traps. No activity.**
0957	**YBI adding tremie pipe to the hole for reverse air drilling methods.**
1021	**Preparing to begin clearing.**
1024	**Begin clearing. Start depth is 1,630 feet bpl.** **Rotary = 24 revolutions per minute (rpm).**
1031	**Kelly down at 1,650 feet bpl. Water has strong odor. YBI is going to purge after each drill rod for 10-15 minutes and will collect cuttings.**
1035	**Per, A. Aanerud/YBI he did not hit anything while clearing, may have felt something closer to 1,650 feet bpl.**
1055	**Setting up to salt kill the well.**
1104	**Adding drill rod.**
1122	**Call with R. Cowles/Stantec.**
1127	**Resume clearing.** **Rotary = 24 rpm.**
1135	**Per, R. Aanerud/YBI, the drill bit plugged up a little bit. Collecting cuttings, water looks black. Per**
1210	**R. Aanerud/YBI he thinks he hit a void at approximately at 1,662 feet bpl.**

1227 R. Aanerud/YBI tagged bottom of the hole (or top of fill) at 1,672.71 feet bpl.

1245 Kelly down at 1,670 feet bpl.

1252 H. Rahman/Stantec checked gopher tortoise traps. No activity.

1259 Water is starting to clear up and hole seems to be getting cleaner.

1301 Received drill pipe tally from R. Aanerud/YBI. See field book for drill pipe tally.

1310 Setting up to salt kill the well.

1330 Resume drilling.

Rotary = 32 rpm.

1450 Per, R. Aanerud/YBI drill bit is still getting plugged up.

1503 YBI is going to circulate for about 20 minutes because drill bit is getting plugged up.

1504 R. Aanerud/YBI is offsite.

1506 H. Rahman/Stantec offsite.

1539 H. Rahman/Stantec onsite. R. Aanerud/YBI already back onsite.

1557 Kelly down at 1,690 feet bpl.

1604 YBI is preparing to add last drill pipe to drill string.

1619 H. Rahman/Stantec checked gopher tortoise traps. No activity.

1621 Setting up to salt kill the well.

1638 Resume drilling.

Rotary = 20 rpm.

1710 R. Aanerud/YBI offsite.

1747 R. Aanerud/YBI onsite.

1751 Call with R. Cowles/Stantec.

1802 Still drilling.

Rotary = 12 rpm.

1815 Reached total depth at 1,700 feet bpl. Stopped drilling.

1826 Call with R. Cowles/Stantec.

1828 Spoke with R. Aanerud/YBI. They are going to take out tremie pipes. Tomorrow they are going to trip out of the hole and then trip back in the hole to begin brushing the casing.

1833 H. Rahman/Stantec offsite.

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/20/2020
1245 - 1710

Sun	Mon	Tue	Wed	Thr	Fri	Sat
				x		

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**07**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec
START DEPTH: 1,672 feet bpl
DRILLER: Ross Aanerud/YBI
END DEPTH: 1,700 feet bpl
ACTIVITY: Drilling/clearing out open hole with 17.5-inch diameter mill tooth drill bit.
SUB CONTRACTORS: None.
FORMATION SAMPLES: Collect samples of lost XY caliper tool.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
1000	**L-63N MIT progress meeting at Okeechobee field station.**
1227	**Call with R. Aanerud/YBI, they finished tripping into hole and are beginning to set the airline for reverse air methods.**
1246	**H. Rahman/Stantec onsite. YBI already onsite.**
1257	**R. Aanerud/YBI showed me all the sediment in the tanks from development. Approximately six inches of sediment and more in some areas of the tank.**
1259	**YBI begins drilling/clearing.** **Rotary = 22 revolutions per minute (rpm).** **No weight on bit.** **Water has a strong odor and looks like oil.**
1300	**Received polyvinyl (PVC) pipe and XY caliper tool samples from R. Aanerud/YBI.**
1322	**Per R. Aanerud/YBI there is 20 feet of fill from casing brushing. At approximately 1,280 feet below pad level (bpl), they are hitting fill.**
1323	**Water looks to be clearing up.**
1337	**Water is black at 1,690 feet bpl.**
1350	**Kenny/YBI offsite.**
1356	**B. Garrett/SFWMD onsite.**
1400	**Kenny/YBI onsite.**
1415	**Spoke with B. Garrett/SFWMD about tortoise traps.**

Observer's Initials HR

1416 Kelly down at 1,692 feet bpl.
1418 R. Aanerud/YBI is going to circulate for a bit and go back down and clean with drill pipe.
1420 B. Garrett/SFWMD trapped a tortoise.
1429 Water is dark and has an odor.
1501 B. Garrett/SFWMD is offsite.
1445 Kelly back down at 1,692 feet bpl.
1446 YBI continues to circulate.
1522 YBI salt kills the well.
1531 YBI is adding last drill pipe.
1540 Resume drilling.
Rotary = 24 rpm
No weight on bit.
1546 Water is starting to clear up, but still has an odor.
1550 Water looks like oil and has an odor.
1610 Kelly is down to total depth at 1,700 feet bpl. YBI circulates.
1645 Call with N. Sharma/Stantec.
1646 Water is starting to really clear up, still has a grayish tint to it.
1654 Call with R. Cowles/Stantec.
1657 Talked with R. Aanerud/YBI about plan for tomorrow and next steps. Drill pipe tally did not change with new bit.
1700 Water looks to be significantly clearer.
1706 Checked tortoise traps – no activity.
1710 H. Rahman/Stantec offsite.

Observer's Initials HR

Photographic Log

Client Name: **SFWMD**

Date: **February 17 - 21, 2020**

Site Location: **SFWMD L-63N MIT, Okeechobee, FL**

Activity: **L-63N MIT**

Project No. **177311456**

Photo No.
1

Date
2/17/2020

Photographer
Hannah Rahman

Description

Youngquist Brothers Inc., (YBI) drilling out fill, tagged fill at 1,672.71 feet below pad level (bpl).

Photo No.
2

Date
2/17/2020

Photographer
Hannah Rahman

Description

Collecting lost XY caliper tool samples while drilling via reverse air methods.

Photo No.
3

Date
2/17/2020

Photographer
Hannah Rahman

Description

Salt kill setup – brings down the artesian head.

Photo No.
4

Date
2/17/2020

Photographer
Hannah Rahman

Description

Discharge water flowing into storage pond.

Photo No.
5

Date
2/17/2020

Photographer
Hannah Rahman

Description

XY caliper tool samples retrieved during drilling.

Photo No.
6

Date
2/17/2020

Photographer
Hannah Rahman

Description

Weir setup.

Stantec

Photo No.
7

Date
2/17/2020

Photographer
Hannah Rahman

Description

XY caliper tool samples retrieved during drilling.

Photo No.

8

Date

2/17/2020

Photographer

Hannah Rahman

Description

Discharge water starting to clear up.

Stantec

Photo No.
9

Date
2/17/2020

Photographer
Hannah Rahman

Description

Discharge water significantly clearing up.

Photo No.
10

Date
2/17/2020

Photographer
Hannah Rahman

Description

Night drilling, YBI hit total depth at 1,700 feet bpl.

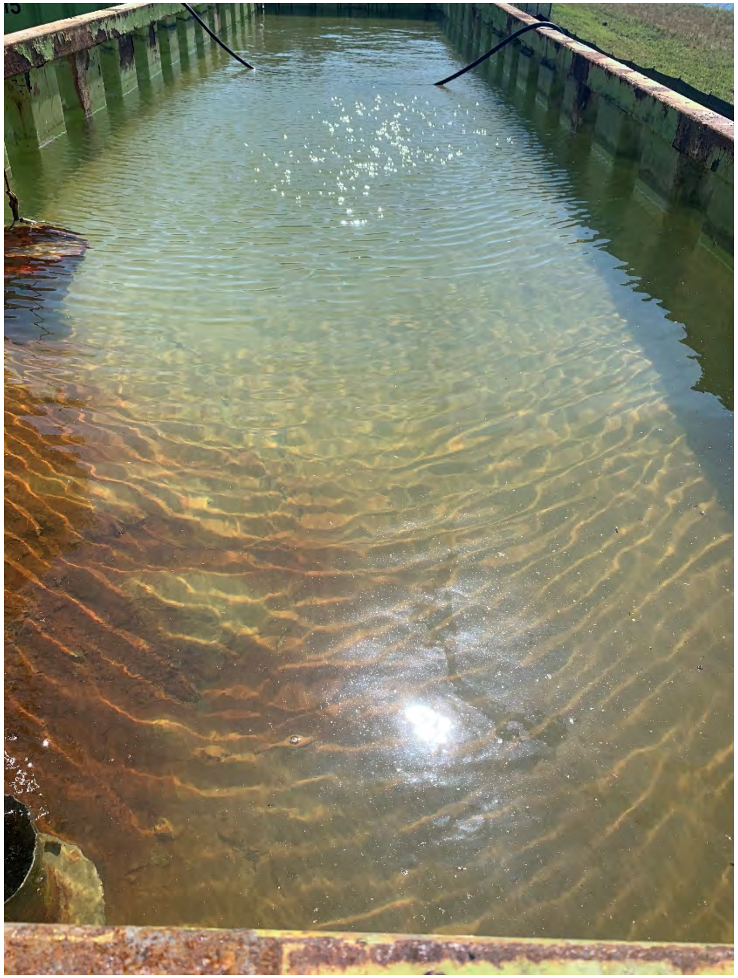
Photo No.
11

Date
2/20/2020

Photographer
Hannah Rahman

Description

Accumulation of sediment and drill cuttings from reverse air drilling methods.



Stantec

Photo No.
12

Date
2/20/2020

Photographer
Hannah Rahman

Description

Polyvinyl (PVC) pipe and XY caliper tool samples drilled out from L-63N ASR well via reverse drilling methods.

Stantec

Photo No.
13

Date
2/20/2020

Photographer
Hannah Rahman

Description

Brush used to clean out encrustation and nodules in the L-63N ASR well.

Photo No.
14

Date
2/20/2020

Photographer
Hannah Rahman

Description

Young female tortoise trapped onsite; she will be relocated.

Photo No.
15

Date
2/20/2020

Photographer
Hannah Rahman

Description

17.5-inch diameter mill tooth drill bit used to clean out L-64N ASR well to total depth at 1,700 feet bpl.

CLIENT	South Florida Water Management District	**YBI Job #**	020-10-064
Job Name	L-63N Taylor Creek ASR Rehab	**Date:**	2/10/20
Rig/Well ID		**Day of Week:**	Monday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER			
Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
4:45	5		Collect material
5	7		Mobilize to site
7	10		Regen rig, set traps, finish discharge line
10	11:15		Trip to 400', prep to flush down well
11:15	2		Flush well, rig up logger,
2	4		Run VIDEO (SEE CALIPER TOOL AT 1599' DEPTH)
4	6		Rig down logger, TRIP OUT CAMERA clean up site

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	11	No
[redacted]	[redacted]	No
Dennis Hurtado	11	No
Kenny Smith	13.15	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/11/20
Day of Week:	Tuesday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7			Pump salt Kill down drill pipe, [illegible] /
			pull drill pipe out of hole / replace
			subsaver, get fuel, break down subs
	4		on wire brush, organize site
4	6:15		Mobilize to Lehigh to get 2ND FISHING TOOL
6:15	8		Mobilize to site WITH FISHING TOOL

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Ross Aanerud	9	No
Kenny Smith	13	No
Dennis Hurtado	7	No

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/12/20
Day of Week:	Wedensday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	8:30		Test tool / tool up and prep to trip in
8:30	3:30		Trip in tool to 1580' TO GRAB CALIPER TOOL
3:30	8		Rig up logger / run down camera / * pull
			camera out of hole / pack up site
		*	(BUMPED CALIPER TOOL & KNOCKED IT DOWN HOLE)
12:30	8 PM		RAFAEL SENT FROM FT MYERS TO
			HELP ROSS IN OKEECHOBEE

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	13	No.
Kenny Smith	13	No
Dennis Hurtado	13	No.
RAFAEL GUTIERREZ	7.5	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/13/20
Day of Week:	Thursday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	22"
STRING WT.	
BIT TYPE	BUTTON

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	3		Regen rig / rig down logger / Trip out of hole / Change subsaver
3	6:30		Tool up bit / trip in bit to 73'/ Seal up well /

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	11.5	No
Kenny Smith	11.5	No
Dennis Hurtado	11.5	No
Rafael Gutierrez	11.5	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

Client	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/14/20
Day of Week:	Friday

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER

Size	Weight	Length	Set At

	Depth Interval		Rotary Table Speed	Weight on Bit
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

Bit Size [illegible]	22"
[illegible]	
Bit Type	Button

DAY SHIFT

Time Log		Time / [illegible]	Details of Operations in Sequence and Remarks
From	To		
7	11		Trip into 1272'
11			Trip in Airline/reamed from 1265' to 1293'
			Adjust swivel on tophead/Kill drill pipe/
			Trip airline out of hole Trip out to
	6:30		412'/ seal well
6:30	8:30		Mobilize to shop
8:30	9		Load material

NIGHT SHIFT

Time Log		Time / [illegible]	Details of Operations in Sequence and Remarks
From	To		
			22" BIT DRILLING NEW (LARGER HOLE)
			FROM BOTTOM OF CASING DOWN TO
			1293 FEET DEPTH - CALLED RICK COWLES
			& HE AGREED WE COULD SWITCH TO
			17½" BIT

DRILLING CREW PAYROLL DATA

Day Shift		
Name	Hours	[illegible]
Ross Aanerud	11.5	No
Kenny Smith	14	No
Dennis Hurtado	11.5	No
Rafael Gutierrez	9	No

Night Shift		
Name	Hours	[illegible]

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/15/20
Day of Week:	Saturday

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	17 1/2
STRING WT.	
BIT TYPE	Button

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
4:45	7		Mobilize to site / get fuel for rig
7	9:15		Trip out of hole / breakdown BHA
9:15	9:45		Tool up BHA / Trip into 50'
9:45	10:15		Replace subsaver
10:15			Trip into 1450' / strip header over drill
	3		pipe / put on rubber can / seal well /
3	5:30		Mobilize to shop

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	8.5	No
~~[illegible]~~	~~[illegible]~~	~~[illegible]~~
Dennis Hurtado	8	No
Kenny Smith	12.75	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

Stantec

Memo

To:	SFWMD South Florida Water Management District	From:	Rick Cowles Stantec
File:	Lake Okeechobee ASR Project L-63N MIT Weekly Progress Report	Date:	March 2, 2020

Work Completed to Date:

On Monday, February 24, 2020, YBI completed the final color television survey log (CTVSL) and the XY caliper log. The casing appeared to be clean of encrustation and sound on the CTVSL. On Friday, February 28, 2020, a casing pressure test was conducted on the 24-inch diameter steel injection casing. A temporary inflatable packer was set at 1,246.30 feet below pad level. The target pressure for the casing pressure test was 50 pounds per square inch (psi). Overall, the pressure test resulted in a 2% decrease in pressure over the hour-long test.

The following attachments are included in this weekly summary report:

- Stantec Daily Reports
- Pressure Gauge Calibration Form
- Signed Pressure Test Log
- Daily Photo Logs
- XY Caliper Log
- YBI Daily Reports

Work to be Completed through Next Period

It is anticipated that the 12-hour step-rate pumping test (consisting of 3, four-hour long steps) will occur towards the end of the week.

Rick Cowles, PG
Senior Hydrogeologist/Senior Associate

Phone: 941-266-3917

Attachment: Attachment

c. C.C.

Jennifer Gent/SFWMD	(jgent@sfwmd.gov)
Robert Verrastro/SFWMD	(bverras@sfwmd.gov)
Neil Johnson/Stantec	(Neil.Johnson@stantec.com)
Cora Summerfield/Stantec	(cora.summerfield@stantec.com)
Nycole Sharma/Stantec	(Nycole.sharma@stantec.com)

Hannah Rahman/Stantec	(hannah.rahman@stantec.com)
Heath Wintz/Stantec	(Heath.Wintz@stantec.com)
Jeovanni Ayala-Lugo/Stantec	(jeovanni.ayala-lugo@stantec.com)

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/24/2020
0930 - 2130

Sun	Mon	Tue	Wed	Thr	Fri	Sat
	x					

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**08**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec
START DEPTH: 1,700 feet bpl
DRILLER: Ross Aanerud/YBI
END DEPTH: 1,700 feet bpl
ACTIVITY: Completing final video survey and XY caliper log.
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0930	**H. Rahman/Stantec onsite. YBI already onsite. G. Cook/SFWMD onsite.**
0942	**YBI logging truck onsite.**
0946	**YBI setting up for final video survey.**
0947	**YBI personnel onsite.**
1017	**YBI putting video survey tool in the hole.**
1022	**Begin video survey.**
	Approximately 30 feet/minute.
	Water is flowing about 100 gallons per minute.
1035	**YBI personnel offsite.**
1059	**YBI personnel back onsite.**
1101	**Reached bottom of casing at 1,268 feet below pad level (bpl).**
1111	**Continue video survey in open hole.**
	Approximately 26 feet/minute.
1127	**Reached total depth of well at 1,700 feet bpl. No XY caliper tool or polyvinyl (PVC) pipe at bottom.**
1130	**Begin recording video survey up hole with 360-degree side view.**
	Approximately 14 feet/minute.
1145	**Slowed down to 12 feet/minute.**
1156	**Quick break.**

Observer's Initials HR

1212 Resume video survey.
Approximately 13 feet/minute.
1222 Forgot to start recording, now recording.
Approximately 12 feet/minute.
1242 Call with R. Cowles and N. Sharma/Stantec.
1424 Changing out cable on TV.
1428 Resume video survey.
1438 Call with R. Cowles/Stantec.
1502 Video survey tool is back up in the drill pipe at about 24 feet bpl.
1503 Complete video survey.
1510 Setting up for XY caliper log.
1538 Calibrating XY caliper tool.
1350 XY caliper tool in hole and running.
1356 Greg/SFWMD offsite.
1600 YBI recalibrating XY caliper tool.
1620 Begin XY caliper log.
1623 Call with N. Sharma/Stantec.
1640 Reached 1,702 feet bpl, running multiple passes.
1642 Coming back up hole with caliper tool at approximately 30 feet per minute.
1723 Issues with XY caliper tool not recording correctly. There is a kink in the wireline. YBI is going to try completing the log with a different XY caliper tool.
1730 YBI troubleshooting the XY caliper tool issue.
1735 H. Rahman/Stantec offsite.
1810 H. Rahman/Stantec onsite.
1820 YBI calibrating the backup XY caliper tool – issue was not the kink in the wireline.
1835 Begin running XY caliper tool.
1848 Reached total depth of ~1,700 feet bpl.
1850 Completing repeat passes.
1900 XY caliper logging up hole.
1930 XY caliper log completed.
1941 XY caliper tool out of hole.
1945 YBI preparing final XY caliper log and video survey.
2024 Waiting on approval for the XY caliper log. YBI loggers needed to make some changes and log is sent back for approval.
2120 XY caliper log final approval received.
2125 Final XY caliper logs sent out via email – hard copies received along with video survey on flash drive.
2130 H. Rahman/Stantec offsite.

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 02/28/2020
0900 - 1110

Sun	Mon	Tue	Wed	Thr	Fri	Sat
					x	

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
		x		
Wind	Still	Medium	High	
		x		
Humidity	Dry	Moderate	Humid	**Report No.**
		x		**09**

SHIFT SUMMARY

OBSERVER: Hannah Rahman and N. Sharma/Stantec

START DEPTH: 1,700 feet bpl

DRILLER: Carlos Lopez/YBI

END DEPTH: 1,700 feet bpl

ACTIVITY: Pressure test for 24-inch diameter steel casing to 1,268 feet bpl.

SUB CONTRACTORS: None.

FORMATION SAMPLES: None.

WATER SAMPLES: None.

TESTING: None.

TIME	DESCRIPTION
0850	**H. Rahman and N. Sharma/Stantec onsite. YBI already onsite.**
0855	**Call with R. Cowles/Stantec.**
0900	**YBI lowering pressure from 60 pounds per square inch (psi) to 50 psi. Pressure is set at 51.5 psi.**
0901	**Received pressure gauge calibration sheet.**
0910	**Received tubing tally and packer measurements from YBI – see photolog and field form.**
0921	**Begin pressure test on 24-inch diameter steel casing.**
1009	**Noticed tiny leak in hole connection to middle pressure gauge.**
1021	**Finished pressure test. Pressure test was less than 2% - see field form.**
1025	**Call with R. Cowles/Stantec.**
1022	**Begin pressure bleed off.**
1024	**Complete pressure bleed off – see field form.**
1026	**YBI signed pressure test field observation form. YBI is taking down packer setup for pressure test.**
1031	**Call with R. Cowles/Stantec.**
1108	**H. Rahman and N. Sharma/Stantec offsite.**

Observer's Initials HR

ØZONE
INDUSTRIES
CORPORATION
15551 PINE RIDGE ROAD
FORT MYERS, FL 33908

Certificate of Calibration

Ozone Industries, Inc.
Precision Measurement Equipment Division

Calibration Performed By:
OZONE INDUSTRIES, INC.
15551 PINE RIDGE RD.
FORT MYERS, FL 33908

Purchase Order #

For:
YOUNGQUIST BROTHERS, INC.
15465 PINE RIDGE RD.
FORT MYERS, FL 33908

EQUIPMENT INFORMATION:

Description: Pressure Guage
Manufacter: McDaniel Controls, Inc.
Model Number: FG
Part Number: FF-GF
Range: 0 - 200 psi
Serial Number: **050417**
Customer I.D.:
Cust. Barcode:
Cust. Location: Fort Myers, FL
Specifications: +/- 0.25% FS

Job Site: Okeechobee
Cal Date: 12/24/2019
Cal. Due Date: 12/24/2020
Cal. Interval Annual
Received: 12/24/2019
Calibration Result: PASS
Environmental Conditions: 76°F / 48% R.H. / 30.07 in Hg
Performed By: R.J.
Procedure: Calibration

This is to certify that the above listed instrument meets or exceeds all specifications as stated in the referenced procedure at the points tested (unless otherwise noted). It has been Calibrated using measurement standards traceable to the National Institute of Standards and Technology (NIST), or to NIST accepted intrinsic standards of measurement, or derived by the ratio type of self-calibration techniques. This calibration is in accordance with Ozone Industries, Inc Quality Assurance Manual. Any number of factors may cause the calibration item to drift out of calibration before the recommended interval has expired.

Calibration Remarks:

THIS UNIT FOUND TO BE IN TOLERANCE AT TIME OF CALIBRATION.
PERFORMED ROUTINE CALIBRATION / CERTIFICATION.

Standards Used to Calibrate Equipment:

Company	I.D.	Description	Last Cal.	Cal. Due Date
OZONE	A1731	EATON UPC5000 PNEUMATIC CALIBRATOR	2/5/2019	2/5/2020

Certified by:

Print: Robert Jodoin
Date: 12/24/2019

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OZONE
INDUSTRIES
CORPORATION

15551 PINE RIDGE ROAD
FORT MYERS, FL 33908

CONTROL NO: 12/24/2019 050417

CUSTOMER: YBI15465

PH: 239-433-3400
FAX: 239-489-3877

CALIBRATION DATA FORM

MFR:	McDaniel Controls, Inc.	**DESCRIPTION**	PRESSURE GAUGE
MODEL NO:	0 - 200 psi	**TECHNICIAN:**	0055
SERIAL NO:	050417	**CAL. DATE:**	12/24/2019
CUST. ID:	YBI	**DUE DATE:**	12/24/2020

RANGE: 0 - 200 psi

Guage Reading	**Reference Reading**	**LOW LIMIT**	**HIGH LIMIT**	% ERR.
0.0	0.00	-1.0	1.0	0.00
40.0	39.70	39.0	41.0	0.15
80.0	80.15	79.0	81.0	0.08
120.0	120.40	119.0	121.0	0.20
160.0	160.20	159.0	161.0	0.10
200.0	199.55	199.0	201.0	0.22

L-63N MIT

DATE: February 28, 2020

Lake Okeechobee ASR Project

JOB NUMBER:

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

DESCRIPTION OF OPERATIONS: Pressure test for 24-inch diameter steel casing installed to 1,268 feet bpl (center of packer at 1,246.3 feet bpl).

START TIME: 9:21

FINISH TIME: 10:21

CASING SIZE: 24-inch Outside Diameter

INITIAL PRESSURE: 51.5

GAUGE SERIAL NUMBER: 050417

CALCULATED WATER VOLUME: 6.9 gallons

OBSERVED WATER VOLUME: 6.5 gallons

TIME	MINUTES	PRESSURE (psi)	COMMENTS
9:21	0	51.50	Start test
9:26	5	51.50	
9:31	10	51.50	
9:36	15	51.25	
9:41	20	51.25	
9:46	25	51.25	
9:51	30	51.00	
9:56	35	51.00	
10:01	40	51.00	
10:06	45	50.75	
10:11	50	50.75	
10:16	55	50.5	
10:21	60	50.5	End test - pressure loss is 1.9%

PRESSSURE BLEED-OFF

TIME	PRESSURE	VOLUME OF WATER COLLECTED (GAL)	CUMULATIVE VOLUME (GAL)
10:22	30		
10:23	10	4	4
10:23	14.5	1	5
10:24	3	1	6
10:24	5	0.5	6.5
*Note: YBI stopped and dumped out first 5 gallon bucket of water.			
*Note: Per YBI, pressure gauge can't go to 0 psi, otherwise it will break.			

Witnessed By:

FDEP Representative

Stantec Representative Nyrole D. Sharma

YBI Representative Carlos Lopes

Photographic Log

Client Name: **SFWMD**

Date: **February 24 - 28, 2020**

Site Location: **SFWMD L-63N MIT, Okeechobee, FL**

Activity: **L-63N MIT**

Project No. **177311456**

Photo No.
1

Date
2/24/2020

Photographer
Hannah Rahman

Description

Camera tool used in the final video survey.

Photo No.
2

Date
2/24/2020

Photographer
Hannah Rahman

Description

Youngquist Brothers Inc., (YBI) completing the final video survey for L-63N ASR well.

Photo No.

3

Date

2/24/2020

Photographer

Hannah Rahman

Description

YBI setting up for the XY caliper log.

Photo No.

4

Date

2/24/2020

Photographer

Hannah Rahman

Description

YBI preparing for the XY caliper log.

Stantec

Photo No.
5

Date
2/24/2020

Photographer
Hannah Rahman

Description

Backup XY caliper tool.

Photo No.
6

Date
2/28/2020

Photographer
Hannah Rahman

Description

Pressure gauge calibrated sticker and initial pressure reading of 51.5 psi (pounds per square inch).

Stantec

Photo No.
7

Date
2/28/2020

Photographer
Hannah Rahman

Description

L-63N ASR well setup for pressure test of the 24-inch diameter steel casing to 1,268 feet below pad level (bpl). The center of the packer is set at 1,246.30 feet bpl.

Stantec

Photo No.
8

Date
2/28/2020

Photographer
Hannah Rahman

Description

Sketch of packer and measurements.

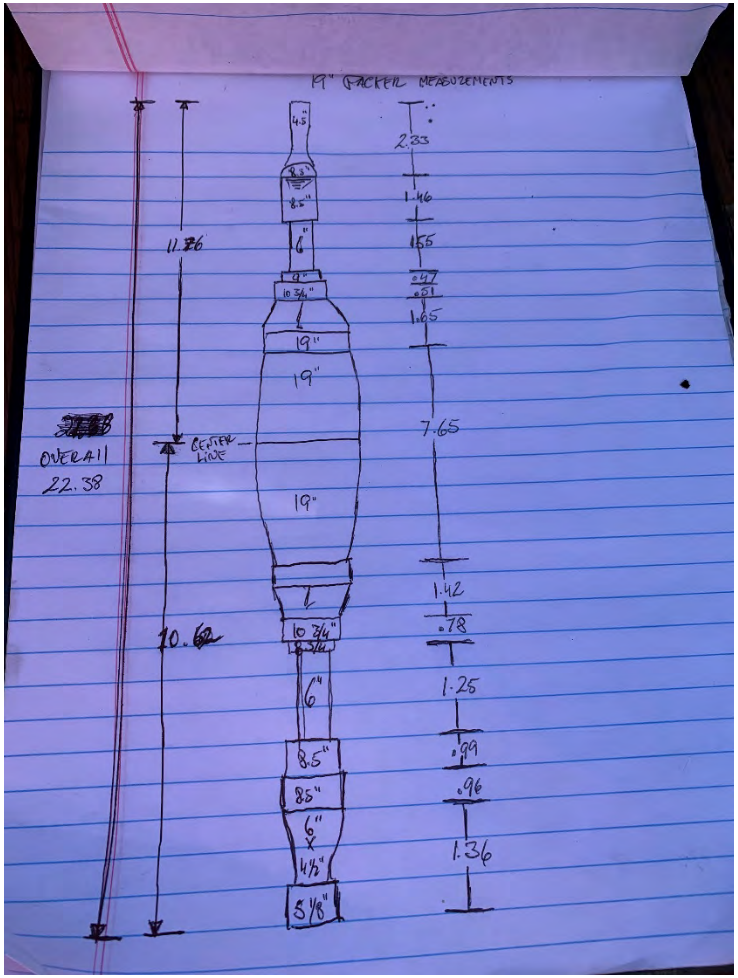


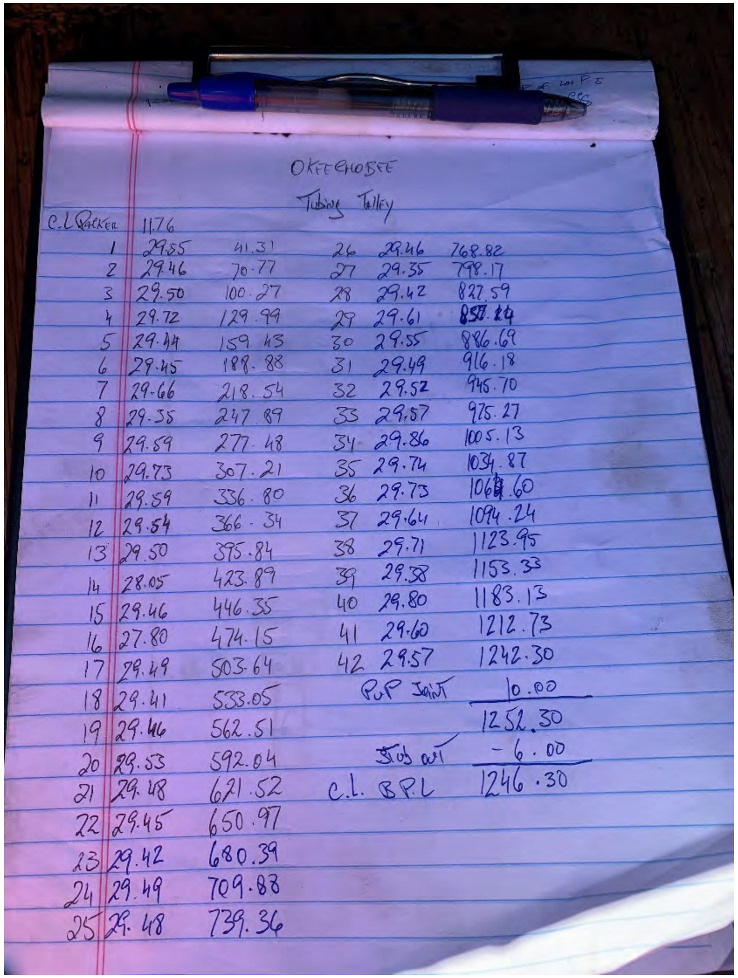
Photo No.
9

Date
2/28/2020

Photographer
Hannah Rahman

Description

Tubing tally for L-63N ASR casing pressure test.



OKEECHOBEE

Tubing Talley

C.L Packer	11.76				
1	29.55	41.31	26	29.46	768.82
2	29.46	70.77	27	29.35	798.17
3	29.50	100.27	28	29.42	827.59
4	29.72	129.99	29	29.61	857.20
5	29.44	159.43	30	29.55	886.69
6	29.45	188.88	31	29.49	916.18
7	29.66	218.54	32	29.52	945.70
8	29.35	247.89	33	29.57	975.27
9	29.59	277.48	34	29.86	1005.13
10	29.73	307.21	35	29.74	1034.87
11	29.59	336.80	36	29.73	1064.60
12	29.54	366.34	37	29.64	1094.24
13	29.50	395.84	38	29.71	1123.95
14	28.05	423.89	39	29.38	1153.33
15	29.46	446.35	40	29.80	1183.13
16	27.80	474.15	41	29.60	1212.73
17	29.49	503.64	42	29.57	1242.30
18	29.41	533.05	PuP Joint		10.00
19	29.46	562.51			1252.30
20	29.53	592.04	Stub out		-6.00
21	29.48	621.52	C.L. BPL		1246.30
22	29.45	650.97			
23	29.42	680.39			
24	29.49	709.88			
25	29.48	739.36			

X-Y CALIPER LOG

Company SFWMD LOWRP
Well L-63N ASR
Field TAYLOR CREEK
County OKEECHOBEE
State FL

Company SFWMD LOWRP
Well L-63N ASR
Field TAYLOR CREEK
County OKEECHOBEE State FL
Location: API # :
4019 SR 710 EAST OKEECHOBEE, FL
SEC TWP RGE
Other Services
SEE COMMENTS

Permanent Datum Elevation
Log Measured From
Drilling Measured From

Elevation
K.B.
D.F.
G.L.

Date	2/24/2020
Run Number	ONE
Depth Driller	1700'
Depth Logger	1700'
Bottom Logged Interval	1700'
Top Log Interval	1150'
Open Hole Size	17.5"
Type Fluid	H20
Density / Viscosity	N/A
Max. Recorded Temp.	N/A
Estimated Cement Top	N/A
Time Well Ready	10:00
Time Logger on Bottom	12:00
Equipment Number	107
Location	FT. MYERS
Recorded By	R.GARCIA K.BOBLITT
Witnessed By	H.RAHMAN

Borehole Record				Tubing Record		
Run Number	Bit	From	To	Size	Weight	From	To
ONE	17.5"	1268'	1700'				

Casing Record	Size	Wgt/Ft	Top	Bottom
Surface String	42"	.500" W.T.	0'	65'
Prot. String	34"	.500" W.T.	0'	200'
Production String	24"	.500" W.T.	0'	1268'
Liner				

<<< Fold Here >>>

Comments

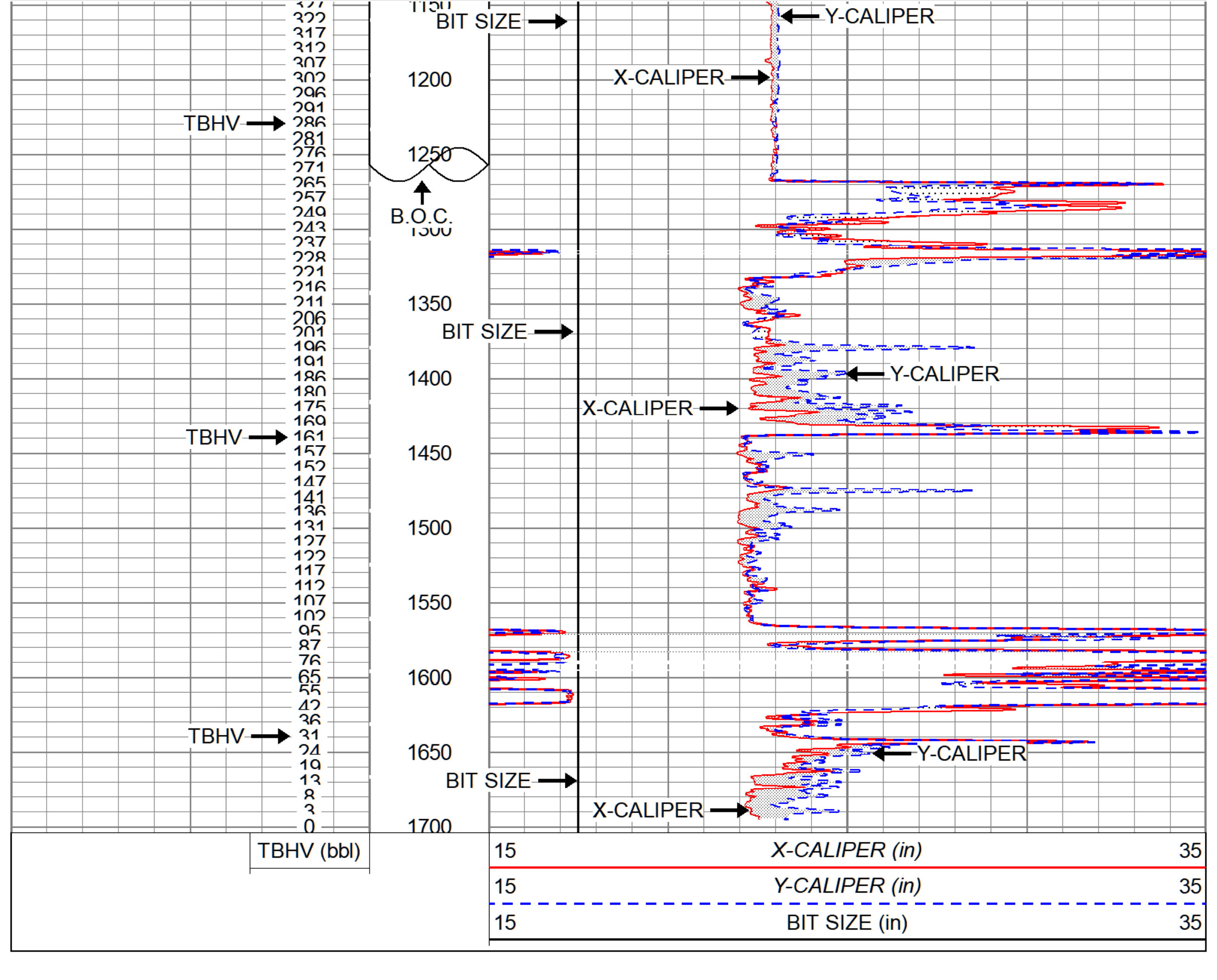
OTHER SERVICES:

VIDEO SURVEY

MAX CALIPER ARM = 36"

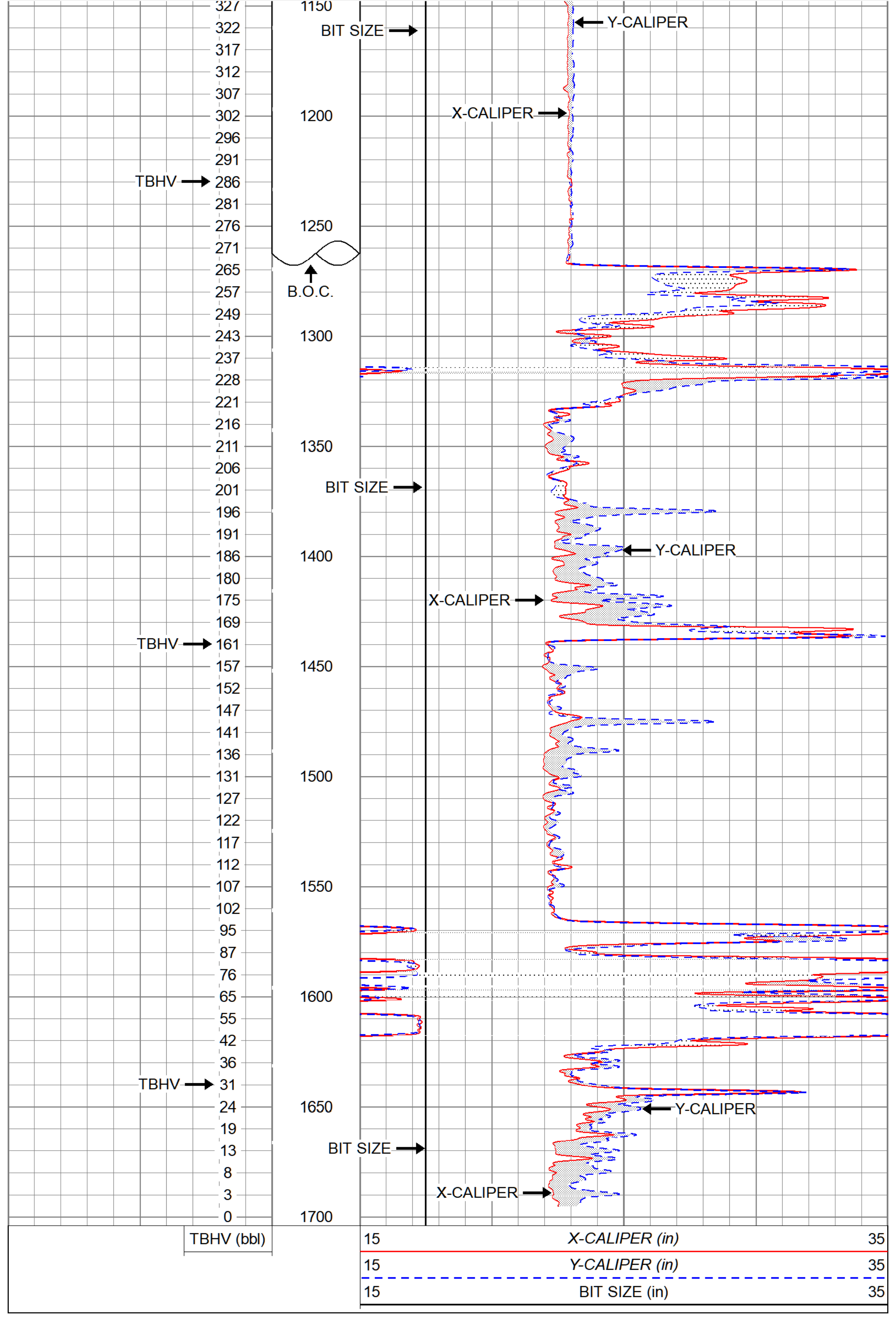
MAIN PASS

Database File sfwmd-l-63n.db
Dataset Pathname XYC5.2
Presentation Format grxyc
Dataset Creation Mon Feb 24 20:40:02 2020
Charted by Depth in Feet scaled 1:1200



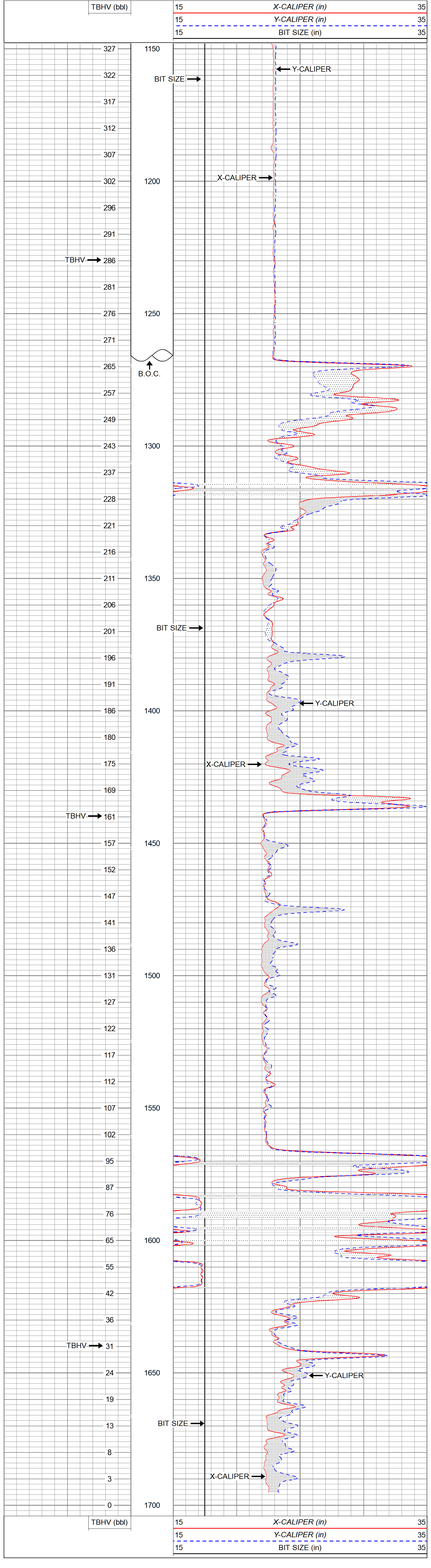
MAIN PASS

Database File sfwmd-l-63n.db
Dataset Pathname XYC5.2
Presentation Format grxyc
Dataset Creation Mon Feb 24 20:40:02 2020
Charted by Depth in Feet scaled 1:600



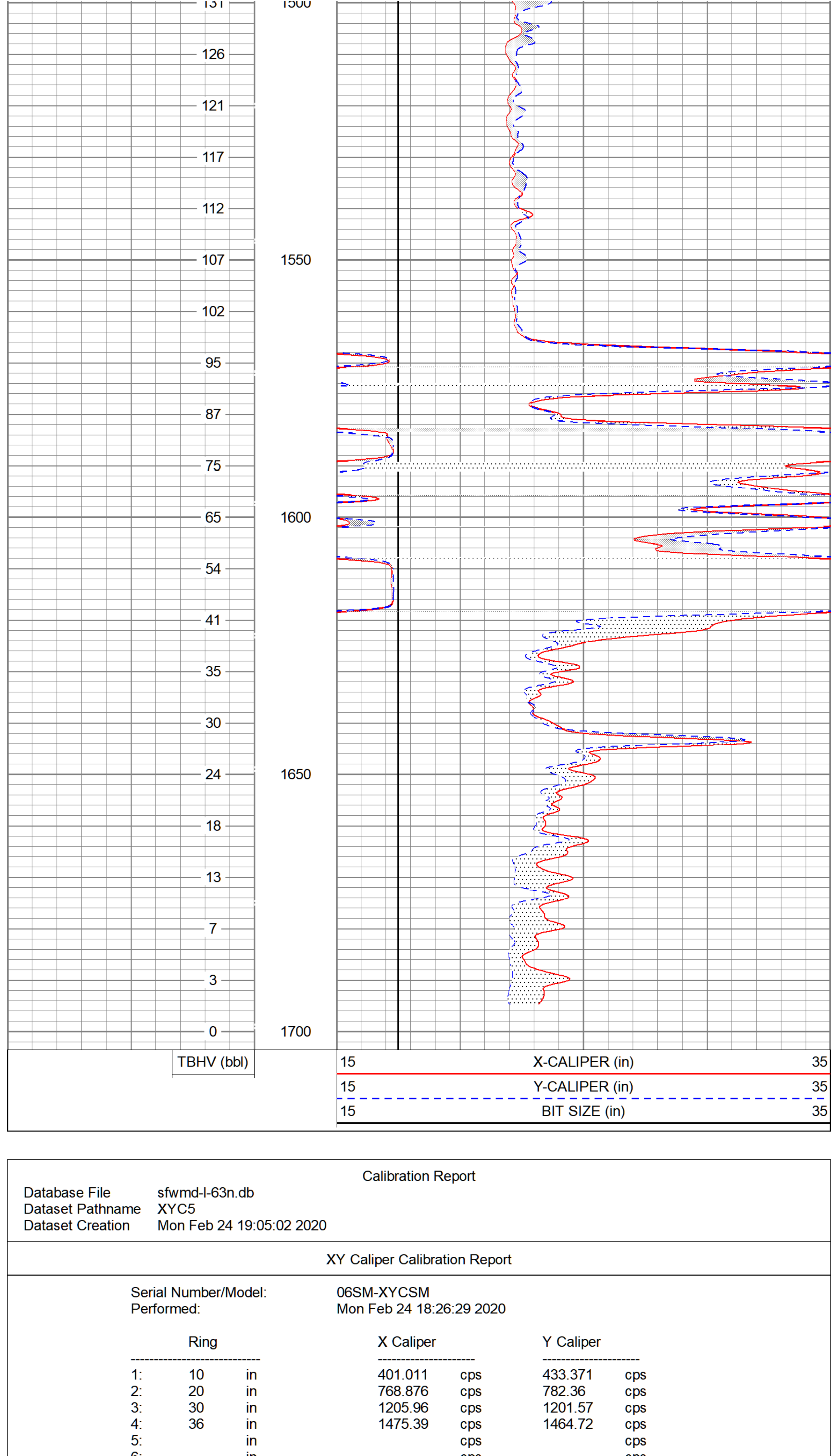
MAIN PASS

Database File sfwmd-l-63n.db
Dataset Pathname XYC5.2
Presentation Format grxyc
Dataset Creation Mon Feb 24 20:40:02 2020
Charted by Depth in Feet scaled 1:240



REPEAT PASS

Database File sfwmd-l-63n.db
Dataset Pathname XYC4.2
Presentation Format grxyc
Dataset Creation Mon Feb 24 20:40:29 2020
Charted by Depth in Feet scaled 1:240



Calibration Report

Database File sfwmd-l-63n.db
Dataset Pathname XYC5
Dataset Creation Mon Feb 24 19:05:02 2020

XY Caliper Calibration Report

Serial Number/Model: 06SM-XYCSM
Performed: Mon Feb 24 18:26:29 2020

Ring			X Caliper		Y Caliper	
1:	10	in	401.011	cps	433.371	cps
2:	20	in	768.876	cps	782.36	cps
3:	30	in	1205.96	cps	1201.57	cps
4:	36	in	1475.39	cps	1464.72	cps
5:		in		cps		cps
6:		in		cps		cps
7:		in		cps		cps
8:		in		cps		cps
9:		in		cps		cps
10:		in		cps		cps

Sensor	Offset (ft)	Schematic	Description	Length (ft)	O.D. (in)	Weight (lb
			CHD-StdCHD	1.00	1.69	10.00
YCAL XCAL	3.50 3.50		XYC-XYCSM (06SM)	6.60	3.50	87.00

Dataset: sfwmd-l-63n.db: field/well/run1/XYC5
Total length: 7.60 ft
Total weight: 97.00 lb
O.D.: 3.50 in

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/10/20
Day of Week:	Monday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
4:45	5		Collect material
5	7		Mobilize to site
7	10		Regen rig, set traps, finish discharge line
10	11:15		Trip to 400', prep to flush down well
11:15	2		Flush well, rig up logger
2	4		Run VIDEO (SEE CALIPER TOOL AT 1599' DEPTH)
4	6		Rig down logger, TRIP OUT CAMERA, clean up site

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	11	No
[redacted]	[redacted]	No
Dennis Hurtado	11	No
Kenny Smith	13.15	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

YOUNGQUIST BROTHERS

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/11/20
Day of Week:	Tuesday

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7			Pump salt kill down drill pipe, [illegible] /
			pull drill pipe out of hole/replace
			subsaver, get fuel, break down subs
	4		on wire brush, organize site
4	6:15		Mobilize to Lehigh to get 2ND FISHING TOOL
6:15	8		Mobilize to site WITH FISHING TOOL

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	9	No
Kenny Smith	13	No
Dennis Hurtado	7	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/12/20
Day of Week:	Wedensday

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	8:30		Test tool / tool up and prep to trip in
8:30	3:30		Trip in tool to 1580' TO GRAB CALIPER TOOL
3:30	8		Rig up logger / run down camera / * pull
			camera out of hole / pack up site
		*	(BUMPED CALIPER TOOL & KNOCKED IT DOWN HOLE)
12:30	8 PM		RAFAEL SENT FROM FT MYERS TO
			HELP ROSS IN OKEECHOBEE

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Acnerud	13	No.
Kenny Smith	13	No
Dennis Hurtado	13	No.
RAFAEL GUTIERREZ	7.5	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/13/20
Day of Week:	Thursday

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	22"
STRING WT.	
BIT TYPE	BUTTON

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7	3		Regen rig / rig down logger / Trip out of hole / Change subsaver
3	6:30		Tool up bit / trip in bit to 73' / Seal up well /

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	11.5	No
Kenny Smith	11.5	No
Dennis Hurtado	11.5	No
Rafael Gutierrez	11.5	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/14/20
Day of Week:	Friday

YOUNGQUIST BROTHERS

LAST CASTING TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTARY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE / NUMBER	22"
STABIL. AT	
BIT TYPE	Button

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7	11		Trip into 1272'
11			Trip in Airline/reamed from 1265' to 1293'
			Adjust swivel on tophead/Kill drill pipe/
			Trip airline out of hole Trip out to
	6:30		412'/ seal well
6:30	8:30		Mobilize to shop
8:30	9		Load material

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
			22" BIT DRILLING NEW (LARGER HOLE)
			FROM BOTTOM OF CASING DOWN TO
			1293 FEET DEPTH - CALLED RICK COWLES
			& HE AGREED WE COULD SWITCH TO
			17½" BIT

DRILLING CREW PAYROLL DATA

DAY TOUR		
NAME	HOURS	LUNCH
Ross Aanerud	11.5	No
Kenny Smith	14	No
Dennis Hurtado	11.5	No
Rafael Gutierrez	9	No

NIGHT TOUR		
NAME	HOURS	LUNCH

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATION

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/15/20
Day of Week:	Saturday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	17 1/2
STRING WT.	
BIT TYPE	Button

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
4:45	7		Mobilize to site / get fuel for rig
7	9:15		Trip out of hole / breakdown BHA
9:15	9:45		Tool up BHA / Trip into 50'
9:45	10:15		Replace subsaver
10:15			Trip into 1450' / strip header over drill
	3		pipe / put on rubber can / seal well /
3	5:30		Mobilize to shop

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	8.5	No
[illegible]	[illegible]	[illegible]
Dennis Hurtado	8	No
Kenny Smith	12.75	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/24/20
Day of Week:	Monday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
5	7		Mobilize to site
7	10:15		Pump / Develop well / rig up logger
10:15	3		Run log video
3	8		Run caliper log
8	9:30		Rig down logger / clean site / upload video

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	16.5	No
Kenny Smith	16.5	No
Brad Bennett	13	No
Danny Atkisson	13.5	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/25/20
Day of Week:	Tuesday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7			Kill well w/ 3 bags of salt/ put on new
			24in flange/clean tanker/ Fill tanker, empty
			settling tank / Start emptying other settling
	4:30		tanks / organize site

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	9.5	No
Kenny Smith	9.5	No.
Brad Bennett	9.5	No.
Danny Atkisson	9.5	No.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	2/26/20
Day of Week:	Wedensday

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7			Rig down rig / pull off of hole / pull
			settling tanks out / Put drill pipe in racks /
			fuel equipment / put crane over hole /
			unload GIW and material / load tank onto
			trailer / Set MIT trailer up on hole /
	6		set up to trip packer into hole

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
3:30pm	6pm		Drive tanker to pit
600	6:30		Empty / clean tanker
6:30	7		Drive tanker to yard

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

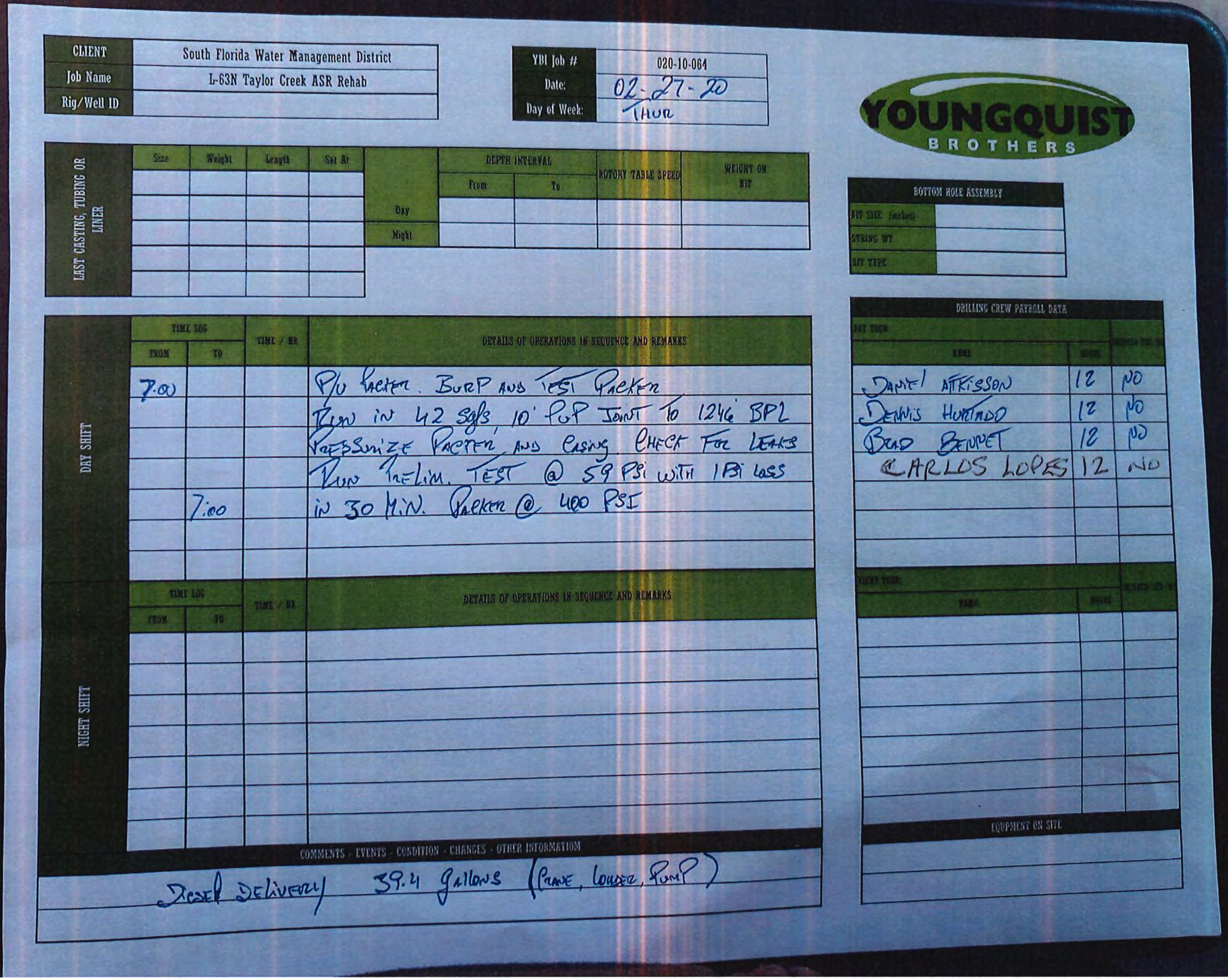
DAY TOUR:

NAME	HOURS	INJURED YES/NO
Ross Aanerud	10	No
Kenny Smith	12	No
Brad Bennett	11	No
Danny Atkisson	11	No

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

EQUIPMENT ON SITE



CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	02-27-20
Day of Week:	THUR

YOUNGQUIST BROTHERS

LAST CASING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00			P/U Packer. Burp and Test Packer
			Run in 42 sgls, 10' PuP Joint To 1246' BPL
			Pressurize Packer and Casing. Check For Leaks
			Run Prelim. Test @ 59 PSi with 1 PSi loss
	7:00		in 30 Min. Packer @ 400 PSI

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	[illegible]
Daniel Atkisson	12	NO
Dennis Hurtado	12	NO
Brad Bennet	12	NO
CARLOS LOPES	12	NO

NIGHT TOUR:

NAME	HOURS	[illegible]

EQUIPMENT ON SITE

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

Diesel Delivery 39.4 gallons (Crane, Loader, Pump)

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Friday, February 28, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		Safety meeting. Service Crane
	7:30	9:20		Run preliminary test @ 51.5 psi. WOE. Stantec Representatives on site.
	9:20	10:20		run Pressure test @51.5 psi. passed test with 1psi loss
	10:20			Deflate Packer. TOOH. L/D packer and secure well with 24x6 with 6" valve.
				Off load truck with 16"pipe rack and misc. parts for pump test. Move MIT trailer from well area.
				Load up truck with open top tank. Continue rig down and removal of all equipment related to
		7:00		packer testing. Place GIW pump on well pad.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO
NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUPMENT ON SITE

Stantec

Memo

To:	SFWMD South Florida Water Management District	From:	Rick Cowles Stantec
File:	Lake Okeechobee ASR Project L-63N MIT Weekly Progress Report	Date:	March 9, 2020

Work Completed to Date:

From Monday, March 2, 2020, through Wednesday, March 4, 2020, Youngquist Brothers Inc. (YBI) setup for the 12-hour step-rate pumping test. On Thursday, March 5, 2020, Stantec personnel were onsite to observe the 12-hour step-rate pumping test. Upon inspection of the setup, it was determined that the pump would need to be reconfigured and a drop pipe added to perform at the target pump rate of 6,500 gallons per minute (gpm) with a maximum of 8,000 gpm. In additional the setup for the discharge pond and the canal would need to be changed. YBI also began work to obtain a National Pollutant Discharge Elimination System (NPDES) permit for possible discharge into the canal.

The following attachments are included in this weekly summary report:

- Stantec Daily Reports
- Daily Photo Logs
- Updated Signed Pressure Test Log

Work to be Completed through Next Period

Once YBI has the NPDES permit and the system (pump, discharge lines, etc.) reconfigured, it is anticipated that the 12-hour step-rate pumping test (consisting of 3, four-hour long steps) will occur towards the end of the week. YBI's daily reports will be included in the next weekly progress report.

Note: The pipe tally for the pressure test was reported incorrectly. The tally was reported to be 1,246.30, and the actual tally is 1,253.36.

Stantec Consulting Services Inc.

Rick Cowles, PG
Senior Hydrogeologist/Senior Associate

Phone: 941-266-3917

Attachment: Attachment

c.	C.C.	Jennifer Gent/SFWMD	(jgent@sfwmd.gov)
		Robert Verrastro/SFWMD	(bverras@sfwmd.gov)
		Neil Johnson/Stantec	(Neil.Johnson@stantec.com)
		Cora Summerfield/Stantec	(cora.summerfield@stantec.com)
		Nycole Sharma/Stantec	(Nycole.sharma@stantec.com)
		Hannah Rahman/Stantec	(hannah.rahman@stantec.com)

Heath Wintz/Stantec	(Heath.Wintz@stantec.com)
Jeovanni Ayala-Lugo/Stantec	(jeovanni.ayala-lugo@stantec.com)

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 03/05/2020
0700 - 0830

Sun	Mon	Tue	Wed	Thr	Fri	Sat
				x		

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			x	
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
		x		**10**

SHIFT SUMMARY

OBSERVER: H. Rahman and C. Summerfield/Stantec

START DEPTH: 1,700 feet bpl

DRILLER: Carlos Lopez/YBI

END DEPTH: 1,700 feet bpl

ACTIVITY: 12-hour Step-Rate Pumping Test.

SUB CONTRACTORS: None.

FORMATION SAMPLES: None.

WATER SAMPLES: None.

TESTING: None.

TIME	DESCRIPTION
0700	**H. Rahman and C. Summerfield/Stantec onsite. YBI already onsite.**
0720	**Begin setting pump rate for first step at 2,167 gallons per minute (gpm).**
0727	**Spoke to YBI, they said the pump is in high gear.**
0735	**Pump is set at approximately 2,167 gpm.**
0742	**Begin Step 1 of Step-Rate Pumping Test.**
0743	**Computers are logging transducer data. YBI has two transducers sitting one on top of the other.**
0800	**C. Lopez/YBI onsite.**
0805	**R. Cowles/Stantec onsite.**
0810	**Discussed how the pump can't pump at high enough rates, how there isn't enough drawdown, and what to do about discharge water in regard to the canal and discharge pond.**
0820	**R. Cowles/Stantec offsite.**
0830	**H. Rahman and C. Summerfield/Stantec offsite.**

Observer's Initials HR & CS

Photographic Log

Client Name: **SFWMD**

Date: **March 5, 2020**

Site Location: **SFWMD L-63N MIT, Okeechobee, FL**

Activity: **L-63N MIT Video logging**

Project No. **177311456**

Photo No.
1

Date
3/5/2020

Photographer
Hannah Rahman

Description

Totalizer to be used for the L-63N Step-Rate Pumping Test.

Stantec

Photo No.
2

Date
3/5/2020

Photographer
Hannah Rahman

Description

Discharge pond to be used in the L-63N Step-Rate Pumping Test.

Photo No.

3

Date

3/5/2020

Photographer

Hannah Rahman

Description

Pump onsite for the L-63N Step-Rate Pumping Test.

Photo No.
4

Date
3/5/2020

Photographer
Hannah Rahman

Description

Data logger setup.

Stantec

L-63N MIT

DATE: February 28, 2020

Lake Okeechobee ASR Project

JOB NUMBER:

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

DESCRIPTION OF OPERATIONS: Pressure test for 24-inch diameter steel casing.
Center of packer installed to 1,253.36 feet bpl.

START TIME: 9:21
FINISH TIME: 10:21
CASING SIZE: 24-inch Outside Diameter

INITIAL PRESSURE: 51.5
GAUGE SERIAL NUMBER: 050417
CALCULATED WATER VOLUME: 6.8 gallons
OBSERVED WATER VOLUME: 6.5 gallons

TIME	MINUTES	PRESSURE (psi)	COMMENTS
9:21	0	51.50	Start test
9:26	5	51.50	
9:31	10	51.50	
9:36	15	51.25	
9:41	20	51.25	
9:46	25	51.25	
9:51	30	51.00	
9:56	35	51.00	
10:01	40	51.00	
10:06	45	50.75	
10:11	50	50.75	
10:16	55	50.5	
10:21	60	50.5	End test - pressure loss is 1.9%

PRESSSURE BLEED-OFF			
TIME	PRESSURE	VOLUME OF WATER COLLECTED (GAL)	CUMULATIVE VOLUME (GAL)
10:22	30		
10:23	10	4	4
10:23	14.5	1	5
10:24	3	1	6
10:24	5	0.5	6.5
*Note: YBI stopped and dumped out first 5 gallon bucket of water.			
*Note: Per YBI, pressure gauge can't go to 0 psi, otherwise it will break.			

Witnessed By:

FDEP Representative

Stantec Representative Nyrde D. Sharma

YBI Representative Carlos Lopes

Stantec

Memo

To:	SFWMD South Florida Water Management District	From:	Rick Cowles Stantec
File:	Lake Okeechobee ASR Project L-63N MIT Weekly Progress Report	Date:	March 16, 2020

Work Completed to Date:

From Monday, March 9, 2020, through Friday, March 13, 2020, Youngquist Brothers Inc. (YBI) setup for the 12-hour step-rate pumping test. On Friday, March 13, 2020, YBI obtained a National Pollutant Discharge Elimination System (NPDES) permit for possible discharge into the canal.

The following attachments are included in this weekly summary report:

- YBI Daily Reports

Work to be Completed through Next Period

Once YBI has the NPDES permit and the system (pump, discharge lines, etc.) reconfigured, it is anticipated that the 12-hour step-rate pumping test (consisting of 3, four-hour long steps) will occur towards the end of the week.

Stantec Consulting Services Inc.

Rick Cowles, PG
Senior Hydrogeologist/Senior Associate

Phone: 941-266-3917

Attachment: Attachment

c.	C.C.	Jennifer Gent/SFWMD	(jgent@sfwmd.gov)
		Robert Verrastro/SFWMD	(bverras@sfwmd.gov)
		Neil Johnson/Stantec	(Neil.Johnson@stantec.com)
		Cora Summerfield/Stantec	(cora.summerfield@stantec.com)
		Nycole Sharma/Stantec	(Nycole.sharma@stantec.com)
		Hannah Rahman/Stantec	(hannah.rahman@stantec.com)
		Heath Wintz/Stantec	(Heath.Wintz@stantec.com)
		Jeovanni Ayala-Lugo/Stantec	(jeovanni.ayala-lugo@stantec.com)

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Monday, March 2, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00			Safety meeting. Service equipment
				Continue plumbing 16" pipe to pond area.
				disconnct 8" discharge line and had welder correcting angle of flange. Reeinstall.
				weld 2" coupling on well head plate (still well inlet)
		7:00		Receive 500 gls of diesel fuel. Place diesel tank in work area adjacent to GIW.

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Tuesday, March 3, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		Safety meeting. Service equipment
				Continue to plumb in 16" pipeline. Connect fuel tank to GIW and run motor on idle for 5 min.
				Install 1.5" still well at 80' in depth. Run transducers to 75' BPL, connect computers and ready
		7:00		system to bring well alive.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	6	no
Brad Bennet	12	no
CARLOS LOPES	12	NO
NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Wednesday, March 4, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		safety meeting. Service equipment
				replace damaged 8" butterfly valve on discharge side of GIW.
				pump well alive into tanker and haul away.
				flood system and check for leaks. Conduct prelim. Pump test
				GIW cavitating at 5000 GPM, free flow at 1000GPM, pumping steady 4000GPM at idle in low gear
		7:00		close well in for the night.
				Per Mike Wilson, we are waiting for a Permit before stantec allow us to proceed.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

Dennis Hurtado fell off GIW suction rubber pipe where he was sitting on while tightning flange bolts. (40" high fall)

Upon being asked if he was ok, he stated he was "just fine" and there was no problem.

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	10	?
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Thursday, March 5, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		Safety meeting. Service Equipment.
	7:30			Pump water to pond. Establish flow rate at iddle speed on Low gear open discharge 4800 GPM.
				pump cavitates at 5000GPM. level @ pond reached max accepted level after 2 hours of pumping
				(552000 gls pumped) Outfall to canal doesn't keep up with GIW. Per Stantec, Ybi is to install an
		3:00		additional pump on pond to pump out to canal and help water levels.
	3:00			Per Tim youngquist, kill well and remove suction hose from GIW and inspect impeler and volute.
		7:00		check gear ratio between impeler and transmission RPM.

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
Carlos Lopes	12	NO

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Friday, March 6, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00			Crew on site. Carlos .Trouble shoot GIW impeler and volute via video With Tim Youngquist.
			Inspect well head assembly for possible suction leaks. Fabricate Gasket for 10" pump suction and
			reassemble suction hose with 12" butterfly valve onto well head.
			Tap into 16" yellow mine pipe and install sand sampler. Seal pump shaft and all flanges with
			gel, install vacuum gauge. Ready to bring well alive. Organize equipment for demob. load out.
			Per cameron webster get measurements on well head.
	7:00		New header pipe being worked on at the shop. W.O.O

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
			Per Harvey youngquist and Ravi, Tadano crane is to be removed from site and sent back to
			rock pit.

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Saturday, March 7, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		Safety meeting. Service equipment
7:30			cntinue to organize demob. Equipment ready to go
			Off load truck with John Deere pump, kelley hoses, loader extension arm, and modified well
			head. Remove spool piece, tee, 6" valve. Install stilling well pipe on new head piece. Cut out 1.5"
			hole doesn't fit in 24" well. Remove all and secure well for the night. Reload header piece and
	7:00		send back to shop.

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

Stantec

Memo

To:	SFWMD South Florida Water Management District	From:	Rick Cowles Stantec
File:	Lake Okeechobee ASR Project L-63N MIT Weekly Progress Report	Date:	March 23, 2020

Work Completed to Date:

From Monday, March 16, 2020, through Thursday, March 19, 2020, Youngquist Brothers Inc. (YBI) setup for the 12-hour step-rate pumping test. On Friday, March 20, 2020, YBI began the 12-hour step-rate pumping test, but approximately 30 minutes into Step 1 (approximately 2,000 gallons per minute) it was observed that the discharge line leading into the canal was eroding the canal embankment and the 12-hour step test was halted until YBI could extend the discharge line further into the canal, away from the canal bank. YBI will also add a floating silt fence to help control the turbidity at the point of discharge.

The following attachments are included in this weekly summary report:

- Stantec Daily Report
- YBI Daily Reports

Work to be Completed through Next Period

The 12-hour step-rate pumping test (consisting of 3, four-hour long steps) is anticipated to occur Monday,

March 23, 2020. **Stantec Consulting Services Inc.**

Rick Cowles, PG
Senior Hydrogeologist/Senior Associate

Phone: 941-266-3917

Attachment: Attachment

c.	C.C.	Jennifer Gent/SFWMD	(jgent@sfwmd.gov)
		Robert Verrastro/SFWMD	(bverras@sfwmd.gov)
		Neil Johnson/Stantec	(Neil.Johnson@stantec.com)
		Cora Summerfield/Stantec	(cora.summerfield@stantec.com)
		Nycole Sharma/Stantec	(Nycole.sharma@stantec.com)
		Hannah Rahman/Stantec	(hannah.rahman@stantec.com)
		Heath Wintz/Stantec	(Heath.Wintz@stantec.com)
		Jeovanni Ayala-Lugo/Stantec	(jeovanni.ayala-lugo@stantec.com)

Stantec

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 03/20/2020
0700 - 1100

Sun	Mon	Tue	Wed	Thr	Fri	Sat
					x	

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	X
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**12**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec and Cora Summerfield/Stantec

START DEPTH:

DRILLER: Danny/YBI

END DEPTH:

ACTIVITY: Step-Rate Pumping Test

SUB CONTRACTORS: None.

FORMATION SAMPLES: None.

WATER SAMPLES: None.

TESTING: None.

TIME	DESCRIPTION
0640	**H. Rahman/Stantec onsite. YBI already onsite.**
0650	**Call with C. Summerfield/Stantec.**
0705	**H. Rahman/Stantec informed that 7,000 gallons per minute (gpm) pumping rate was sustained for over 3 hours on March 19, 2020, without any issue with drawdown.**
0718	**C. Summerfield/Stantec onsite.**
0725	**R. Cowles/Stantec onsite.**
0730	**Stepped the test from background into Step 1.**
0731	**YBI starting pump.**
0732	**Begin Step 1.**
0734	**Pumping rate at 2,000 gpm. Totalizer at 721.5 gallons.**
0740	**Water quality sample taken.**
0749	**Pumping rate at 2,400 gpm.**
0754	**Pumping rate at 2,400 gpm.**
0803	**YBI shutting down test to fix issue with discharge area.**
0845	**R. Cowles/Stantec call South Florida Water Management District to inform of delay.**
0930	**YBI still working on fixing discharge to the canal but adding a polyvinyl chloride (PVC) pipe to allow water to discharge further out into the canal as to prevent bank erosion.**
0935	**Transducer not set up correctly and needs to be adjusted.**

Observer's Initials HR/CS

0945	**Connecting the PVC pipe to existing pipe did not work. Discharge water is still hitting the bank of the canal. YBI to see if they can extend further into canal and will need to add silt fence and re-sod the bank after the test.**
0955	**R. Cowles/Stantec calls M. Wilson/YBI.**
1002	**R. Cowles/Stantec calls M. Wilson/YBI. Decision made to postpone testing till Monday, March 23, 2020.**
1015	**R. Cowles/Stantec offsite.**
1040	**YBI shows H. Rahman/Stantec and C. Summerfield/Stantec improved discharge pipe to canal.**
1042	**Call with R. Cowles/Stantec.**
1046	**Call with R. Cowles/Stantec.**
1050	**YBI waiting on silt fence equipment. C. Summerfield/Stantec and H. Rahman/Stantec offsite.**

Observer's Initials **HR/CS**

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Monday, March 9, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Service equipment
7:30			install John deere pump and run kelley hoses from pond to canal.
			remove well cover. Install 12" sweep header with stilling well. Move GIW to accommodate new
			angle. Install 6" gate valve. Install transducers 18' BPL reprogram computers for new test
			Bring well alive and pump 320000 gls of water. GIW will not pump more than 2800GPM and cav.
			Prime pond pump and flood kelley hoses. No leaks. Head on well at 7'30.
	6:00		shut in transducer read out at 24', drawdown to 21' while running

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	11	
Dennis Hurtado	11	
Brad Bennet	11	
CARLOS LOPES	11	NO

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Tuesday, March 10, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Service equipment
7:30			Kill well (1 tank of water, 1/2 bag salt) pull 12" header out . Move GIW pump to new alignment
			install 12" drop pipe header. Discharge pipe too short. Call for welder. Continue to demobe equip.
			to ship out. Make up flange bolts and pump suction. Install transducers 18' BPL . Pump well alive
			. Transducers reading 24' w/ well closed in. Flowing 3750 gpm @970 RPM. Drawdown to 19'
			Manometer tube 7' 5 shut in and 3'1/2 pumping (right on bottom of suction pipe).
	7:00		pumped 200.000 gls water and no improvement. Call Cameron. Secure well for the night.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Wednesday, March 11, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		afety meeting. Service equipment.
7:30			contact office video chat and trouble shoot with Tim, Harvey,Cameron, Mike
			Prime GIW once again and raise end of 16" discharge line 7' above ground level.
			establisha step pump rate of 450 rpm @3800GPM 7' draw down, 900 rpm @5250gpm,
			1100 rpm between 5250 and 5750 Gpm, 1300 rpm between 5250 and 5750 with 14' drawdown.
			1550 rpm (pump maxed out) no change in GPM or drawdown. Vacuum gauge at -16 to -25 inches
	7:00		continue developing well at 5000gpm. W.O.O. continue demob, site clean up.

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

Continue to onitor gopher Tortoise holes twice per day. No presence noted so far.

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Thursday, March 12, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASING, TUBING OR LINER			
Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Service equipment.
7:30			W.O.O. Continue demob work. Office decided on changing set up and use 2 pumps.
			load truck to go back to shop. Organize MIT trailer.
	5:00		Kill well to remove well head.

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	10	no
Dennis Hurtado	10	no
Brad Bennet	10	no
CARLOS LOPES	10	NO

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Friday, March 13, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		Safety meeting. Service equipment. Tortoise training.
				Uninstall drop pipe header
				secure well with 24"x 6" flange. Instal 6" gate valve.
				site clean out and repir silt fence. Tortoisee watch in AM and PM. No sightings
		5:00		W.O. new drop pipe header 16"x doble suction.
				CARLOS AT SHOP GATHERING ADDITIONAL
				PUMPS & PIPING, LOADING TRUCKS TO TRANSPORT

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
				MATERIAL TO JOBSITE

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	10	no
Dennis Hurtado	10	no
Brad Bennet	10	no
CARLOS LOPES - SHOP	12	NO
NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Saturday, March 14, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7:00	7:30		safety meeting. Service equipment
7:30			offload 16" drop pipe header with tee and reducer flanges. Adjust GIW-1 in new position
			install stiiling well pipe and run it in hole. Install tee and connect to GIW number one.
			offload second truck with GIW number 2 john deere pump 8"certalock fittings box.
	7:00		secure well for the night
			check tortoise traps twice. No movement.

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Daniel Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no
CARLOS LOPES	12	NO

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Sunday, March 15, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7:00	7:30		safety meeting. Inspect tortoise traps. Service equipment.
7:30	12:00		continue Rigging up new 24"x 16" header and GIW-2

DRILLING CREW PAYROLL DATA

DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	5	no
Dennis Hurtado	5	no
Brad Bennet	5	no
CARLOS LOPES	5	NO

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

Memo

To:	SFWMD South Florida Water Management District	From:	Rick Cowles Stantec
File:	Lake Okeechobee ASR Project L-63N MIT Weekly Progress Report	Date:	April 3, 2020

Work Completed to Date:

From Saturday, March 21, 2020 to Sunday, March 22, 2020 Youngquist Brothers Inc. (YBI) installed the floating silt fence and ran background for the 9-hour step-rate pumping test. On Monday, March 23, 2020, YBI began and completed the 9-hour step-rate pumping test. From Tuesday, March 24, 2020, to Saturday, March 28, 2020, YBI began the demobilization of the site.

The following attachments are included in this weekly summary report:

- Stantec Daily Report
- YBI Daily Reports
- Step-rate pumping test water level log
- Step-rate pumping test water quality log
- Step-rate pumping test and dual-zone monitoring well water level graph

Work to be Completed through Next Period

YBI will complete demobilization and site clean-up.

Stantec Consulting Services Inc.

Rick Cowles, PG
Senior Hydrogeologist/Senior Associate

Phone: 941-266-3917

Attachment: Attachment

c. C.C.	Jennifer Gent/SFWMD	(jgent@sfwmd.gov)
	Robert Verrastro/SFWMD	(bverras@sfwmd.gov)
	Neil Johnson/Stantec	(Neil.Johnson@stantec.com)
	Cora Summerfield/Stantec	(cora.summerfield@stantec.com)
	Nycole Sharma/Stantec	(Nycole.sharma@stantec.com)
	Hannah Rahman/Stantec	(hannah.rahman@stantec.com)
	Heath Wintz/Stantec	(Heath.Wintz@stantec.com)
	Jeovanni Ayala-Lugo/Stantec	(jeovanni.ayala-lugo@stantec.com)

L-63N MIT DAILY SHIFT REPORT

Lake Okeechobee ASR Project

DATE(S) & TIME(S): 03/23/2020
0700 - 1700

Sun	Mon	Tue	Wed	Thr	Fri	Sat
	X					

JOB NUMBER: 177311456

CONTRACTOR: Youngquist Brothers Inc. (YBI)

PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD

Weather	Clear	Overcast	Rain	Heavy Rain
	x			
Temperature	32 - 50	50 - 70	70 - 85	> 85
			X	X
Wind	Still	Medium	High	
	x			
Humidity	Dry	Moderate	Humid	**Report No.**
			X	**13**

SHIFT SUMMARY

OBSERVER: Hannah Rahman/Stantec and Cora Summerfield/Stantec
START DEPTH:
DRILLER: Danny Atkisson/YBI
END DEPTH:
ACTIVITY: Step-Rate Pumping Test (totalizer readings in 10,000 gallons).
SUB CONTRACTORS: None.
FORMATION SAMPLES: None.
WATER SAMPLES: None.
TESTING: None.

TIME	DESCRIPTION
0640	**H. Rahman/Stantec onsite. YBI already onsite.**
0700	**R. Cowles/Stantec onsite.**
0702	**D. Atkisson/YBI onsite.**
0715	**C. Summerfield/Stantec onsite. Discharge pipe is extended 40 feet into the canal and silt fence is set up.**
0721	**Totalizer reading taken. Cowles/Stantec informs water quality to be taken 15 minutes after the start of each step, then every 30 minutes, then 15 minutes before the end of each step.**
0730	**Step 1 begins. First step pumping rate at about 2,000 gallons per minute (gpm).**
0731	**Pumping rate at ~2,000 gpm.**
0736	**Pumping rate at ~2,100 gpm.**
0739	**Transducer set at 18 feet bpl the concrete pad.**
0745	**No sampling port because of new pump.**
0756	**Turbidity meter calibrated.**
0758	**Sampling port for water quality fixed.**
0800	**Water quality sample taken. Refer to field form.**
0822	**Totalizer reading taken. Refer to field form.**
0823	**YBI informs Stantec that the transducer is set 18 feet bpl the concrete pad, not the land surface. Both transducers were calibrated at the same time, both are equally accurate.**

Observer's Initials HR/CS

0827	**Per YBI, transducers are set side by side, but one may be sitting slightly higher than the other after being lowered into the well.**
0830	**Water quality sample taken.**
0843	**Totalizer reading taken. Refer to field form.**
0900	**Water quality sample taken. Refer to field form.**
0901	**Totalizer reading taken. Refer to field form.**
0902	**Per YBI, there is 40 feet of drop pipe in the well.**
0920	**B. Verrastro/SFWMD, J. Shaw/SFWMD, and T. Colios/SFWMD onsite.**
0921	**Totalizer reading taken. Refer to field form.**
0930	**Water quality sample taken. Refer to field form.**
0945	**Stantec gave SFWMD the XY caliper log, XY caliper samples, and video log DVD.**
0957	**Leak in south side of the discharge pipe.**
1000	**Water quality sample taken. Refer to field form.**
1010	**Totalizer reading taken. Refer to field form.**
1015	**Water quality sample taken. Refer to field form.**
1021	**YBI placed plastic wrap around leak in discharge pipe.**
1022	**J. Gent/Stantec onsite.**
1023	**Totalizer reading taken. Refer to field form.**
1030	**Water quality sample taken. Refer to field form. Step 1 ends and step 2 begins at a pumping rate of 5,000 gpm. YBI steps computer**
1031	**Pumping rate reading taken. Refer to field form.**
1037	**Totalizer reading taken. Refer to field form**
1045	**Water quality sample taken. Refer to field form.**
1049	**Sand sample taken. Refer to field form.**
1052	**Totalizer and pump rate recorded. Refer to field form.**
1100	**Water quality sample taken. See field form.**
1112	**B. Verrastro/SFWMD, J. Shaw/SFWMD, and T. Colios/SFWMD offsite.**
1113	**Totalizer and pumping rate recorded. Refer to field form.**
1130	**Water quality sample taken. Refer to field form.**
1135	**R. Cowles/Stantec offsite.**
1158	**R. Cowles/Stantec onsite.**
1200	**Water quality sample taken. Refer to field form.**
1204	**B. Verrastro/SFWMD, J. Shaw/SFWMD, and T. Colios/SFWMD onsite.**
1205	**J. Gent/SFWMD offsite.**
1210	**Totalizer and pump rate reading taken. Refer to field form.**
1230	**Water quality sample taken. Refer to field form.**
1300	**Water quality sample taken. Refer to field form.**
1303	**Totalizer and pump rate recorded. Refer to field form.**
1315	**Water quality sample taken, and totalizer and pump rate recorded. Refer to field form.**
1330	**Water quality sample taken Refer to field form. End of step 2. Step 3 begins with a pumping rate of approximately 7,000 gpm.**
1331	**Totalizer and pump rate recorded. Refer to field form.**
1335	**Water quality sample taken. Refer to field form.**
1342	**Totalizer and pump rate recorded. Refer to field form.**
1345	**B. Verrastro/SFWMD, J. Shaw/SFWMD, and T. Colios/SFWMD offsite.**
1354	**Totalizer and pump rate recorded. Refer to field form.**
1400	**Water quality sample taken. Refer to field form.**
1416	**Totalizer and pump rate recorded. Refer to field form.**
1430	**Water quality sample taken. Refer to field form.**
1435	**R. Cowles/Stantec offsite.**
1439	**Totalizer and pump rate recorded. Refer to field form.**
1500	**Water quality sample taken. Refer to field form.**
1512	**Totalizer and pump rate recorded. Refer to field form.**
1530	**Water quality sample taken. Refer to field form.**
1542	**Totalizer and pump rate recorded. Refer to field form.**
1600	**Water quality sample taken. Refer to field form.**
1607	**Totalizer and pump rate recorded. Refer to field form.**

1615	**Water quality sample taken. Refer to field form.**
1620	**Totalizer and pump rate recorded. Refer to field form.**
1625	**Water quality sample taken. Refer to field form.**
1630	**End of step 3. YBI will email recovery data tomorrow morning.**
1631	**Pump turned off.**
1632	**Totalizer recorded. Refer to field form.**
1635	**YBI begins taking down discharge pipe from canal. YBI downloads step-rate pumping test data to flash drive for Stantec.**
1640	**The pump is a CAT 600-cylinder diesel. Horsepower of the pump is unknown.**
1700	**H. Rahman/Stantec and C. Summerfield/Stantec offsite.**

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Saturday, March 21, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER

Size	Weight	Length	Set At

	DEPTH INTERVAL From	DEPTH INTERVAL To	ROTORY TABLE SPEED	WEIGHT ON BIT
Day				
Night				

BOTTOM HOLE ASSEMBLY

BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7:00	7:30		safety meeting. Service equipment
7:30	12:00		spot crane on canal side. Launch boat and install silt boom in canal.
			Called Rick Cowles and rescheduled the pump test for Momday morning.

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Daniel Attkisson	5	NO
Dennis Hurtado	5	NO

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Sunday, March 22, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	3:00	5:00		final check on location prior to testing. Start Background for 12 hours.

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	2	NO

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab.
Rig/Well ID	

YBI Job #	020-27-20
Date:	Monday, March 23, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7:00	7:30		safety meeting.
			start pump test @ 2000GPM for 3 hours
			step pumping rate to 5000gpm for 3 hours
			step pumping rate to 7000gpm for 3 hours
	6:00		end pumping and step box to recovery. Secure site for the night.

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Daniel Attkisson	11	NO
Dennis Hurtado	11	NO
Brad Bennet	11	NO

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District	**YBI Job #**	020-27-20
Job Name	L-63N Taylor Creek ASR Rehab.	**Date:**	Tuesday, March 24, 2020
Rig/Well ID		**Day of Week:**	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7:00	7:30		safety meeting. Service crane and loader
	7:30			stop test download data and W.O approval.
				Stantac approved data and authorized demob. Demob 2 GIW pumps and John deere pumps.
		7:00		load and ship GIW's to yard. Continue to demob water line to pond.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Daniel Attkisson	12	NO
Dennis Hurtado	12	NO
Brad Bennet	12	NO
NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Wednesday, March 25, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7am	7:30		Safety meeting
				Continue demob. Kill well. Remove pumphead tee and 40 ft suction pipe from well. Bolt final 24"
		7pm		flange with 6" gate valve on top of the well.

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Danny Attkisson	12	no
Dennis Hurtado	12	no
Brad Bennet	12	no

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Thursday, March 26, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		
7am			Safety meeting
			Continue demob. Bring well alive. Pump kill into a tanker and haul offsite for disposal
			Plumb 6" flow line with water meter from well to pond. Begin free flowing well to pond.
	7:30		Shut in well overnite.

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Danny Attkisson	12.5	no
Dennis Hurtado	12.5	no
Brad Bennet	12.5	no

NIGHT SHIFT

TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
FROM	TO		

NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Friday, March 27, 2020
Day of Week:	

YOUNGQUIST
BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		
	7am	7:30		Safety meeting
				Continue demob. Load trucks and send to shop.
				Free flow water from well to pond. Rate of flow at 1000 gpms
		6:30		Shut in well overnite.

NIGHT SHIFT	TIME LOG		TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
	FROM	TO		

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

DRILLING CREW PAYROLL DATA		
DAY TOUR:		INJURED YES/NO
NAME	HOURS	
Danny Attkisson	11.5	no
Dennis Hurtado	11.5	no
Brad Bennet	11.5	no
NIGHT TOUR:		INJURED YES/NO
NAME	HOURS	

EQUIPMENT ON SITE

CLIENT	South Florida Water Management District
Job Name	L-63N Taylor Creek ASR Rehab
Rig/Well ID	

YBI Job #	020-10-064
Date:	Saturday, March 28, 2020
Day of Week:	

YOUNGQUIST BROTHERS

LAST CASTING, TUBING OR LINER	Size	Weight	Length	Set At

	DEPTH INTERVAL		ROTORY TABLE SPEED	WEIGHT ON BIT
	From	To		
Day				
Night				

BOTTOM HOLE ASSEMBLY	
BIT SIZE (inches)	
STRING WT.	
BIT TYPE	

DAY SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS
7am	7:30		Safety meeting
			Continue demob. Load trucks and send to shop.
			Remove 6" flow line and meter from well
	5:00		Trackhoe delivered to site for repairs to washouts on Monday

NIGHT SHIFT

TIME LOG FROM	TIME LOG TO	TIME / HR	DETAILS OF OPERATIONS IN SEQUENCE AND REMARKS

DRILLING CREW PAYROLL DATA

DAY TOUR:

NAME	HOURS	INJURED YES/NO
Danny Attkisson	10	no
Dennis Hurtado	10	no
Brad Bennet	10	no

NIGHT TOUR:

NAME	HOURS	INJURED YES/NO

COMMENTS - EVENTS - CONDITION - CHANGES - OTHER INFORMATIOM

EQUIPMENT ON SITE

Stantec

Step-Rate Pumping Test Field Log

L-63N MIT

Page: 1 of 1

Project: Lake Okeechobee ASR Project
Project: 177311456
Well No.: L-63N
Interval: 1,268 to 1,700 ft bpl
Observers: Hannah Rahman & Core Summerfield
Start Time: 7:30
End Time: 16:30
Meter Readings (10,000 gallons): Start: 733 End: 991 Total: **218**
Total Gallons
Transducer Depth: 18 ft from top of concrete well pad
Static Water Level: 8.083 ft als

Date	Time	Elapsed Time (hrs:min)	Elapsed Time mins	Temperature (°F)	Water Level (feet above transducer)	Drawdown (feet)	Pump Rate (gpm)	Pressure (psi)	Comments
3/23/2020	7:29	0:00	0	79.556	26.074	0.000		11.295	beginning of step 1; totalizer = 733 gallons
3/23/2020	7:30	0:01	1	79.561	25.067	1.007		10.875	
3/23/2020	7:32	0:03	3	79.544	23.476	2.598		10.363	
3/23/2020	7:33	0:04	4	79.562	23.866	2.208		10.174	
3/23/2020	7:34	0:05	5	79.605	23.662	2.412		10.324	
3/23/2020	7:35	0:06	6	79.615	23.903	2.171	2100	10.292	
3/23/2020	7:36	0:07	7	79.628	23.658	2.416		10.274	
3/23/2020	7:37	0:08	8	79.700	23.855	2.219		10.213	
3/23/2020	7:38	0:09	9	79.666	24.022	2.052		10.313	
3/23/2020	7:39	0:10	10	79.698	23.878	2.196		10.267	
3/23/2020	7:40	0:11	11	79.736	23.816	2.258		10.214	
3/23/2020	7:45	0:16	16	79.991	23.783	2.291		10.283	
3/23/2020	7:50	0:21	21	80.585	23.647	2.427		10.256	
3/23/2020	7:55	0:26	26	81.203	23.662	2.412	2100	10.193	totalizer = 739 gallons; specific capacity = 786 gpm/ft dd
3/23/2020	8:00	0:31	31	81.816	23.746	2.328		10.223	
3/23/2020	8:10	0:41	41	82.942	23.230	2.844		10.151	
3/23/2020	8:20	0:51	51	83.462	23.437	2.637		9.893	
3/23/2020	8:30	1:01	61	83.717	23.229	2.845		10.881	
3/23/2020	8:40	1:11	71	84.037	23.219	2.855	2200	10.096	
3/23/2020	8:50	1:21	81	84.301	23.077	2.997		10.057	
3/23/2020	9:00	1:31	91	84.428	23.194	2.880	2200	10.091	totalizer = 7553 gallons; specific capacity = 770.85 gpm/ft dd
3/23/2020	9:21	1:52	112	84.566	23.422	2.652		10.343	
3/23/2020	9:15	1:46	106				2150		totalizer = 757.5 gallons
3/23/2020	9:30	2:01	121	84.628	23.165	2.909	2200	10.132	
3/23/2020	9:45	2:16	136	84.679	23.674	2.400		10.223	
3/23/2020	10:00	2:31	151	84.776	23.542	2.532		10.077	
3/23/2020	10:10	2:41	161				2200		totalizer = 769 gallons
3/23/2020	10:15	2:46	166	84.691	23.264	2.810		10.208	
3/23/2020	10:23	2:54	174				2200		totalizer = 769 gallons
3/23/2020	10:29	3:00	180	84.789	23.452	2.622		10.171	end of step 1
3/23/2020	10:30	3:01	181	84.822	14.080	11.994		7.960	beginning of step 2
3/23/2020	10:31	3:02	182	84.798	17.043	9.031		7.322	
3/23/2020	10:32	3:03	183	84.816	15.203	10.871		6.472	
3/23/2020	10:33	3:04	184	84.836	13.495	12.579		6.329	
3/23/2020	10:34	3:05	185	84.805	14.781	11.293		6.416	
3/23/2020	10:35	3:06	186	84.836	14.956	11.118		6.471	
3/23/2020	10:36	3:07	187	84.810	14.766	11.308		6.544	
3/23/2020	10:37	3:08	188	84.824	15.213	10.861	5200	6.565	totalizer = 777.5 gallons; specific capacity = 498.2 gpm/ft dd
3/23/2020	10:38	3:09	189	84.828	14.731	11.343		6.154	
3/23/2020	10:39	3:10	190	84.840	13.655	12.419		5.880	
3/23/2020	10:40	3:11	191	84.837	14.433	11.641		6.157	
3/23/2020	10:45	3:16	196	84.849	14.201	11.873		6.971	
3/23/2020	10:50	3:21	201	84.811	13.816	12.258	5200	6.325	totalizer = 784 gallons
3/23/2020	10:55	3:26	206	84.889	14.383	11.691		6.782	
3/23/2020	11:00	3:31	211	84.989	14.478	11.596		6.980	
3/23/2020	11:10	3:41	221	84.954	15.709	10.365		6.785	
3/23/2020	11:24	3:55	235	84.967	15.519	10.555		6.115	
3/23/2020	11:30	4:01	241	84.988	15.247	10.827		6.478	
3/23/2020	11:40	4:11	251	85.011	14.673	11.401		6.397	
3/23/2020	11:50	4:21	261	85.032	13.949	12.125	5200	5.953	totalizer = 824.5 gallons; specific capacity = 438.97 gpm/ft dd
3/23/2020	12:00	4:31	271	85.038	14.461	11.613		6.698	
3/23/2020	12:15	4:46	286	85.065	14.205	11.869		6.310	
3/23/2020	12:30	5:01	301	85.034	14.805	11.269		6.425	
3/23/2020	12:45	5:16	316	85.052	14.848	11.226		6.133	
3/23/2020	13:00	5:31	331	85.090	14.284	11.790	5050	6.299	totalizer = 852 gallons; specifc capacity = 465 gpm/ft dd
3/23/2020	13:15	5:46	346	85.064	14.508	11.566		6.265	
3/23/2020	13:23	5:54	354				5200		totalizer = 861.5 gallons; specific capacity = 465.62 gpm/ft dd
3/23/2020	13:29	6:00	360	85.046	13.582	12.492		6.478	end of step 2
3/23/2020	13:30	6:01	361	85.006	5.719	20.355		1.845	beginning of step 3
3/23/2020	13:31	6:02	362	85.054	5.676	20.398		2.643	
3/23/2020	13:32	6:03	363	85.047	6.918	19.156	7000	3.123	
3/23/2020	13:33	6:04	364	84.957	7.494	18.580		3.129	
3/23/2020	13:34	6:05	365	85.003	7.206	18.868		3.193	
3/23/2020	13:35	6:06	366	84.999	7.580	18.494		3.037	
3/23/2020	13:36	6:07	367	84.591	7.540	18.534		3.117	
3/23/2020	13:37	6:08	368	85.012	7.362	18.712		3.364	
3/23/2020	13:38	6:09	369	85.006	7.449	18.625		3.264	
3/23/2020	13:39	6:10	370	84.974	7.912	18.162		3.21	
3/23/2020	13:40	6:11	371	84.96	7.381	18.693	6900	3.035	totalizer = 873 gallons; specific capacity = 359 gpm/ft dd
3/23/2020	13:45	6:16	376	84.992	5.711	20.363		2.357	
3/23/2020	13:50	6:21	381	84.956	5.653	20.421	7100	2.373	
3/23/2020	13:55	6:26	386	84.976	5.489	20.585		2.63	
3/23/2020	14:00	6:31	391	84.997	5.741	20.333		2.51	
3/23/2020	14:10	6:41	401	84.967	5.864	20.210		2.436	
3/23/2020	14:16	6:47	407	84.983	5.145	20.929		2.351	
3/23/2020	14:20	6:51	411	84.99	5.520	20.554	7100	2.494	totalizer = 898; specific capacity = 351.66 pm/ft dd
3/23/2020	14:25	6:56	416	85.051	5.554	20.520		2.443	
3/23/2020	14:30	7:01	421	85.048	5.684	20.390		2.384	
3/23/2020	14:35	7:06	426	85.002	5.451	20.623		2.48	
3/23/2020	14:40	7:11	431	85.021	5.351	20.723		2.499	
3/23/2020	14:53	7:24	444	84.893	5.952	20.122	7100	2.607	totalizer = 915 gallons; specific capacity = 344.83 gpm/ft dd
3/23/2020	15:00	7:31	451	85.032	5.772	20.302		2.37	
3/23/2020	15:10	7:41	461	85.083	5.773	20.301		2352	
3/23/2020	15:20	7:51	471	85.021	5.763	20.311	7000	2.32	totalizer = 937 gallons; specific capacity = 343.27 gpm/ft dd
3/23/2020	15:30	8:01	481	85.037	5.789	20.285		2.457	
3/23/2020	15:40	8:11	491	85.034	5.167	20.907	7100	2.497	totalizer = 958 gallons; specific capacity = 372.44 gpm/ft dd
3/23/2020	15:50	8:21	501	85.012	5.700	20.374		2.455	
3/23/2020	16:00	8:31	511	85.024	5.187	20.887		2.559	
3/23/2020	16:15	8:46	526	84.989	5.530	20.544		2.492	
3/23/2020	16:29	9:00	540	85.07	5.641	20.433	7000	2.477	end of step 3; totalzer = 991 gallons
3/23/2020	16:31	9:02	542	85.046	25.572	0.502		10.772	beginning of recovery
3/23/2020	16:32	9:03	543	85.077	25.445	0.629		10.992	
3/23/2020	16:33	9:04	544	85.063	25.5	0.574		11.032	
3/23/2020	16:34	9:05	545	85.055	25.583	0.491		11.076	

Step-Rate Pumping Test Water Quality Field Log
L-63N MIT

Page: 1 of 1

Project: Lake Okeechobee ASR Project

Project: 177311456 **Interval:** 1,268 to 1,700 ft bpl

Well No.: L-63N

Observers: Hannah Rahman & Core Summerfield

Start 7:30

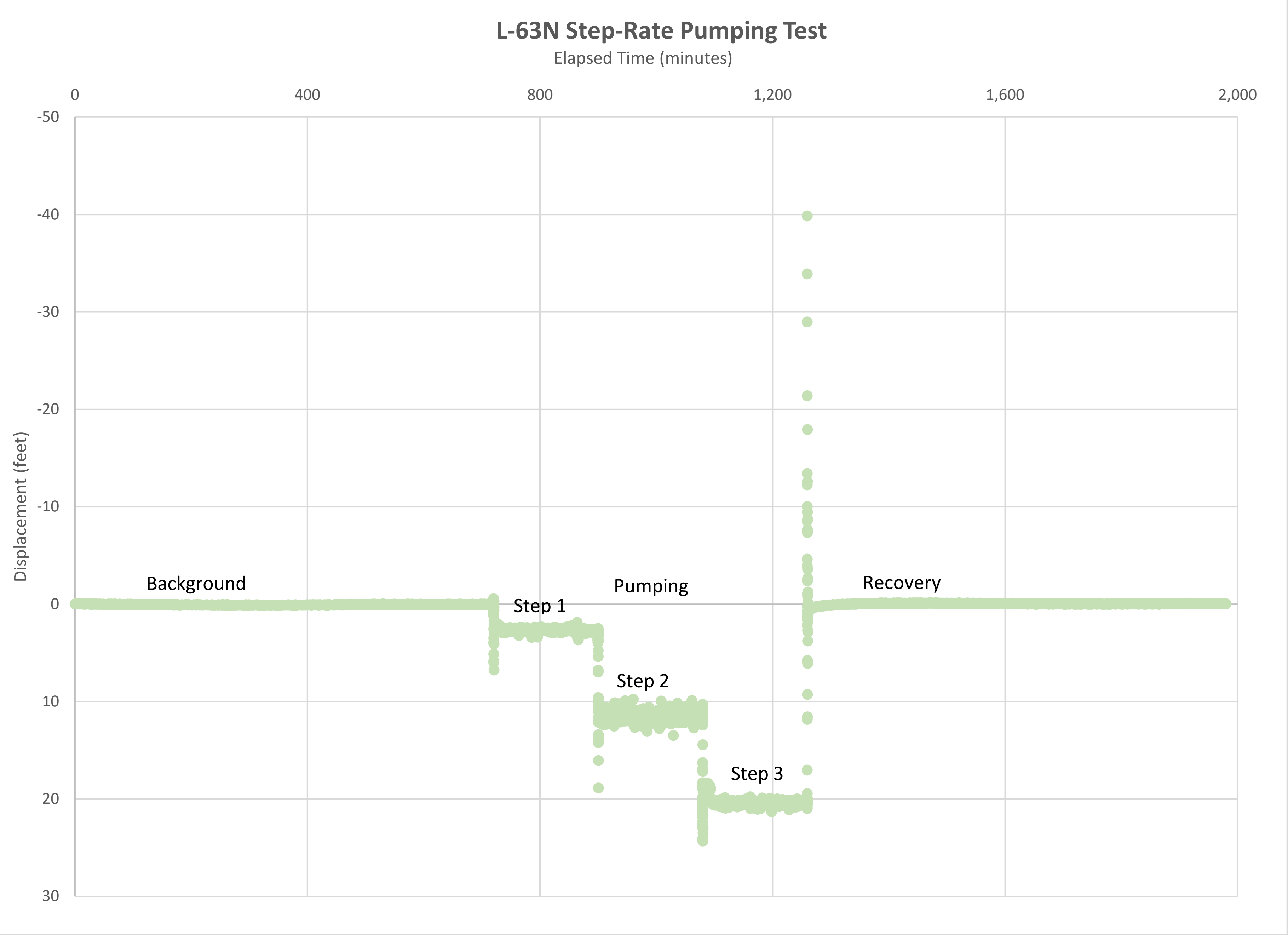
End Time: 16:30

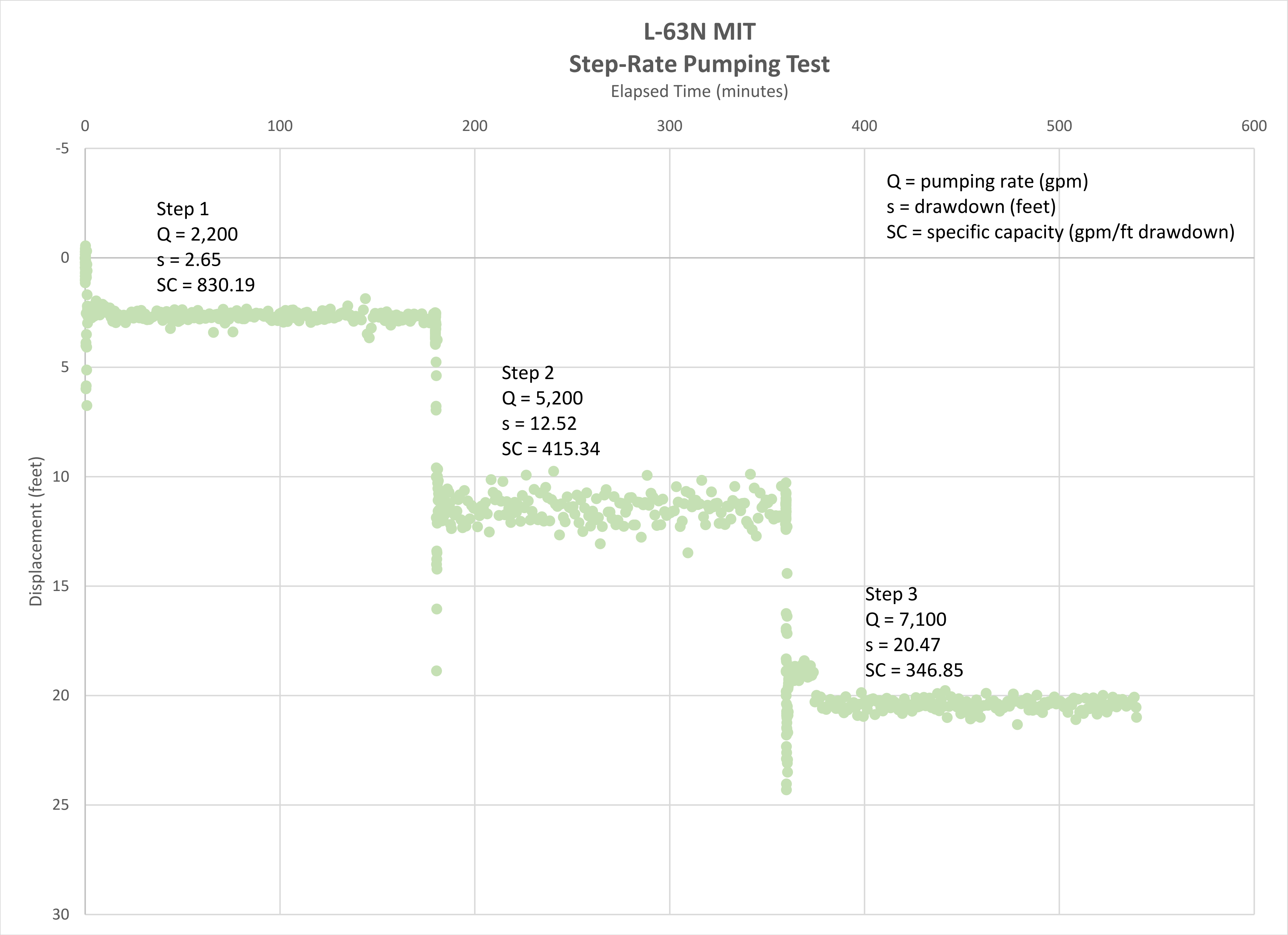
Meter Readings (10,000 gallons): Start: 733 End: 991 Total: **218**

Total Gallons

Transducer Depth: 18 ft bpl
Static Water Level: 8.083 ft als

Date	Time	Elapsed Time (hrs:min)	Elapsed Time mins	Specific Conductance (mS/cm)	Est. TDS (mg/l)	pH (std. units)	Temperature (°C)	Turbidity (NTU) Pine/YBI	Salinity (ppt)	Rossum Sand Content (mL)	Sand (ppm)	Comments
3/23/2020	7:45	0:00	0				27.90	6.33/6.59				Step 1. No Rossum Sand Test because not enough water in pipe. Flow rate isn't high enough.
3/23/2020	8:00	0:15	15	11.77	7663.5	7.97	27.90	6.33/6.59	6.71			
3/23/2020	8:50	1:05	65	1.81	7637.5	7.85	28.80	1.14/1.40	6.72			
3/23/2020	9:00	1:15	75	11.82	7702.5	0.88	29.20	0.39/0.30	6.76			
3/23/2020	9:30	1:45	105	11.77	7663.5	7.80	29.60	1.79/1.74	6.68			
3/23/2020	10:00	2:15	135	1.88	7728.5	7.72	29.5	2.4/2.43	6.74			
3/23/2020	10:15	2:30	150	11.64	7709.0	7.67	29.5	1.63/1.79	6.72			
3/23/2020	10:30	2:45	165	11.81	7676.5	7.72	29.6	0.38/0.33	6.71			
3/23/2020	10:45	3:00	180	12.01	7813.5	7.68	29.8	7.00/7.13	6.81	<0.01	<0.5	Step 2
3/23/2020	11:00	3:15	195	11.79	7663.5	7.70	29.2	3.9/3.73	6.68			
3/23/2020	11:30	3:45	225	11.81	7676.5	7.60	29.7	4.42/4.75	6.69			
3/23/2020	12:00	4:15	255	11.90	7728.5	7.68	29.5	2.62/2.68	6.74			
3/23/2020	12:30	4:45	285	11.85	7702.5	7.74	29.7	4.85/4.80	6.71			
3/23/2020	13:00	5:15	315	11.84	7696.0	7.69	29.8	3.04/3.01	6.71			
3/23/2020	13:15	5:30	330	11.85	7702.5	7.67	29.7	2.01/2.49	6.72	<0.01	<0.5	
3/23/2020	13:30	5:45	345	11.76	7637.5	7.68	29.4	0.93/1.36	6.66			
3/23/2020	13:35	5:50	350	11.86	7722.0	7.63	29.7	3.44/3.71	6.73			Step 3
3/23/2020	14:00	6:15	375	12.03	7813.0	7.71	29.9	23.00/25.11	6.81	<0.01	<0.5	
3/23/2020	14:30	6:45	405	11.97	7769.0	7.68	29.7	3.48/3.85	6.72			
3/23/2020	15:00	7:15	435	11.91	7741.5	7.68	29.8	2.79/2.51	6.75			
3/23/2020	15:30	7:45	465	11.98	7780.5	7.62	29.8	1.98/2.14	6.79			
3/23/2020	16:00	8:15	495	11.98	7787.0	7.67	30.0	7.2/7.11	6.79			
3/23/2020	16:15	8:30	510	11.89	8815.5	7.68	29.7	1.98/2.02	6.72	<0.01	<0.5	
3/23/2020	16:25	8:40	520	11.87	7715.5	7.64	29.8	2.12/1.57	6.73			


L-63N Step-Rate Pumping Test
Elapsed Time (minutes)
0
400
800
1,200
1,600
2,000
Displacement (feet)
-50
-40
-30
-20
-10
0
10
20
30
Background
Step 1
Pumping
Step 2
Step 3
Recovery



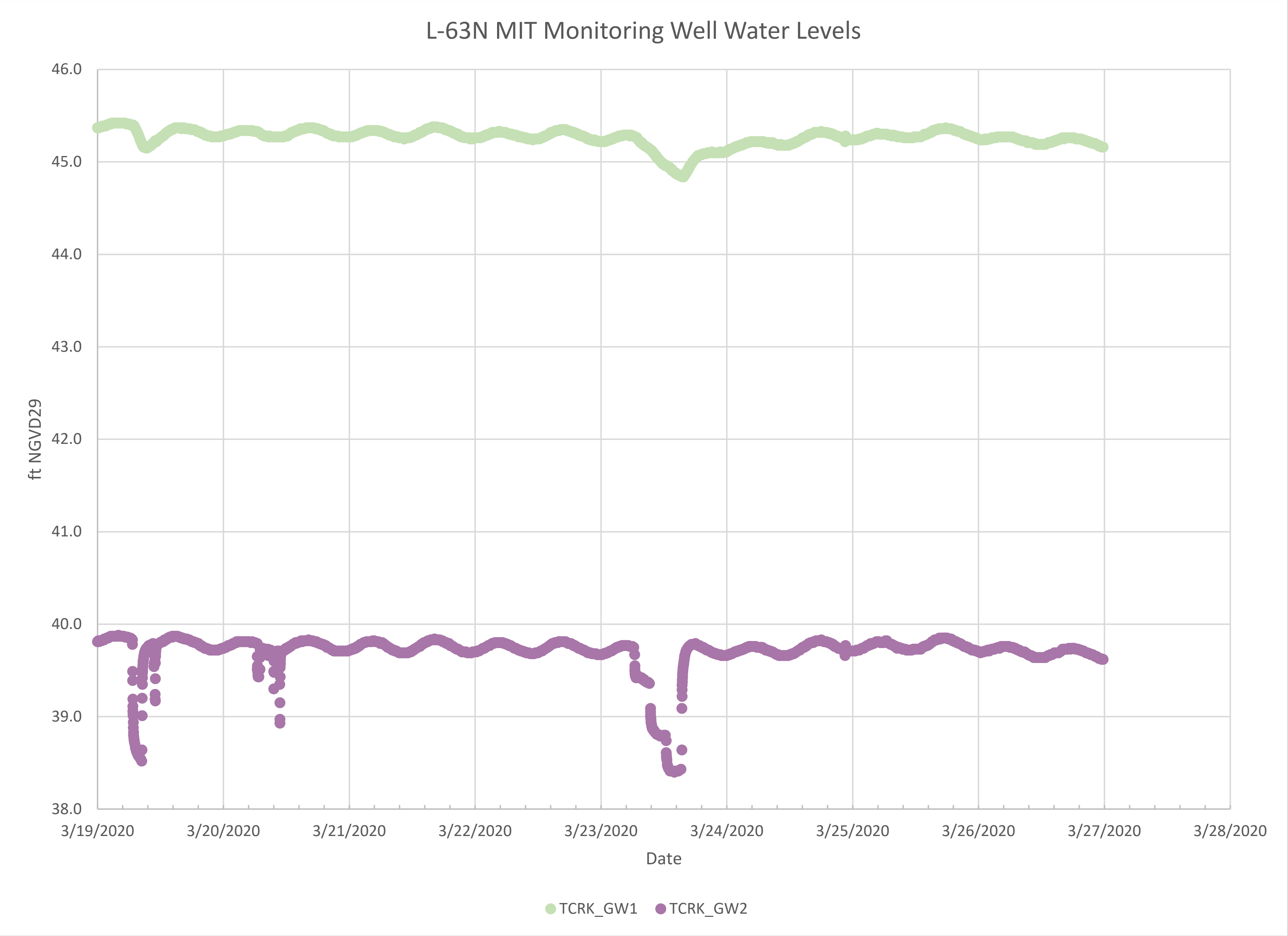
L-63N MIT
Step-Rate Pumping Test

Step 1
Q = 2,200
s = 2.65
SC = 830.19

Step 2
Q = 5,200
s = 12.52
SC = 415.34

Step 3
Q = 7,100
s = 20.47
SC = 346.85

Q = pumping rate (gpm)
s = drawdown (feet)
SC = specific capacity (gpm/ft drawdown)


L-63N MIT Monitoring Well Water Levels
46.0
45.0
44.0
43.0
42.0
41.0
40.0
39.0
38.0
ft NGVD29
3/19/2020
3/20/2020
3/21/2020
3/22/2020
3/23/2020
3/24/2020
3/25/2020
3/26/2020
3/27/2020
3/28/2020
Date
TCRK_GW1
TCRK_GW2

APPENDIX D

Initial CTVSL Detailed Summary and Screenshots

Appendix D

D.1 INITIAL CTVSL DETAILED SUMMARY WITH SCREENSHOTS

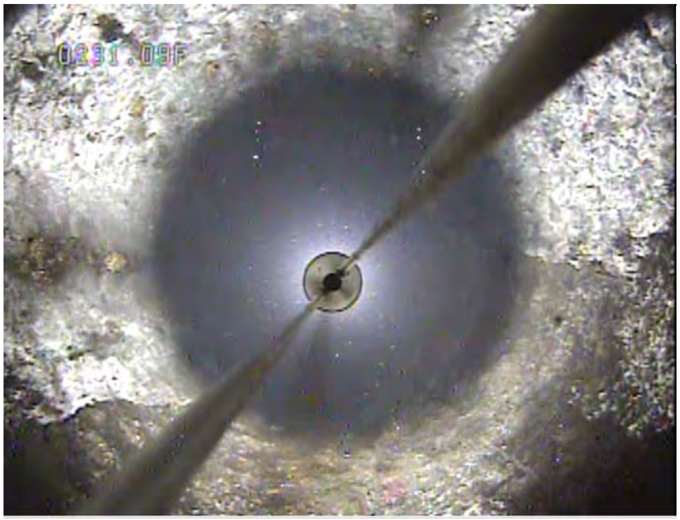
L-63N MIT Initial CTVSL Detailed Summary
01-30-2020

Interval (feet bpl)	Description
0	Top of encrustation
0-14	Encrustation
14-15	Peeling encrustation or casing (?)
15-34	Encrustation
34-40	Small encrustation nodule clusters (possible spalling or encrustation along casing)
40-55	Encrustation
55-56	Small encrustation nodule cluster
55-83	Encrustation with small nodule clusters
83-144	Encrustation appears to be thicker
144-157	Appears to be more nodule clusters on side of encrusted casing wall
157-181	Thicker encrustation
181-230	Small sporadic nodule clusters
230-234	Encrustation or casing (?) peeling off, white encrustation **(A)**
234-260	Thicker encrustation, nodule clusters
260-262	Spalling in casing or encrustation
262-289	Encrustation with small nodule clusters
289-296	Thicker gray encrustation with small nodule clusters
296-301	Holes and tears/spall in encrustation
301-310	Encrustation with small nodule clusters **approximately 300 feet below land surface (bpl) to top of casing encrustation is whitish in color and resembles blocky nodules (fenced pattern) with a slimy dark brown background color. Less abundant closer to top of casing. Almost none from 0 to 10 feet bpl.*
310-319	Spalling in encrustation
319-397	Encrustation with sporadic small nodule clusters
397-406	Spalling in encrustation, peeling
406-416	Encrustation with sporadic nodule clusters
416-418	Spalling in encrustation
418-427	Encrustation appears thinner with sporadic nodule clusters
427-554	Diameter of casing changes as a result of encrustation, black encrustation **change in encrustation from 495 to 480 feet bpl, possible weld seam at 469 feet bpl* (**B**)
554-557	Spalling in encrustation, appears to be peeling, casing appears irregular
557-569	Encrustation appears slightly thicker, nodule clusters
569-572	Spalling in encrustation, appears to be peeling **red piece of something (casing?)*
572-585	Encrustation
585-587	Peeling
587-602	Encrustation with small nodule clusters **583 feet bpl, pieces missing, black nodules*
602-614	Encrustation peeling/spalling of casing (**C**)
614-634	Encrustation with small sporadic nodule clusters **weld seam at 629 feet bpl, pieces missing & potential casing peeling from 610 to 617 feet bpl*
634-637	Peeling
637-678	Encrustation with fewer nodule clusters

678-682	Peeling
682-695	Encrustation with small nodule clusters
695-699	Peeling
699-717	Encrustation
717-719	Large piece of encrustation appears to be peeling
719-755	Encrustation with sporadic nodule clusters
755-757	Peeling
757-773	Encrustation appears thicker, nodule clusters
773-777	Peeling
777-809	Encrustation with more nodule clusters
809-810	Casing diameter seems to change slightly as a result of encrustation
810-950	Encrustation appears thicker with more nodule clusters (large and small) (**D**)
950-961	Peeling
961-979	Encrustation with sporadic nodule clusters **949 feet bpl possible spalling or encrustation of casing and possible at 969 feet bpl*
979-981	Large encrustation nodule cluster
981-1,000	Encrustation with larger nodule clusters
1,000-1,027	Encrustation and spall peeling from casing wall(**E**)
1,027-1,081	Encrustation with sporadic nodule clusters **small vertical fracture in casing throughout, well seam at 1,030 feet bpl (?)*
1,081-1,086	Change in casing diameter as a result of encrustation
1,086-1,105	Encrustation appears thicker with larger nodule clusters
1,105-1,150	Encrustation with smaller nodule clusters, sporadic **possible weld seam at 1,111 and 1,030 feet bpl* (**F**)
1,150-1,155	Change in casing diameter as a result of encrustation
1,155-1,247	Encrustation with smaller nodule clusters, sporadic, vertical spall (**G**)
1,247-1,249	Large nodule cluster
1,249-1,265	Encrustation with large sporadic clusters
1,265-1,268	Large nodule clusters
1,268-1,269	Three windows in casing filled with encrustation or cement, 24-inch steel injection casing seat (**H**)
1,269-1,271	Casing foot, encrustation to bottom of casing. Cement came down (**I, J**)
1,271-1,284	Oblate borehole (K)
1,284-1,292	Irregular and oblate borehole, partial collapse **very dark in borehole* (**L**)
1,292-1,301	Irregular borehole **very dark in borehole*
1,301-1,307	Irregular borehole with cavities **very dark in borehole*
1,307-1,314	Irregular, oblate borehole with small cavities **bacteria at 1,310 feet bpl, very dark in borehole*
1,314-1,316	Oblate borehole, with large cavity
1,316-1,321	Irregular, oblate borehole with brecciated cavities **possible flow zone in this area* (**M**)
1,321-1,333	Gauge borehole, vug field, heavily vugged
1,333-1,354	Irregular borehole, small cavities, brecciated along some bedding planes, vuggy, 120-degree striations on borehole wall **bacteria from 1,333 to 1,334 feet bpl* (**N**)
1,354-1,355	Slightly irregular borehole, possible bedding (?), sporadic vugs
1,355-1,357	Brecciated borehole
1,357-1,364	Irregular borehole with small fractures and vugs **1,359* feet bpl *tiny cavity*
1,364-1,365	Lithology change (?)
1,365-1,378	Gauge borehole, vuggy, vug chains
1,378-1,380	Irregular, brecciated borehole, very vuggy **bacteria at 1,379 feet bpl*
1,380-1,390	Irregular borehole, small cavities, vuggy

1,390-1,405	Irregular borehole, small cavities, brecciated
1,405-1,410	Possible flow zone, video becomes slightly cloudy and wavy
1,410-1,411	Possible lithology change (?)
1,411-1,431	Irregular borehole, brecciated with small cavities and fractures (**O**)
1,431-1,432	Irregular, oblate borehole, vuggy and brecciated
1,432-1,439	Small cavern, very brecciated, drilling induced fractures (?) (**P**)
1,439-1,453	Gauge borehole, bedded lithology, vuggy, small fractures (**Q**)
1,453-1,466	Irregular borehole, small fractures, vugs, slightly brecciated
1,466-1,473	Gauge borehole, vuggy, vug chains
1,473-1,475	Irregular, oblate borehole, brecciated, small cavity
1,475-1,477	Irregular borehole, fractures, brecciated
1,477-1,483	Gauge borehole, vuggy, vug chains, brecciated
1,483-1,490	Irregular borehole
1,490-1,499	Gauge borehole **small cavity with vugs at 1,493 feet bpl*
1,499-1,503	Irregular borehole, brecciated
1,503-1,505	Gauge borehole, vuggy
1,505-1,510	Irregular, brecciated borehole, vuggy **fracture swarm (possible thin horizontal cavity) and bacteria from 1,510 -1,507 feet bpl*
1,510-1,541	Gauge borehole, vuggy, small cavities, vug chains
1,541-1,544	Slightly irregular borehole, brecciated, fractures **bacteria at 1,543 feet bpl* (**R**)
1,544-1,554	Gauge borehole, vuggy, vug fields (**S**)
1,554-1,560	Possible flow zone in this area **camera centralizer markings at 1,557 feet bpl*
1,560-1,565	Gauge borehole, vuggy, vug fields
1,565-1,567	Irregular borehole, very brecciated
1,567-1,570	Large cavernous room (**T**)
1,570	Fill blockage, geophysical tools and cable, PVC pipe, partial cavern floor (**U**)
Notes:	*CTVSL tool centralizer pattern (120° white lines) throughout casing and borehole. *below pad level (bpl). *Water is clear throughout video. *Three windows at bottom of the casing at approximately 1,268 feet bpl. *A 360° view of the bottom of the casing was completed at 1,271 feet bpl. *A side view of the entire borehole and casing was completed. *Bold letters correspond with labeled screenshots below. **Description came from the side view portion of the video.*

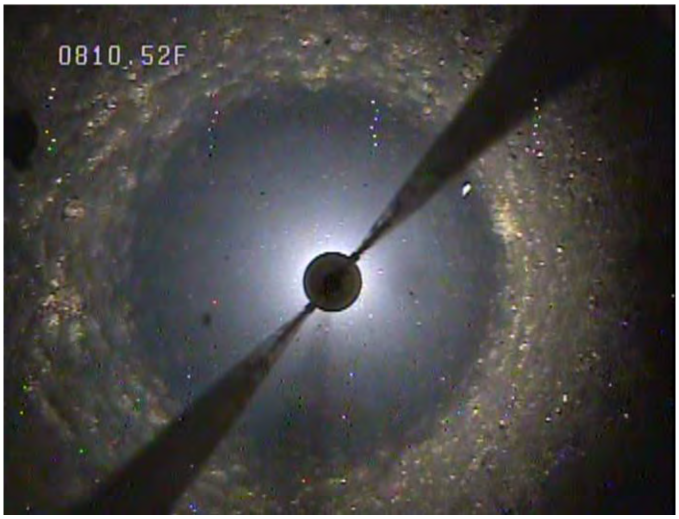
Screenshots



A

B

C



D

E

F

G

H

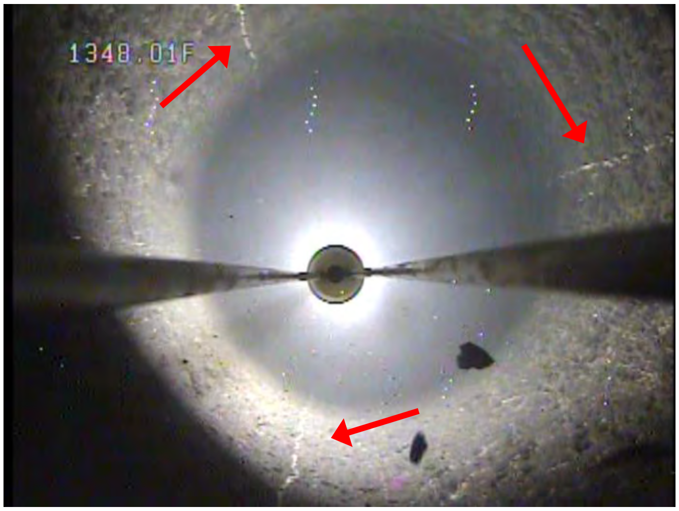
I

J

K

L

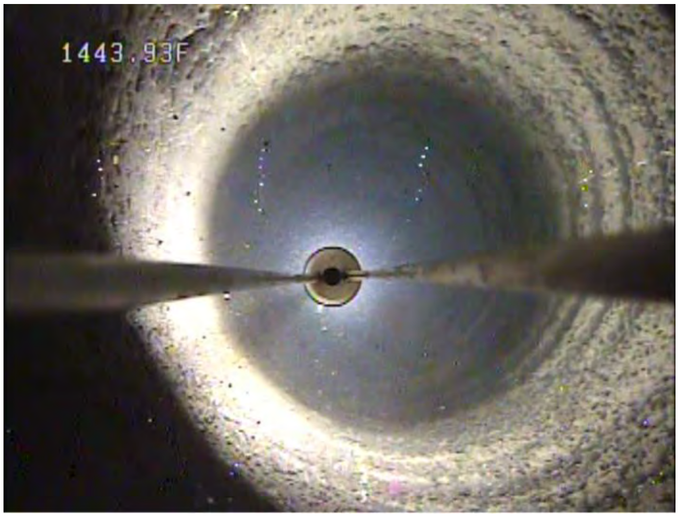
M



N

O

P



Q

R

S

T

U

APPENDIX E

Final CTVSL Detailed Summary and Screenshots

Appendix E

E.1 FINAL CTVSL DETAILED SUMMARY WITH SCREENSHOTS

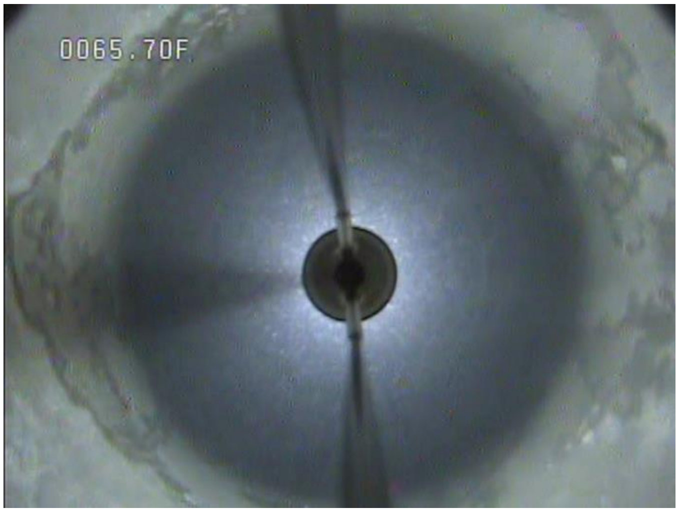
L-63N MIT Final CTVSL Detailed Summary
2-24-2020

Interval (feet bpl)	Description
0-24	Inside drill pipe
24-67	Some sporadic encrustation **(A)**
67-82	More encrustation, appears slightly thicker *weld seam at ~68 feet bpl
82-137	Some encrustation **(B)** *weld seam at ~108 feet bpl
137-158	Almost no encrustation *weld seam at ~148 feet bpl **(C)**
158-162	Some encrustation
162-172	Very little encrustation
172-177	Some sporadic encrustation
177-188	Very little encrustation *small piece of reddish encrustation nodule, weld seam at ~188 feet bpl **(D)**
188-192	Sporadic encrustation
192-206	Very little encrustation
206-208	Possible spalling (?)
208-212	Encrustation
212-228	Possible spalling (?) **(E)**
228-344	Appears to be very little encrustation, few sporadic nodules *weld seams at ~228, 268, and 308 feet bpl **(F), (G)**
344-355	Some sporadic encrustation *weld seam at ~348 feet bpl
355-390	Thicker sporadic encrustation, white encrustation (?) *weld seam at ~388 feet bpl
390-430	Possible spalling or seam (?), break in encrustation (?) **(H), (I)** *weld seam at ~428 feet bpl
430-474	Some sporadic encrustation **(J)** *weld seam at ~468 feet bpl
474-542	Thicker, more sporadic encrustation **(L)** *weld seam at ~509 feet bpl **(K)**
542-547	Less encrustation
547-552	More encrustation **(M)**
552-557	Almost no encrustation
557-640	Almost no encrustation with sporadic pockets of encrustation **(N), (O), (P)** *weld seams at ~558 feet bpl and ~628 feet bpl
640-700	Encrustation **(Q)** *weld seam at ~668 feet bpl **(R)**
700-793	Appears to be significant encrustation that is peeling (?) **(T), (U), (W)** *peeling at ~790 feet bpl *some type of seam at ~780 feet bpl *encrustation nodule and spalling (?) *vertical seam at ~715 feet bpl **(S)**, weld seams at ~708 feet bpl and ~749 feet bpl **(V)**
793-805	Less encrustation
805-822	Encrustation
822-960	Encrustation thicker and more sporadic in some areas **(Y), (Z)** *at 953 feet bpl and 936 feet bpl spalling (?), small vertical seam at ~860 feet bpl **(X)**
960-970	Almost no encrustation
970-1,217	Encrustation, thicker in some areas **(A.1), (B.1), (C.1), (D.1), (E.1)** *peeling/break in encrustation (?), weld seam at ~1,108 feet bpl, small holes (?)
1,217-1,231	Significant encrustation on side of borehole, peeling (?) **(F.1)** *weld seam at ~1,229 feet bpl (?) **(G.1)**
1,231-1,265	Encrustation, appears to be more abundant **(H.1)**

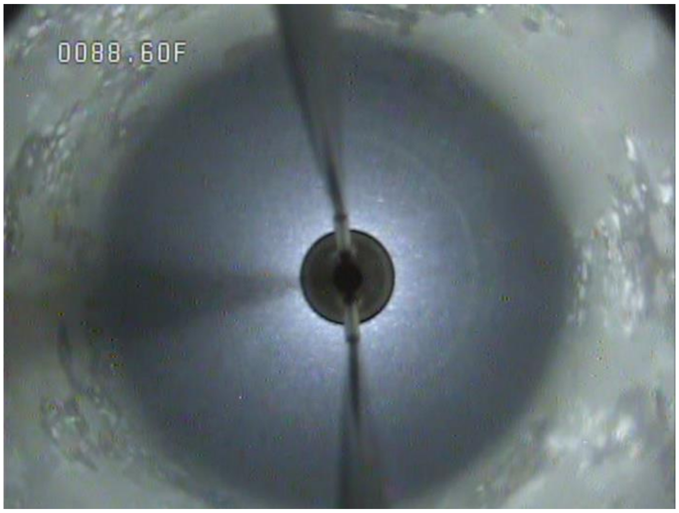
1,265-1,267	Piece of casing missing (?) **(I.1), (J.1)** *appears to be a piece of casing missing from ~1,265 feet bpl to ~1,271 feet bpl **(O.1), (P.1), (Q.1), (R.1), (T.1)**
1,267-1,268	Three windows in casing filled with encrustation or cement (?) **(K.1), (L.1), M.1), (N.1)**
1,268-1,271	Bottom of casing **(S.1)**
1,271-1,284	Gauge borehole
1,284-1,298	Irregular borehole, very brecciated
1,298-1,307	Irregular borehole with cavities, brecciated **(U.1)**
1,307-1,314	Irregular, oblate borehole with small cavities *small white yellowish pieces of rock (?) at ~1,305 feet bpl
1,314-1,320	Irregular borehole with large cavity
1,320-1,333	Gauge borehole, heavily vugged, vug field
1,333-1,334	Small cavity
1,334-1,354	Gauge borehole, vuggy, small cavities, brecciated
1,354-1,356	Oblate, irregular borehole, small brecciated cavity
1,356-1,359	Vertical spall/cavity
1,359-1,363	Gauge borehole
1,363-1,366	Vertical spall
1,366-1,376	Gauge borehole, vuggy
1,376-1,378	Vug chain
1,378-1,380	Irregular, brecciated borehole, vuggy
1,380-1,390	Irregular borehole, small cavities, vuggy
1,390-1,406	Irregular borehole, small cavities, brecciated
1,406-1,414	Possible flow zone (?), gauge borehole
1,414-1,431	Irregular, very brecciated borehole, small cavities and fractures
1,431-1,438	Partial collapse, very brecciated
1,438-1,452	Gauge borehole, vuggy, small fracture
1,452-1,462	Slightly irregular borehole, slightly brecciated, vuggy, small fractures
1,462-1,473	Gauge borehole, vuggy, vug chains
1,473-1,477	Irregular borehole, fractures, brecciated
1,477-1,483	Gauge borehole, very vuggy, small cavity
1,483-1,490	Irregular borehole, vuggy
1,490-1,499	Gauge borehole, vug chains
1,499-1,506	Gauge borehole
1,506-1,508	Irregular borehole, brecciated vuggy
1,508-1,541	Gauge borehole, very vuggy, vug chains *bedded lithology at ~1,538 feet bpl, possible lithology change (?) at ~1,522 feet bpl **(V.1)**
1,541-1,544	Slightly irregular borehole, brecciated, fractures
1,544-1,566	Gauge borehole, vuggy, vug fields **(W.1)** *some type of lithology change at ~1,551 feet bpl and ~1,557 feet bpl
1,566-1,568	Irregular borehole, very brecciated **(X.1)**
1,568-1,571	Cavern
1,571-1,583	Irregular, very brecciated borehole
1,583-1,584	Cavern
1,584-1,608	Irregular, oblate borehole, extreme brecciation, fractures, partial collapse *possible flow zone at ~1,582 feet bpl
1,608-1,617	Cavern *bacteria at ~1,610 feet bpl
1,617-1,629	Irregular, oblate borehole, brecciated, fractures, vuggy
1,629-1,643	Irregular borehole, vug fields
1,643-1,644	Small cavern
1,644-1,654	Irregular borehole, bedded lithology, extremely vuggy, vug chains & fields **(Y.1)**

1,654-1,675	Gauge borehole, bedded lithology, extremely vuggy, vug chains & fields *lamination (?) at 1,664 feet bpl **(Z.1)**
1,675-1,693	Slightly irregular borehole, bedded lithology, vuggiest *horizontal spall from ~1,682 feet bpl to ~1,683 feet bpl, lamination (?) at ~1,676 feet bpl **(A.2), (B.2)**
1,693-1,700	Gauge borehole, bedded lithology, vuggy
1,700	Total depth **(C.2)**
Notes:	*Casing joints (weld seams) appear to be ~40 feet (did stop and look for them during video survey. *Overall casing appears to have significantly less encrustation and scaling throughout. *Weld seams started at ~1,228 feet bpl to ~68 feet bpl from bottom of casing to the top of casing and they were approximately every 40 feet to top of casing. *Water is clear throughout video. *Three windows at bottom of the casing at approximately 1,268 feet bpl. *A 360° view of the bottom of the casing was completed at 1,271 feet bpl. *A side view of the entire borehole and casing was completed. *No polyvinyl (PVC) pipe or caliper tools at bottom of hole (total depth is 1,700 feet bpl) *Missing up hole (side view) portion of video from 1,010 to 1,070 feet bpl *below pad level (bpl) *Bold letters correspond with labeled screenshots below. *Description came from the side view portion of the video.*

Screenshots



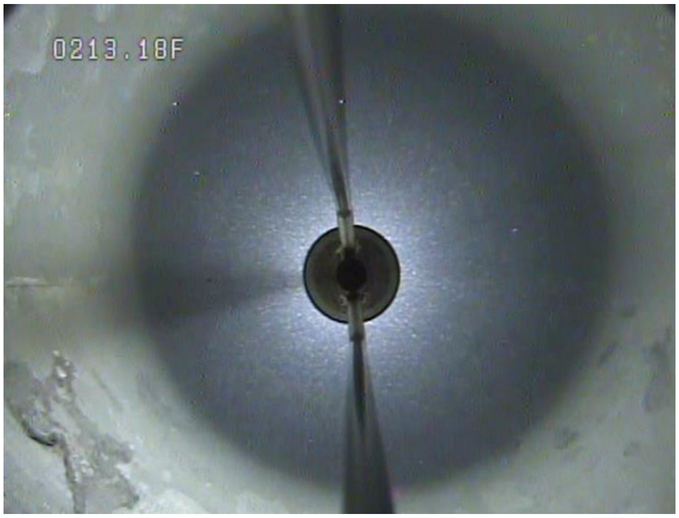
A



B

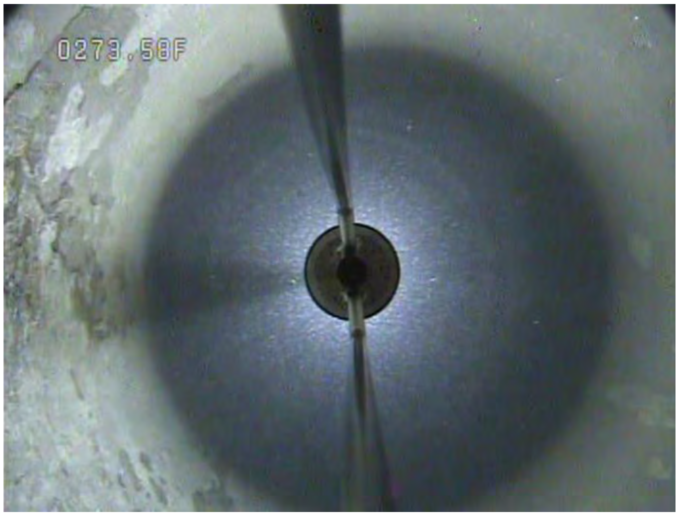
C

D

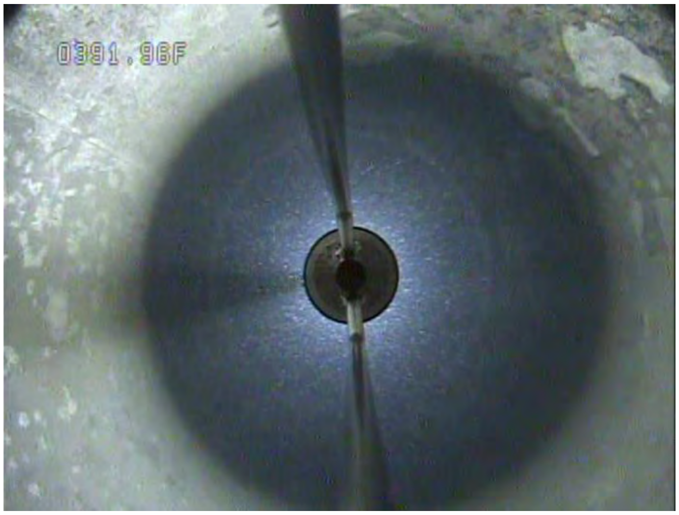


E

F



G

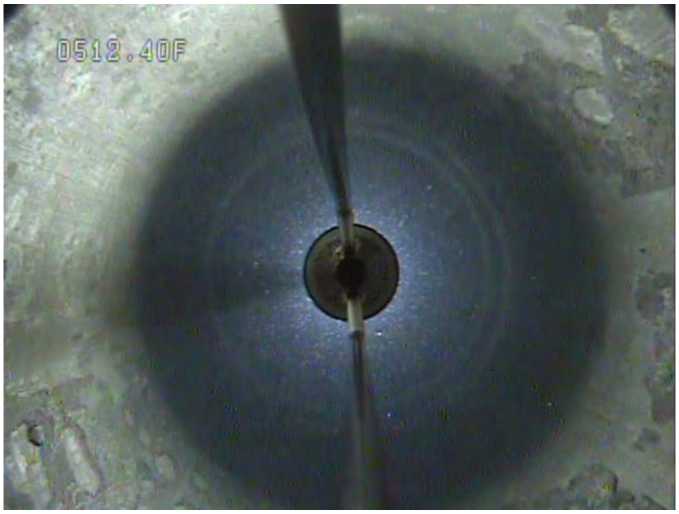


H

I

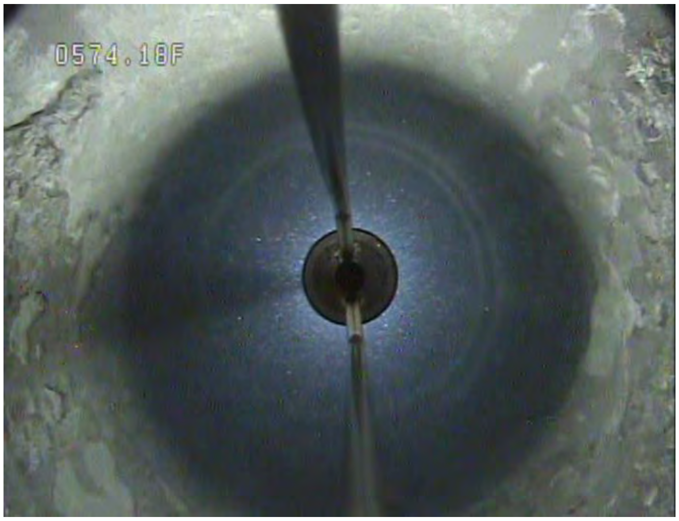
J

K



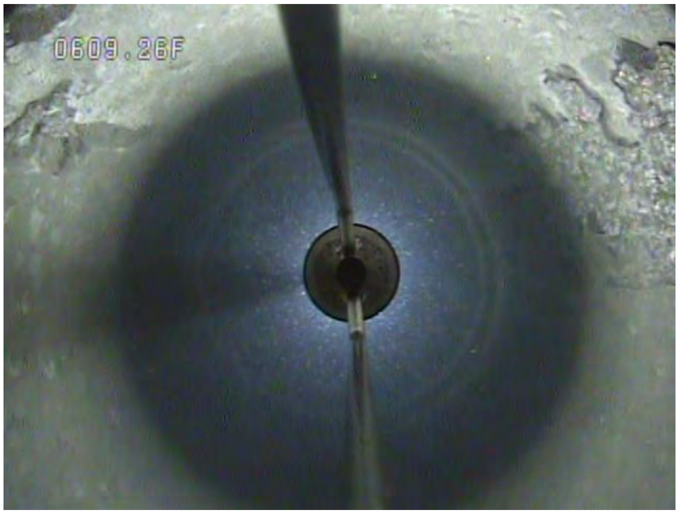
L

M

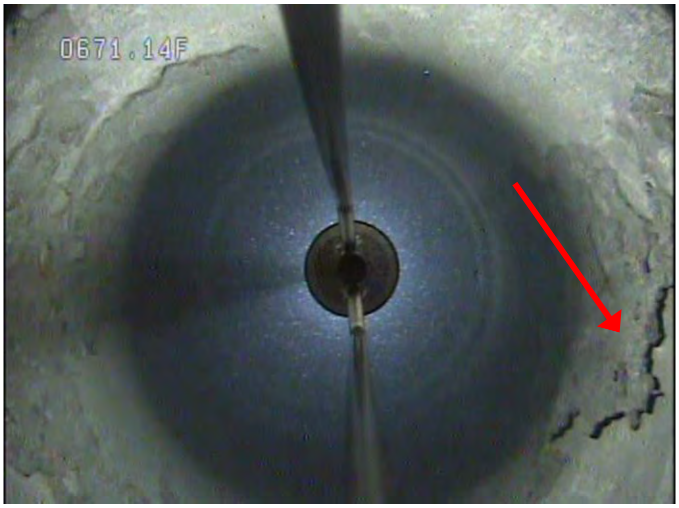


N

O



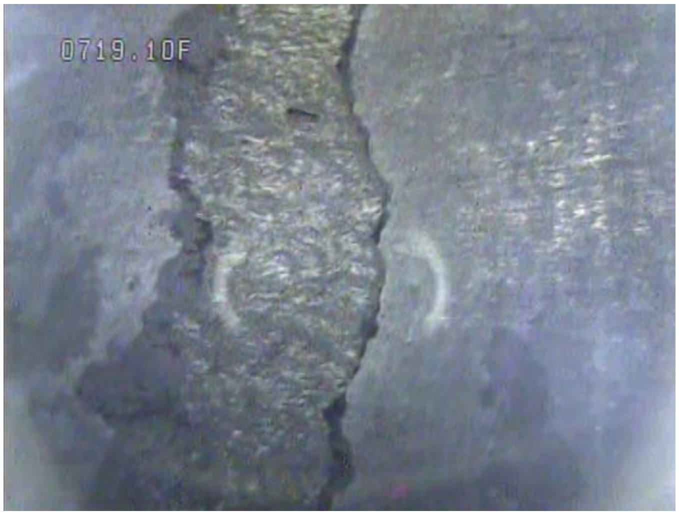
P



Q

R

S



T

U

V

W

X

Y

Z

A.1

B.1

C.1

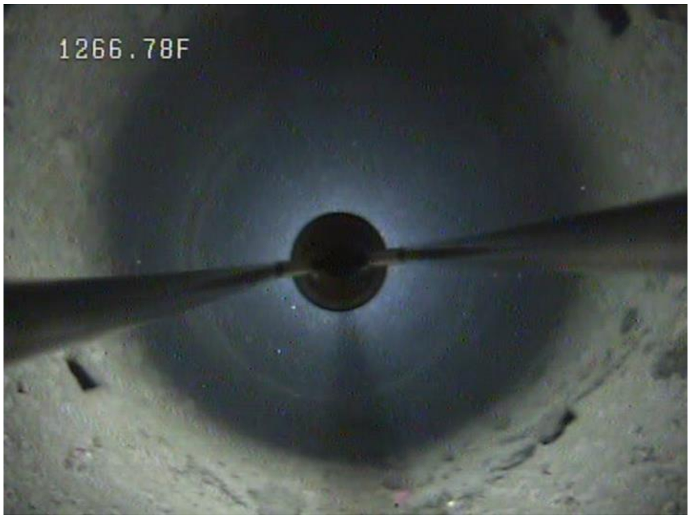
D.1

E.1

F.1

G.1

H.1



I.1

J.1

K.1

L.1

M.1

N.1

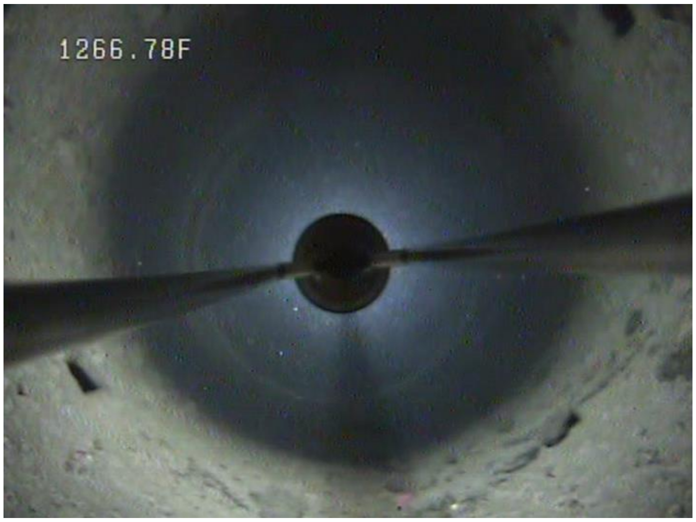
O.1

P.1

Q.1

R.1

S.1



T.1

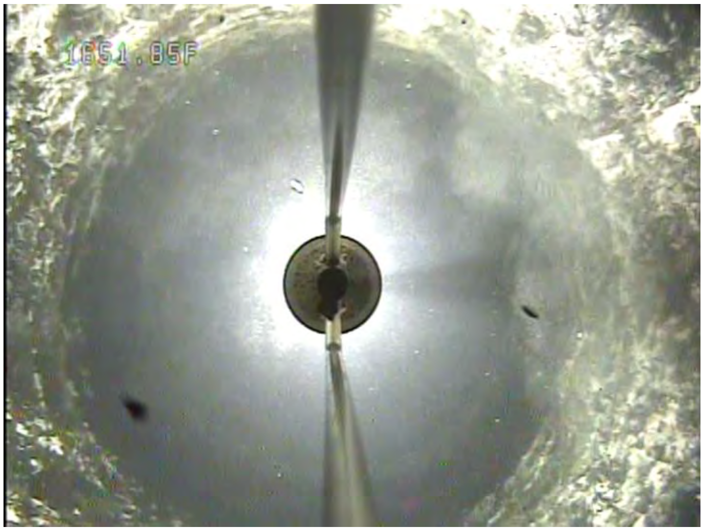
U.1

V.1

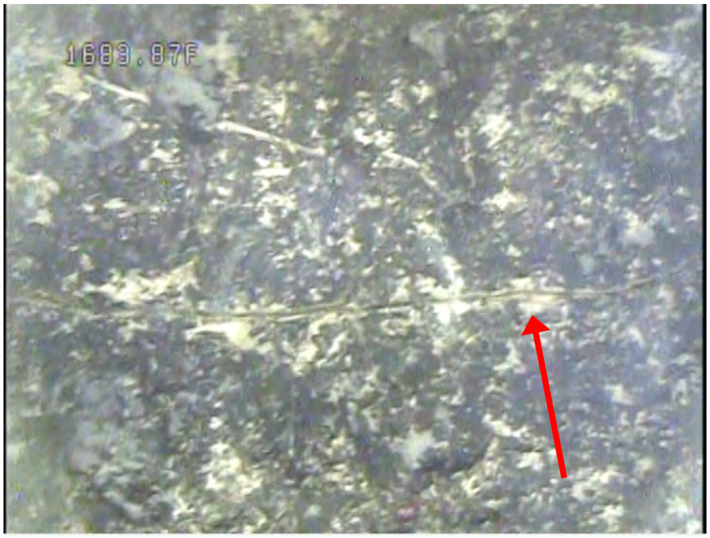
W.1

X.1

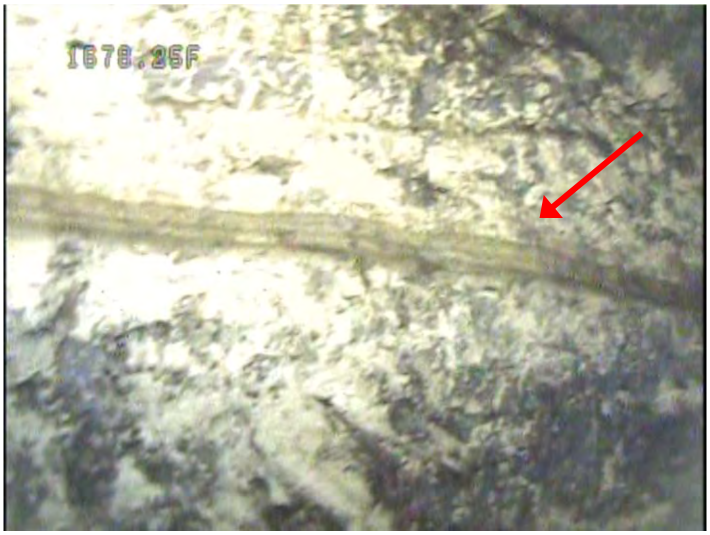
Y.1



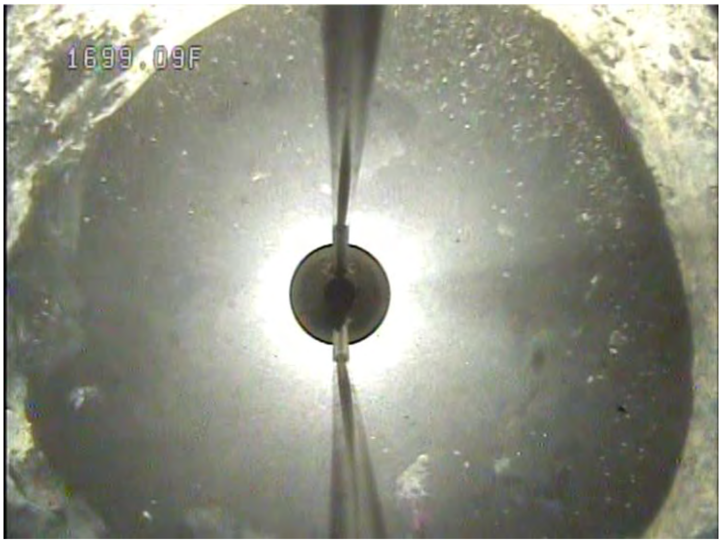
Z.1



A.2



B.2



C.2

APPENDIX F

XY Caliper Log

Appendix F

F.1 XY CALIPER LOG

YOUNGQUIST BROTHERS

X-Y CALIPER LOG

Company	SFWMD LOWRP
Well	L-63N ASR
Field	TAYLOR CREEK
County	OKEECHOBEE
State	FL

Company SFWMD LOWRP
Well L-63N ASR
Field TAYLOR CREEK
County OKEECHOBEE State FL
Location: API #:
4019 SR 710 EAST OKEECHOBEE, FL
SEC TWP RGE
Other Services
SEE
COMMENTS
Permanent Datum Elevation
Log Measured From
Drilling Measured From
Elevation
K.B.
D.F.
G.L.

Date	2/24/2020	
Run Number	ONE	
Depth Driller	1700'	
Depth Logger	1700'	
Bottom Logged Interval	1700'	
Top Log Interval	1150'	
Open Hole Size	17.5"	
Type Fluid	H20	
Density / Viscosity	N/A	
Max. Recorded Temp.	N/A	
Estimated Cement Top	N/A	
Time Well Ready	10:00	
Time Logger on Bottom	12:00	
Equipment Number	107	
Location	FT. MYERS	
Recorded By	R.GARCIA	K.BOBLITT
Witnessed By	H.RAHMAN	

Borehole Record				Tubing Record			
Run Number	Bit	From	To	Size	Weight	From	To
ONE	17.5"	1268'	1700'				

Casing Record	Size	Wgt/Ft	Top	Bottom
Surface String	42"	.500" W.T.	0'	65'
Prot. String	34"	.500" W.T.	0'	200'
Production String	24"	.500" W.T.	0'	1268'
Liner				

<<< Fold Here >>>

Comments

OTHER SERVICES:

VIDEO SURVEY

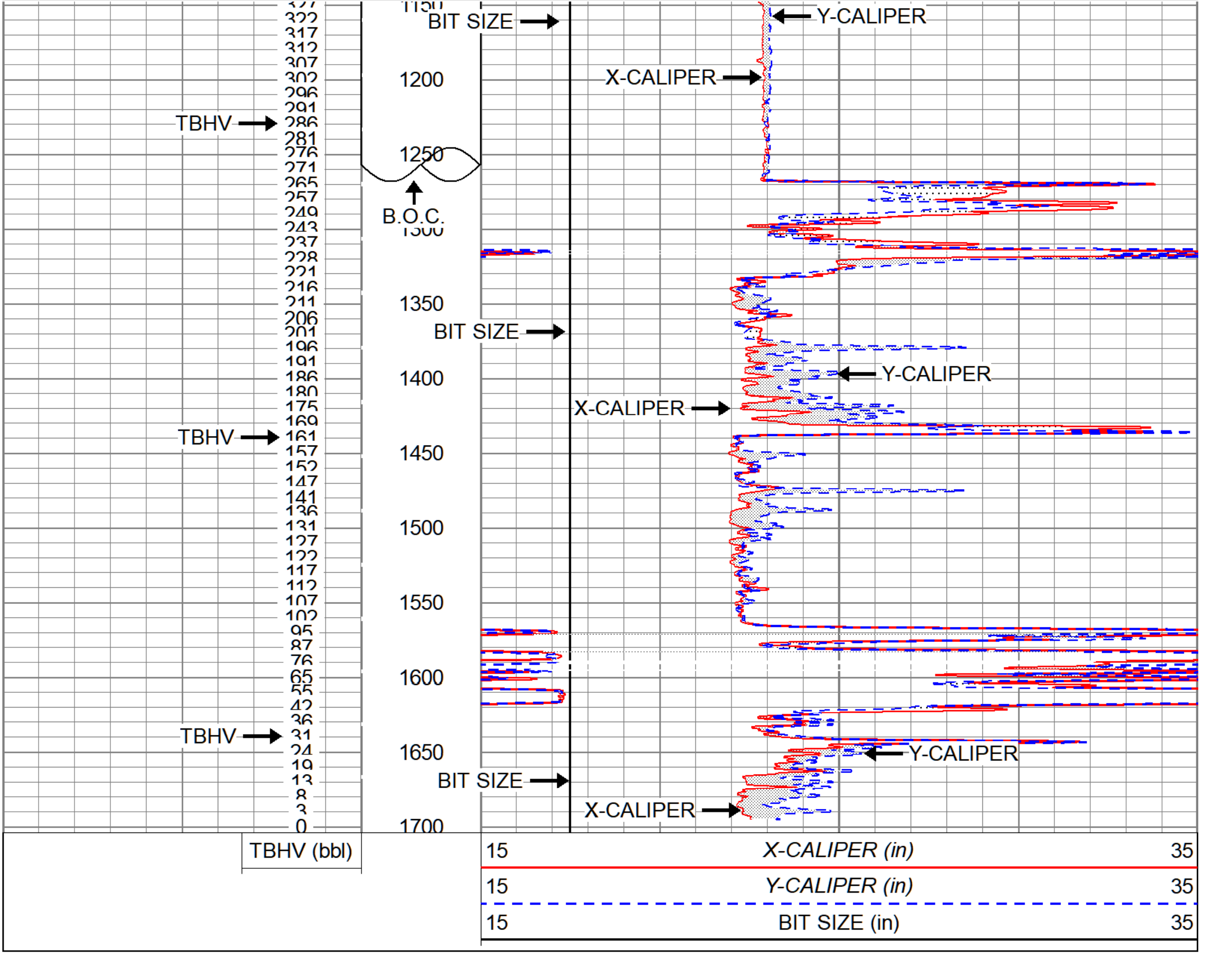
MAX CALIPER ARM = 36"

YOUNGQUIST BROTHERS

MAIN PASS

Database File sfwmd-l-63n.db
Dataset Pathname XYC5.2
Presentation Format grxyc
Dataset Creation Mon Feb 24 20:40:02 2020
Charted by Depth in Feet scaled 1:1200

TBHV (bbl)
15 X-CALIPER (in) 35
15 Y-CALIPER (in) 35
15 BIT SIZE (in) 35



TBHV (bbl)
15 X-CALIPER (in) 35
15 Y-CALIPER (in) 35
15 BIT SIZE (in) 35

YOUNGQUIST BROTHERS

MAIN PASS

Database File sfwmd-l-63n.db
Dataset Pathname XYC5.2
Presentation Format grxyc
Dataset Creation Mon Feb 24 20:40:02 2020
Charted by Depth in Feet scaled 1:600

TBHV (bbl)
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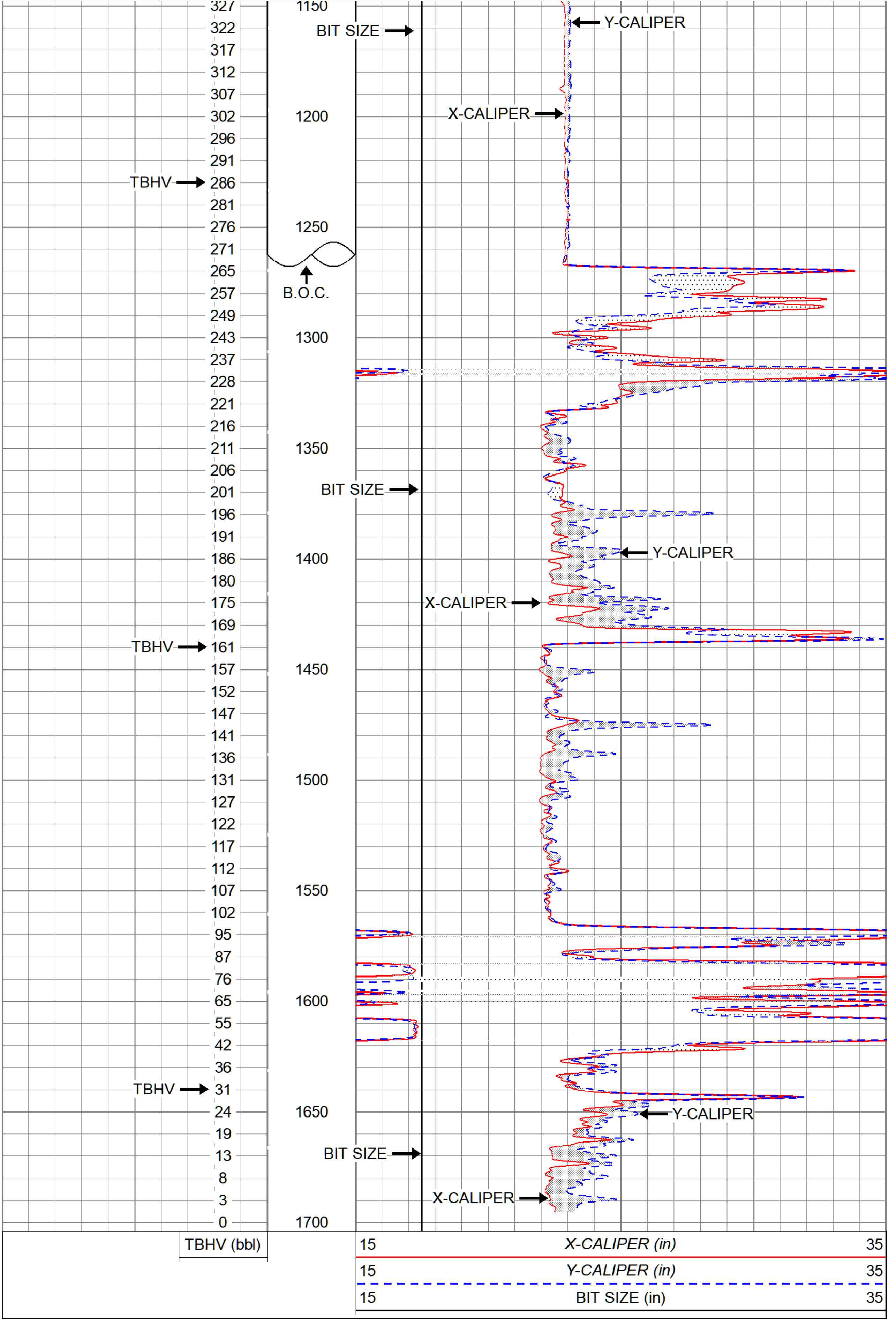
15 Y-CALIPER (in) 35
15 BIT SIZE (in) 35



TBHV (bbl)
15 X-CALIPER (in) 35
15 Y-CALIPER (in) 35
15 BIT SIZE (in) 35

YOUNGQUIST BROTHERS

MAIN PASS

Database File sfwmd-l-63n.db
Dataset Pathname XYC5.2
Presentation Format grxyc
Dataset Creation Mon Feb 24 20:40:02 2020
Charted by Depth in Feet scaled 1:240

TBHV (bbl)
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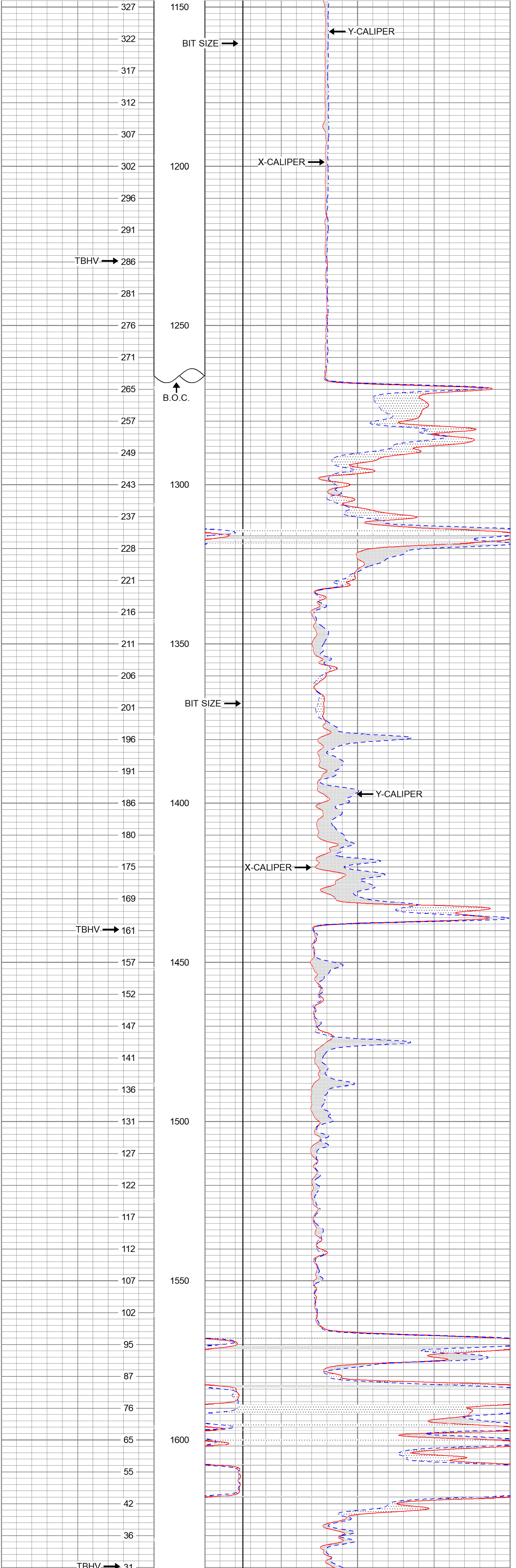
15 Y-CALIPER (in) 35
15 BIT SIZE (in) 35



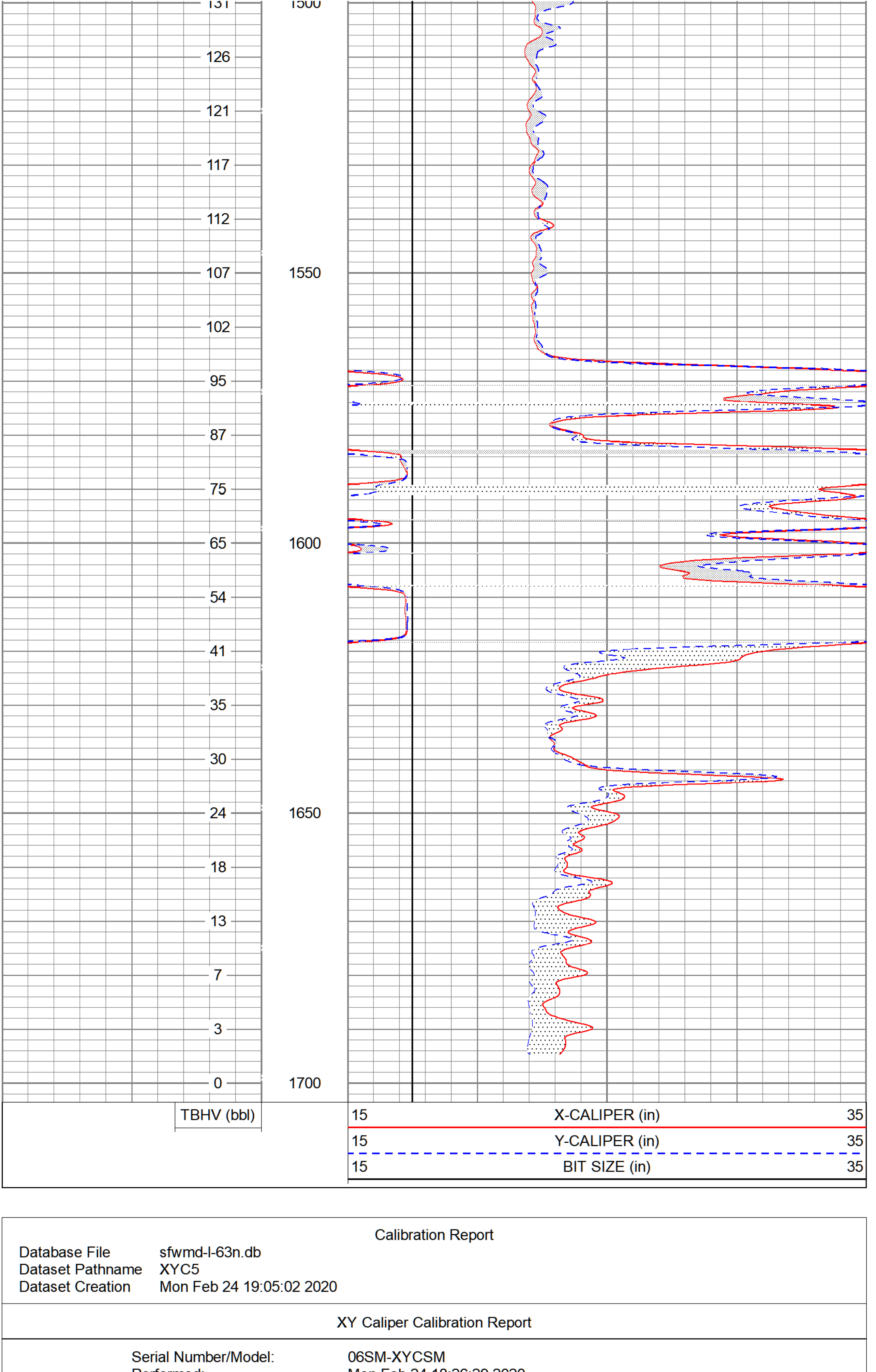
TBHV (bbl)
15 X-CALIPER (in) 35
15 Y-CALIPER (in) 35
15 BIT SIZE (in) 35

YOUNGQUIST BROTHERS

REPEAT PASS

Database File sfwmd-l-63n.db
Dataset Pathname XYC4.2
Presentation Format grxyc
Dataset Creation Mon Feb 24 20:40:29 2020
Charted by Depth in Feet scaled 1:240

TBHV (bbl)
15 X-CALIPER (in) 35
15 Y-CALIPER (in) 35
15 BIT SIZE (in) 35



TBHV (bbl)
15 X-CALIPER (in) 35
15 Y-CALIPER (in) 35
15 BIT SIZE (in) 35

Calibration Report

Database File sfwmd-l-63n.db
Dataset Pathname XYC5
Dataset Creation Mon Feb 24 19:05:02 2020

XY Caliper Calibration Report

Serial Number/Model: 06SM-XYCSM
Performed: Mon Feb 24 18:26:29 2020

Ring			X Caliper		Y Caliper	
1:	10	in	401.011	cps	433.371	cps
2:	20	in	768.876	cps	782.36	cps
3:	30	in	1205.96	cps	1201.57	cps
4:	36	in	1475.39	cps	1464.72	cps
5:		in		cps		cps
6:		in		cps		cps
7:		in		cps		cps
8:		in		cps		cps
9:		in		cps		cps
10:		in		cps		cps

Sensor	Offset (ft)	Schematic	Description	Length (ft)	O.D. (in)	Weight (lb
			CHD-StdCHD	1.00	1.69	10.00
YCAL XCAL	3.50 3.50		XYC-XYCSM (06SM)	6.60	3.50	87.00

Dataset: sfwmd-l-63n.db: field/well/run1/XYC5
Total length: 7.60 ft
Total weight: 97.00 lb
O.D.: 3.50 in

APPENDIX G

Pressure Test Documentation

Appendix G

G.1 PRESSURE TEST DOCUMENTATION

Stantec

L-63N MIT Casing Pressure Test Log

DATE: February 28, 2020

Lake Okeechobee ASR Project

JOB NUMBER: 177311456
CONTRACTOR: Youngquist Brothers Inc. (YBI)
PROJECT MGR: Rick Cowles/Stantec

OWNER: SFWMD
DESCRIPTION OF OPERATIONS: Pressure test for 24-inch diameter steel casing. Center of packer installed to 1,253.36 feet bpl.

START TIME: 9:21
FINISH TIME: 10:21
CASING SIZE: 24-inch Outside Diameter
INITIAL PRESSURE: 51.5
GAUGE SERIAL NUMBER: 050417
CALCULATED WATER VOLUME: 6.8 gallons
OBSERVED WATER VOLUME: 6.5 gallons

TIME	MINUTES	PRESSURE (psi)	COMMENTS
9:21	0	51.50	Start test
9:26	5	51.50	
9:31	10	51.50	
9:36	15	51.25	
9:41	20	51.25	
9:46	25	51.25	
9:51	30	51.00	
9:56	35	51.00	
10:01	40	51.00	
10:06	45	50.75	
10:11	50	50.75	
10:16	55	50.5	
10:21	60	50.5	End test - pressure loss is 1.9%

PRESSSURE BLEED-OFF			
TIME	PRESSURE	VOLUME OF WATER COLLECTED (GAL)	CUMULATIVE VOLUME (GAL)
10:22	30		
10:23	10	4	4
10:23	14.5	1	5
10:24	3	1	6
10:24	5	0.5	6.5
*Note: YBI stopped and dumped out first 5 gallon bucket of water.			
*Note: Per YBI, pressure gauge can't go to 0 psi, otherwise it will break.			

Witnessed By:

FDEP Representative

Stantec Representative Nyrole D. Sharma

YBI Representative Carlos Lopes

Stantec

YBI Pipe Tally

L-63N MIT Lake Okeechobee ASR Project

Well Name **L-63N**
Job Number **177311456**
Owner **SFWMD**

Item	Length (feet)	String Length (feet)	Date
C. L Packer	11.76	11.76	02/28/20
1	29.55	41.31	
2	29.46	70.77	
3	29.50	100.27	
4	29.72	129.99	
5	29.44	159.43	
6	29.45	188.88	
7	29.66	218.54	
8	29.35	247.89	
9	29.59	277.48	
10	29.73	307.21	
11	29.59	336.80	
12	29.54	366.34	
13	29.50	395.84	
14	28.05	423.89	
15	29.46	453.35	
16	27.80	481.15	
17	29.49	510.64	
18	29.41	540.05	
19	29.46	569.51	
20	29.53	599.04	
21	29.48	628.52	
22	29.45	657.97	
23	29.42	687.39	
24	29.49	716.88	
25	29.48	746.36	
26	29.46	775.82	
27	29.35	805.17	
28	29.42	834.59	
29	29.61	864.20	
30	29.55	893.75	
31	29.49	923.24	
32	29.52	952.76	
33	29.57	982.33	
34	29.86	1012.19	
35	29.74	1041.93	
36	29.73	1071.66	
37	29.64	1101.30	
38	29.71	1131.01	
39	29.38	1160.39	
40	29.80	1190.19	
41	29.60	1219.79	
42	29.57	1249.36	
Pup Joint	10.00	1259.36	
Sub Out (stick-up)	-6.00		
C. L. B.P.L		1253.36	

Certificate of Calibration

ØZONE
INDUSTRIES
CORPORATION
15551 PINE RIDGE ROAD
FORT MYERS, FL 33908

Ozone Industries, Inc.

Precision Measurement Equipment Division

Purchase Order #

Calibration Performed By:
OZONE INDUSTRIES, INC.
15551 PINE RIDGE RD.
FORT MYERS, FL 33908

For:
YOUNGQUIST BROTHERS, INC.
15465 PINE RIDGE RD.
FORT MYERS, FL 33908

EQUIPMENT INFORMATION:

Description:	Pressure Guage	Job Site:	Okeechobee
Manufacter:	McDaniel Controls, Inc.	Cal Date:	12/24/2019
Model Number:	FG	Cal. Due Date:	12/24/2020
Part Number:	FF-GF	Cal. Interval	Annual
Range:	0 - 200 psi	Received:	12/24/2019
		Calibration Result:	PASS
Serial Number:	**050417**	Environmental Conditions:	76°F / 48% R.H. / 30.07 in Hg
Customer I.D.:		Performed By:	R.J.
Cust. Barcode:			
Cust. Location:	Fort Myers, FL	Procedure:	Calibration
Specifications:	+/- 0.25% FS		

This is to certify that the above listed instrument meets or exceeds all specifications as stated in the referenced procedure at the points tested (unless otherwise noted). It has been Calibrated using measurement standards traceable to the National Institute of Standards and Technology (NIST), or to NIST accepted intrinsic standards of measurement, or derived by the ratio type of self-calibration techniques. This calibration is in accordance with Ozone Industries, Inc Quality Assurance Manual. Any number of factors may cause the calibration item to drift out of calibration before the recommended interval has expired.

Calibration Remarks:

THIS UNIT FOUND TO BE IN TOLERANCE AT TIME OF CALIBRATION.
PERFORMED ROUTINE CALIBRATION / CERTIFICATION.

Standards Used to Calibrate Equipment:

Company	I.D.	Description	Last Cal.	Cal. Due Date
OZONE	A1731	EATON UPC5000 PNEUMATIC CALIBRATOR	2/5/2019	2/5/2020

Certified by:

Print: Robert Jodoin
Date: 12/24/2019

ØZONE
INDUSTRIES
CORPORATION
15551 PINE RIDGE ROAD
FORT MYERS, FL 33908

PH: 239-433-3400
FAX: 239-489-3877

CONTROL NO: 12/24/2019 050417

CUSTOMER: YBI15465

CALIBRATION DATA FORM

MFR:	McDaniel Controls, Inc.	**DESCRIPTION**	PRESSURE GAUGE
MODEL NO:	0 - 200 psi	**TECHNICIAN:**	0055
SERIAL NO:	050417	**CAL. DATE:**	12/24/2019
CUST. ID:	YBI	**DUE DATE:**	12/24/2020

RANGE: 0 - 200 psi

Guage Reading	Reference Reading	LOW LIMIT	HIGH LIMIT	% ERR.
0.0	0.00	-1.0	1.0	0.00
40.0	39.70	39.0	41.0	0.15
80.0	80.15	79.0	81.0	0.08
120.0	120.40	119.0	121.0	0.20
160.0	160.20	159.0	161.0	0.10
200.0	199.55	199.0	201.0	0.22

APPENDIX H

Step-Rate Pumping Test Field Log

Appendix H

H.1 STEP-RATE PUMPING TEST FIELD LOG

Step-Rate Pumping Test Field Log

L-63N MIT

Project: Lake Okeechobee ASR Project

Well No.: **L-63N**

Observers: Hannah Rahman & Cora Summerfield/Stantec

Meter Readings (10,000 gallons): Start: 733 End: 991 Total: **218** **Total Gallons**

Project: 177311456

Interval: 1,268 to 1,700 ft bpl

Start Time: 7:30 **End Time:** 16:30

Transducer Depth: 18 feet from top of concrete well pad

Static Water Level: 8.083 ft als

Date	Time	Elapsed Time (hrs:min)	Elapsed Time mins	Temperature (°F)	Water Level (feet above transducer)	Drawdown (feet)	Pump Rate (gpm)	Pressure (psi)	Comments
3/23/2020	7:29	0:00	0	79.556	26.074	0.000		11.295	beginning of step 1; totalizer = 733 gallons
3/23/2020	7:30	0:01	1	79.561	25.067	1.007		10.875	
3/23/2020	7:32	0:03	3	79.544	23.476	2.598		10.363	
3/23/2020	7:33	0:04	4	79.562	23.866	2.208		10.174	
3/23/2020	7:34	0:05	5	79.605	23.662	2.412		10.324	
3/23/2020	7:35	0:06	6	79.615	23.903	2.171	2100	10.292	
3/23/2020	7:36	0:07	7	79.628	23.658	2.416		10.274	
3/23/2020	7:37	0:08	8	79.700	23.855	2.219		10.213	
3/23/2020	7:38	0:09	9	79.666	24.022	2.052		10.313	
3/23/2020	7:39	0:10	10	79.698	23.878	2.196		10.267	
3/23/2020	7:40	0:11	11	79.736	23.816	2.258		10.214	
3/23/2020	7:45	0:16	16	79.991	23.783	2.291		10.283	
3/23/2020	7:50	0:21	21	80.585	23.647	2.427		10.256	
3/23/2020	7:55	0:26	26	81.203	23.662	2.412	2100	10.193	totalizer = 739 gallons; specific capacity = 786 gpm/ft dd
3/23/2020	8:00	0:31	31	81.816	23.746	2.328		10.223	
3/23/2020	8:10	0:41	41	82.942	23.230	2.844		10.151	
3/23/2020	8:20	0:51	51	83.462	23.437	2.637		9.893	
3/23/2020	8:30	1:01	61	83.717	23.229	2.845		10.881	
3/23/2020	8:40	1:11	71	84.037	23.219	2.855	2200	10.096	
3/23/2020	8:50	1:21	81	84.301	23.077	2.997		10.057	
3/23/2020	9:00	1:31	91	84.428	23.194	2.880	2200	10.091	totalizer = 755.3 gallons; specific capacity = 770.85 gpm/ft dd
3/23/2020	9:21	1:52	112	84.566	23.422	2.652		10.343	
3/23/2020	9:15	1:46	106				2150		totalizer = 757.5 gallons
3/23/2020	9:30	2:01	121	84.628	23.165	2.909	2200	10.132	
3/23/2020	9:45	2:16	136	84.679	23.674	2.400		10.223	
3/23/2020	10:00	2:31	151	84.776	23.542	2.532		10.077	
3/23/2020	10:10	2:41	161				2200		totalizer = 769 gallons
3/23/2020	10:15	2:46	166	84.691	23.264	2.810		10.208	
3/23/2020	10:23	2:54	174				2200		totalizer = 769 gallons
3/23/2020	10:29	3:00	180	84.789	23.452	2.622		10.171	end of step 1
3/23/2020	10:30	3:01	181	84.822	14.080	11.994		7.960	beginning of step 2
3/23/2020	10:31	3:02	182	84.798	17.043	9.031		7.322	
3/23/2020	10:32	3:03	183	84.816	15.203	10.871		6.472	
3/23/2020	10:33	3:04	184	84.836	13.495	12.579		6.329	
3/23/2020	10:34	3:05	185	84.805	14.781	11.293		6.416	
3/23/2020	10:35	3:06	186	84.836	14.956	11.118		6.471	
3/23/2020	10:36	3:07	187	84.810	14.766	11.308		6.544	
3/23/2020	10:37	3:08	188	84.824	15.213	10.861	5200	6.565	totalizer = 777.5 gallons; specific capacity = 498.2 gpm/ft dd
3/23/2020	10:38	3:09	189	84.828	14.731	11.343		6.154	
3/23/2020	10:39	3:10	190	84.840	13.655	12.419		5.880	
3/23/2020	10:40	3:11	191	84.837	14.433	11.641		6.157	
3/23/2020	10:45	3:16	196	84.849	14.201	11.873		6.971	

Date	Time	Elapsed Time (hrs:min)	Elapsed Time mins	Temperature (°F)	Water Level (feet above transducer)	Drawdown (feet)	Pump Rate (gpm)	Pressure (psi)	Comments
3/23/2020	10:50	3:21	201	84.811	13.816	12.258	5200	6.325	totalizer = 784 gallons
3/23/2020	10:55	3:26	206	84.889	14.383	11.691		6.782	
3/23/2020	11:00	3:31	211	84.989	14.478	11.596		6.980	
3/23/2020	11:10	3:41	221	84.954	15.709	10.365		6.785	
3/23/2020	11:24	3:55	235	84.967	15.519	10.555		6.115	
3/23/2020	11:30	4:01	241	84.988	15.247	10.827		6.478	
3/23/2020	11:40	4:11	251	85.011	14.673	11.401		6.397	
3/23/2020	11:50	4:21	261	85.032	13.949	12.125	5200	5.953	totalizer = 824.5 gallons; specific capacity = 438.97 gpm/ft dd
3/23/2020	12:00	4:31	271	85.038	14.461	11.613		6.698	
3/23/2020	12:15	4:46	286	85.065	14.205	11.869		6.310	
3/23/2020	12:30	5:01	301	85.034	14.805	11.269		6.425	
3/23/2020	12:45	5:16	316	85.052	14.848	11.226		6.133	
3/23/2020	13:00	5:31	331	85.090	14.284	11.790	5050	6.299	totalizer = 852 gallons; specifc capacity = 465 gpm/ft dd
3/23/2020	13:15	5:46	346	85.064	14.508	11.566		6.265	
3/23/2020	13:23	5:54	354				5200		totalizer = 861.5 gallons; specific capacity = 465.62 gpm/ft dd
3/23/2020	13:29	6:00	360	85.046	13.582	12.492		6.478	end of step 2
3/23/2020	13:30	6:01	361	85.006	5.719	20.355		1.845	beginning of step 3
3/23/2020	13:31	6:02	362	85.054	5.676	20.398		2.643	
3/23/2020	13:32	6:03	363	85.047	6.918	19.156	7000	3.123	
3/23/2020	13:33	6:04	364	84.957	7.494	18.580		3.129	
3/23/2020	13:34	6:05	365	85.003	7.206	18.868		3.193	
3/23/2020	13:35	6:06	366	84.999	7.580	18.494		3.037	
3/23/2020	13:36	6:07	367	84.591	7.540	18.534		3.117	
3/23/2020	13:37	6:08	368	85.012	7.362	18.712		3.364	
3/23/2020	13:38	6:09	369	85.006	7.449	18.625		3.264	
3/23/2020	13:39	6:10	370	84.974	7.912	18.162		3.21	
3/23/2020	13:40	6:11	371	84.96	7.381	18.693	6900	3.035	totalizer = 873 gallons; specific capacity = 359 gpm/ft dd
3/23/2020	13:45	6:16	376	84.992	5.711	20.363		2.357	
3/23/2020	13:50	6:21	381	84.956	5.653	20.421	7100	2.373	
3/23/2020	13:55	6:26	386	84.976	5.489	20.585		2.63	
3/23/2020	14:00	6:31	391	84.997	5.741	20.333		2.51	
3/23/2020	14:10	6:41	401	84.967	5.864	20.210		2.436	
3/23/2020	14:16	6:47	407	84.983	5.145	20.929		2.351	
3/23/2020	14:20	6:51	411	84.99	5.520	20.554	7100	2.494	totalizer = 898; specific capacity = 351.66 gpm/ft dd
3/23/2020	14:25	6:56	416	85.051	5.554	20.520		2.443	
3/23/2020	14:30	7:01	421	85.048	5.684	20.390		2.384	
3/23/2020	14:35	7:06	426	85.002	5.451	20.623		2.48	
3/23/2020	14:40	7:11	431	85.021	5.351	20.723		2.499	
3/23/2020	14:53	7:24	444	84.893	5.952	20.122	7100	2.607	totalizer = 915 gallons; specific capacity = 344.83 gpm/ft dd
3/23/2020	15:00	7:31	451	85.032	5.772	20.302		2.37	
3/23/2020	15:10	7:41	461	85.083	5.773	20.301		2352	
3/23/2020	15:20	7:51	471	85.021	5.763	20.311	7000	2.32	totalizer = 937 gallons; specific capacity = 343.27 gpm/ft dd
3/23/2020	15:30	8:01	481	85.037	5.789	20.285		2.457	
3/23/2020	15:40	8:11	491	85.034	5.167	20.907	7100	2.497	totalizer = 958 gallons; specific capacity = 372.44 gpm/ft dd
3/23/2020	15:50	8:21	501	85.012	5.700	20.374		2.455	
3/23/2020	16:00	8:31	511	85.024	5.187	20.887		2.559	
3/23/2020	16:15	8:46	526	84.989	5.530	20.544		2.492	
3/23/2020	16:29	9:00	540	85.07	5.641	20.433	7000	2.477	end of step 3; totalzer = 991 gallons
3/23/2020	16:31	9:02	542	85.046	25.572	0.502		10.772	beginning of recovery
3/23/2020	16:32	9:03	543	85.077	25.445	0.629		10.992	
3/23/2020	16:33	9:04	544	85.063	25.5	0.574		11.032	
3/23/2020	16:34	9:05	545	85.055	25.583	0.491		11.076	

APPENDIX I

STEP-RATE PUMPING TEST WATER QUALITY DATA (TABULAR)

Appendix I

I.1 STEP-RATE PUMPING TEST WATER QUALITY DATA (TABULAR)

Stantec

Step-Rate Pumping Test Water Quality Field Log
L-63N MIT

Project: Lake Okeechobee ASR Project

Project: 177311456 **Interval:** 1,268 to 1,700 ft bpl

Well No.: L-63N

Observers: Hannah Rahman & Cora Summerfield/Stantec

Start Time: 7:30 **End Time:** 16:30

Meter Readings (10,000 gallons): Start: 733 End: 991 Total: **218**

Transducer Depth: 18 feet from top of concrete well pad

Static Water Level: 8.083 ft als

Date	Time	Specific Conductance (mS/cm)	Est. TDS (mg/l)	pH (std. units)	Temperature (°C)	Turbidity (NTU) Pine/YBI	Salinity (ppt)	Rossum Sand Content (mL)	Sand (ppm)	Comments
3/23/2020	8:00	11.77	7663.5	7.97	27.90	6.33/6.59	6.71			Step 1. No Rossum Sand Test. Flow rate isn't high enough and not enough water flowing through pipe.
3/23/2020	8:30	11.81	7637.5	7.85	28.80	1.14/1.40	6.72			
3/23/2020	9:00	11.82	7702.5	7.81	29.20	0.39/0.30	6.76			
3/23/2020	9:30	11.77	7663.5	7.80	29.60	1.79/1.74	6.68			
3/23/2020	10:00	11.88	7728.5	7.72	29.5	2.4/2.43	6.74			
3/23/2020	10:15	11.64	7709.0	7.67	29.5	1.63/1.79	6.72			
3/23/2020	10:30	11.81	7676.5	7.72	29.6	0.38/0.33	6.71			
3/23/2020	10:45	12.01	7813.5	7.68	29.8	7.00/7.13	6.81	<0.01	<0.5	Step 2.
3/23/2020	11:00	11.79	7663.5	7.70	29.2	3.9/3.73	6.68			
3/23/2020	11:30	11.81	7676.5	7.60	29.7	4.42/4.75	6.69			
3/23/2020	12:00	11.90	7728.5	7.68	29.5	2.62/2.68	6.74			
3/23/2020	12:30	11.85	7702.5	7.74	29.7	4.85/4.80	6.71			
3/23/2020	13:00	11.84	7696.0	7.69	29.8	3.04/3.01	6.71			
3/23/2020	13:15	11.85	7702.5	7.67	29.7	2.01/2.49	6.72	<0.01	<0.5	
3/23/2020	13:30	11.76	7637.5	7.68	29.4	0.93/1.36	6.66			
3/23/2020	13:35	11.86	7722.0	7.63	29.7	3.44/3.71	6.73			Step 3.
3/23/2020	14:00	12.03	7813.0	7.71	29.9	23.00/25.11	6.81	<0.01	<0.5	
3/23/2020	14:30	11.97	7769.0	7.68	29.7	3.48/3.85	6.72			
3/23/2020	15:00	11.91	7741.5	7.68	29.8	2.79/2.51	6.75			
3/23/2020	15:30	11.98	7780.5	7.62	29.8	1.98/2.14	6.79			
3/23/2020	16:00	11.98	7787.0	7.67	30.0	7.2/7.11	6.79			
3/23/2020	16:15	11.89	7715.5	7.68	29.7	1.98/2.02	6.72	<0.01	<0.5	
3/23/2020	16:25	11.87	7715.5	7.64	29.8	2.12/1.57	6.73			

INSTRUMENT CALIBRATION REPORT

Pine Environmental Services LLC
3902 Corporex Park Drive, Suite 450
Tampa, FL 33619
Toll-free: (877) 259-PINE (7463)

Pine Environmental Services, Inc.

Instrument ID 45102
Description YSI Professional Plus
Calibrated 3/12/2020 5:02:07PM

Manufacturer YSI
Model Number Professional Plus
Serial Number/ Lot Number 19D103570
Location Florida
Department

State Certified NJ Cert#: 11034
Status Pass
Temp °C 24.5
Humidity % 49

Calibration Specifications

Group # 1
Group Name PH
Stated Accy Pct of Reading

Range Acc % 0.0000
Reading Acc % 3.0000
Plus/Minus 0.00

✓

Nom In Val / In Val	In Type	Out Val	Out Type	Fnd As	Lft As	Dev%	Pass/Fail
7.00 / 7.00	PH	7.00	PH	6.91	7.00	0.00%	Pass
4.00 / 4.00	PH	4.00	PH	3.88	4.00	0.00%	Pass
10.00 / 10.00	PH	10.00	PH	9.93	10.00	0.00%	Pass

Group # 2
Group Name Conductivity
Stated Accy Pct of Reading

Range Acc % 0.0000
Reading Acc % 3.0000
Plus/Minus 0.000

Nom In Val / In Val	In Type	Out Val	Out Type	Fnd As	Lft As	Dev%	Pass/Fail
1.413 / 1.413	ms/cm	1.413	ms/cm	1.396	1.413	0.00%	Pass

Group # 3
Group Name Redox (ORP)
Stated Accy Pct of Reading

Range Acc % 0.0000
Reading Acc % 3.0000
Plus/Minus 0.00

Nom In Val / In Val	In Type	Out Val	Out Type	Fnd As	Lft As	Dev%	Pass/Fail
240.00 / 240.00	mv	240.00	mv	228.00	240.00	0.00%	Pass

Group # 4
Group Name Disolved Oxygen Span
Stated Accy Pct of Reading

Range Acc % 0.0000
Reading Acc % 3.0000
Plus/Minus 0.00

Nom In Val / In Val	In Type	Out Val	Out Type	Fnd As	Lft As	Dev%	Pass/Fail
100.00 / 100.00	%	100.00	%	97.10	100.00	0.00%	Pass

INSTRUMENT CALIBRATION REPORT

Pine Environmental Services LLC
3902 Corporex Park Drive, Suite 450
Tampa, FL 33619
Toll-free: (877) 259-PINE (7463)

Pine Environmental Services, Inc.

Instrument ID 45102
Description YSI Professional Plus
Calibrated 3/12/2020 5:02:07PM

Test Instruments Used During the Calibration

(As Of Cal Entry Date)

Test Standard ID	Description	Manufacturer	Model Number	Serial Number / Lot Number	Last Cal Date/ Opened Date	Next Cal Date / Expiration Date
FL 1413 11591	FL 1413 (7G1347) CONDUCTIVITY BUFFER SOLUTION	AquaPhoenix Scientific		9GC450		3/10/2020
FL ORP 240MV 8154	FL ORP 240MV 8154	AquaPhoenix Scientific	32001	9GF122		3/10/2020
FL PH 10 2412384	FL PH 10 (7GG543) BUFFER SOLUTION	AquaPhoenix Scientific		9GD483		4/30/2021
FL PH 4 4503589	FL PH 4 (7G1006) BUFFER SOLUTION	AquaPhoenix Scientific		9GE1020	9/30/2017	5/30/2021
FL PH 7 2503C03	FL PH 7 (7GH1000) BUFFER SOLUTION	AquaPhoenix Scientific		9GF357		6/30/2021

Notes about this calibration

Calibration Result Calibration Successful
Who Calibrated Donny Mahadeo

All instruments are calibrated by Pine Environmental Services LLC according to the manufacturer's specifications, but it is the customer's responsibility to calibrate and maintain this unit in accordance with the manufacturer's specifications and/or the customer's own specific needs.

Notify Pine Environmental Services LLC of any defect within 24 hours of receipt of equipment
Please call 800-301-9663 for Technical Assistance

INSTRUMENT CALIBRATION REPORT

Pine Environmental Services LLC
3902 Corporex Park Drive, Suite 450
Tampa, FL 33619
Toll-free: (877) 259-PINE (7463)

Pine Environmental Services, Inc.

Instrument ID 26253
Description Hach 2100Q Turbidimeter
Calibrated 3/13/2020 9:33:41AM

Manufacturer HACH
Model Number 2100Q
Serial Number/ Lot Number 14080C034416
Location Florida
Department

State Certified
Status Pass
Temp °C 24.1
Humidity % 49

Calibration Specifications

Group # 1
Group Name Turbidity
Stated Accy Pct of Reading

Range Acc % 0.0000
Reading Acc % 10.0000
Plus/Minus 0.00

Nom In Val / In Val	In Type	Out Val	Out Type	Fnd As	Lft As	Dev%	Pass/Fail
10.00 / 10.00	NTU	10.00	NTU	9.79	9.82	-1.80%	Pass
20.00 / 20.00	NTU	20.00	NTU	20.30	20.00	0.00%	Pass
100.00 / 100.00	NTU	100.00	NTU	98.70	100.00	0.00%	Pass
800.00 / 800.00	NTU	800.00	NTU	800.00	800.00	0.00%	Pass

Test Instruments Used During the Calibration

(As Of Cal Entry Date)

Test Standard ID	Description	Manufacturer	Model Number	Serial Number / Lot Number	Last Cal Date/ Opened Date	Next Cal Date / Expiration Date
FL HACH 100NTU	FL HACH 100 NTU A9336	HACH	2684901	A9336		3/30/2021
FL HACH 10NTU	FL HACH 10 NTU A9331	HACH	2961801	A9331		3/30/2021
FL HACH 20NTU	FL HACH 20 NTU A9329	HACH	2684801	A9329		2/28/2021
FL HACH 800NTU	FL HACH 800 NTU A9325	HACH	2660501	A9325		2/28/2021

Notes about this calibration

Calibration Result Calibration Successful
Who Calibrated Donny Mahadeo

INSTRUMENT CALIBRATION REPORT

Pine Environmental Services LLC

3902 Corporex Park Drive, Suite 450
Tampa, FL 33619
Toll-free: (877) 259-PINE (7463)

Pine Environmental Services, Inc.

Instrument ID	26253
Description	Hach 2100Q Turbidimeter
Calibrated	3/13/2020 9:33:41AM

All instruments are calibrated by Pine Environmental Services LLC according to the manufacturer's specifications, but it is the customer's responsibility to calibrate and maintain this unit in accordance with the manufacturer's specifications and/or the customer's own specific needs.

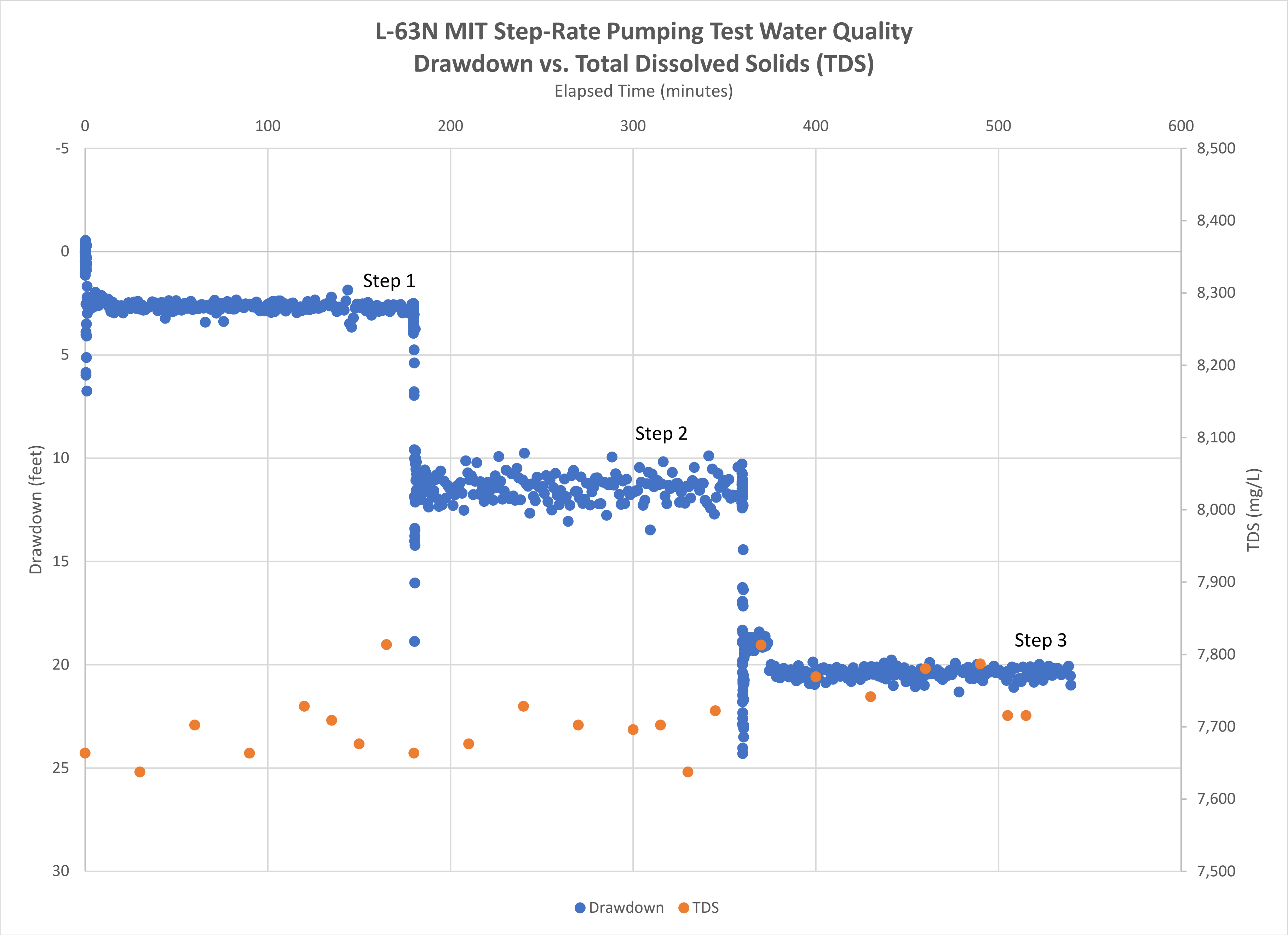
Notify Pine Environmental Services LLC of any defect within 24 hours of receipt of equipment
Please call 800-301-9663 for Technical Assistance

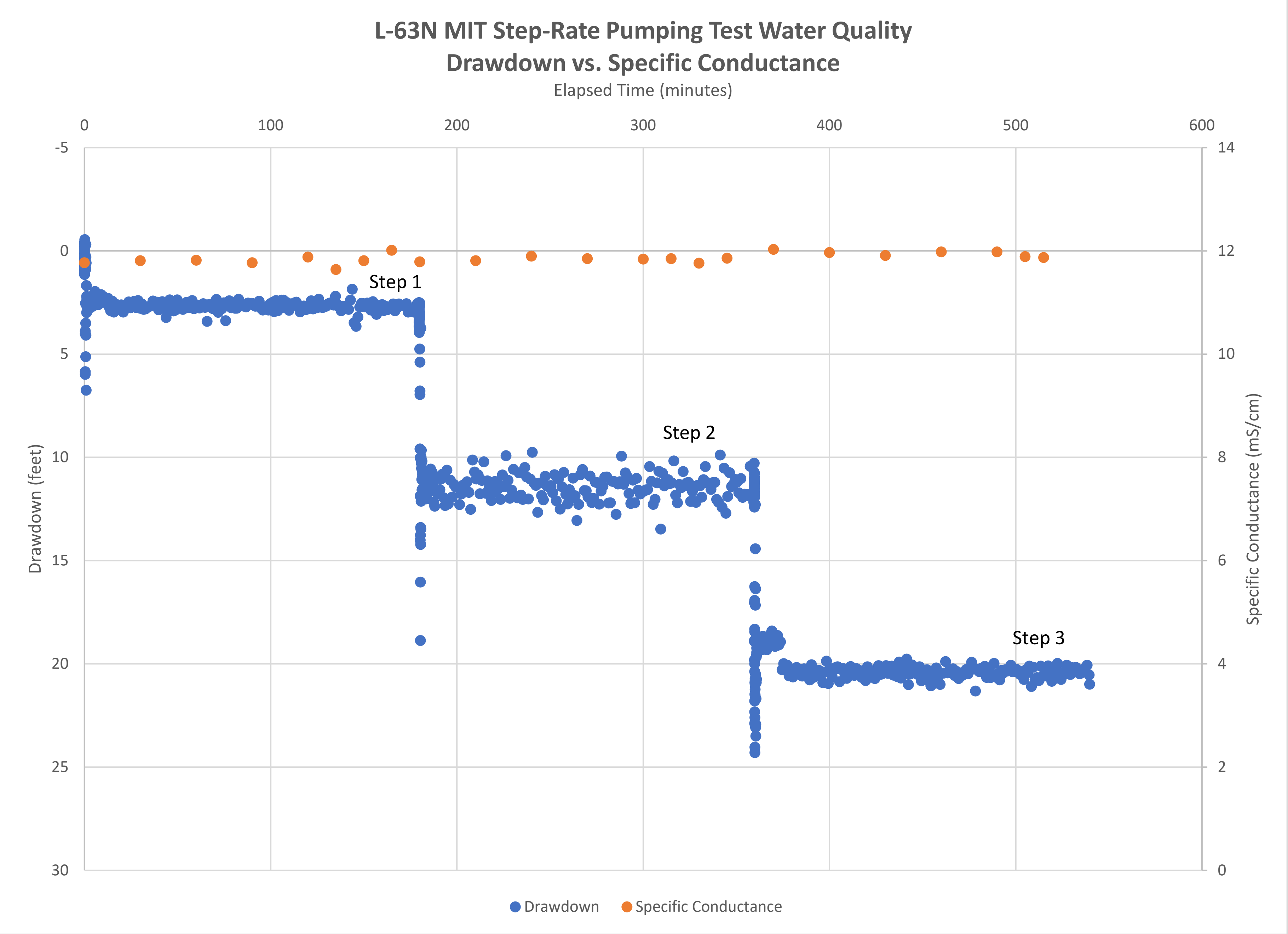
APPENDIX J

Step-Rate Pumping Test Water Quality Data (Graphical)

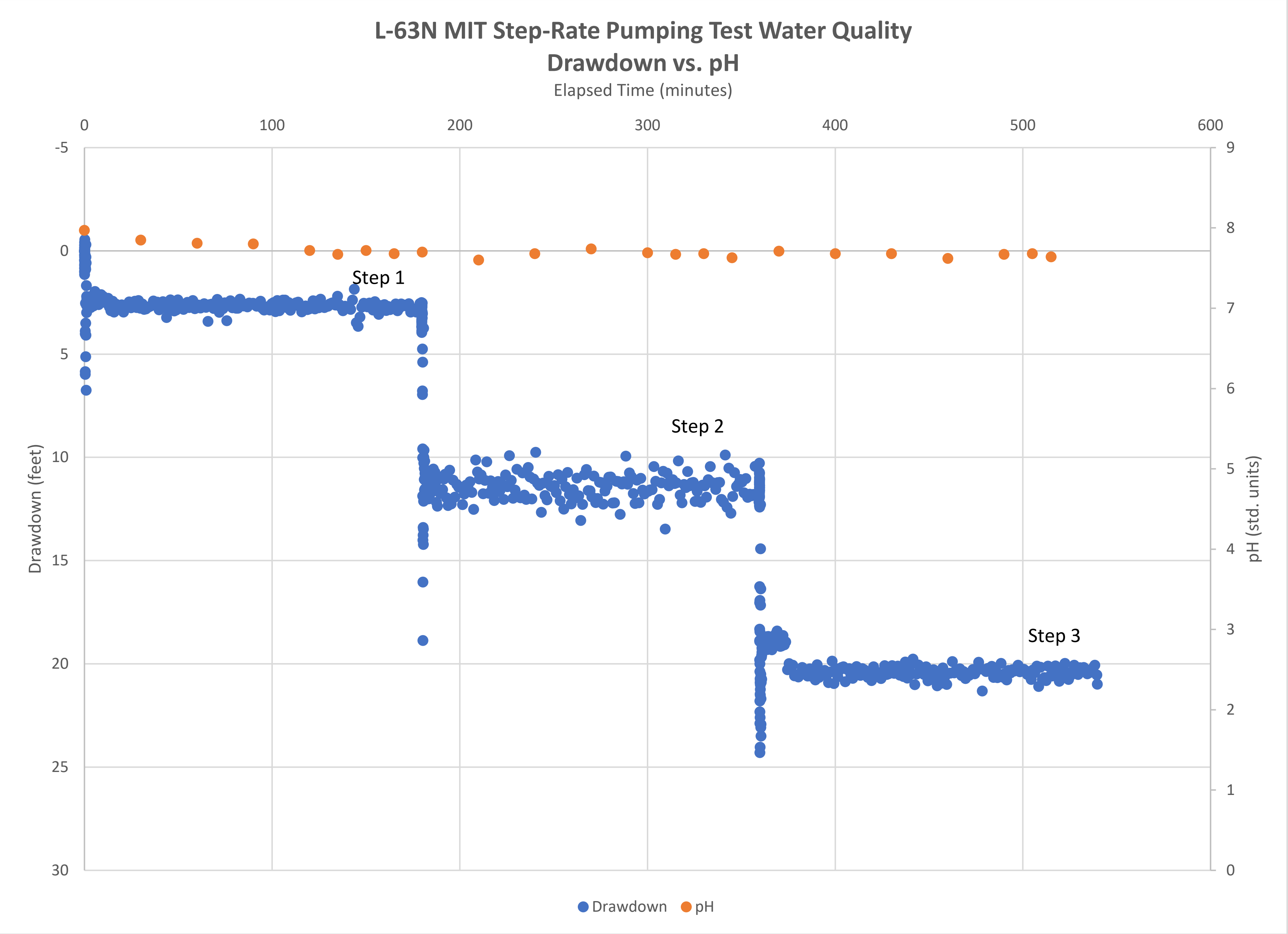
Appendix J

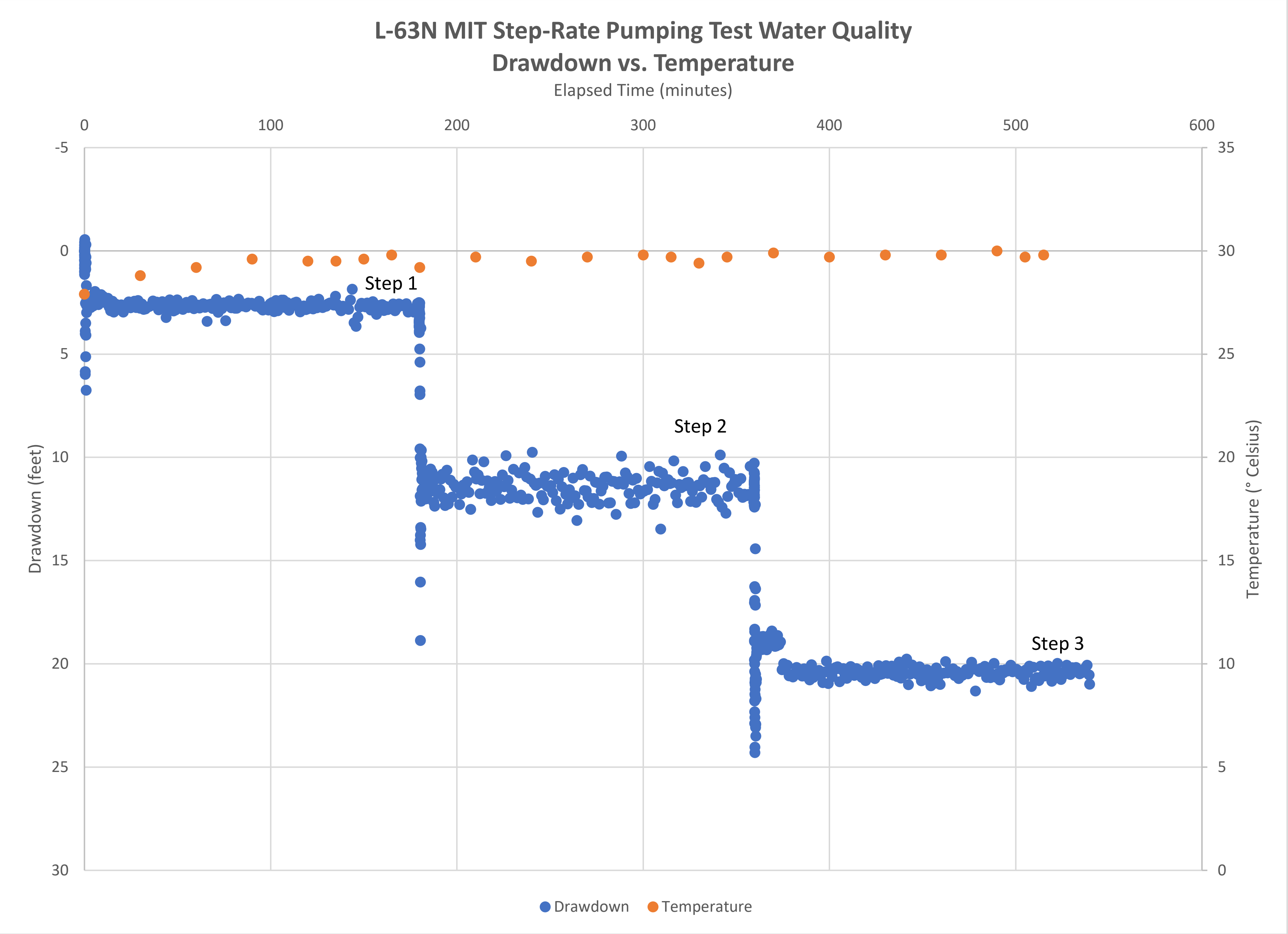
J.1 STEP-RATE PUMPING TEST WATER QUALITY DATA (GRAPHICAL)

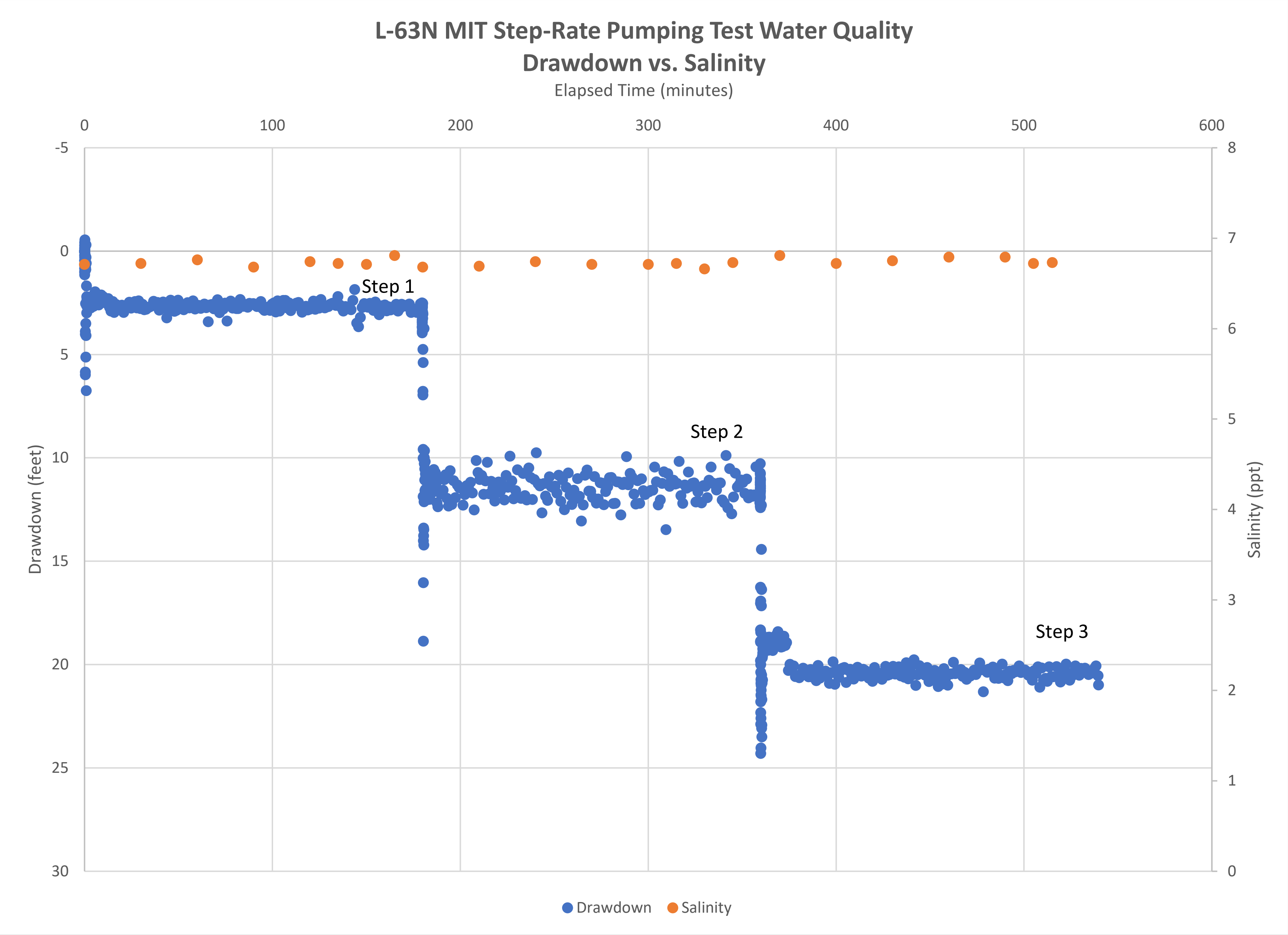

L-63N MIT Step-Rate Pumping Test Water Quality
Drawdown vs. Total Dissolved Solids (TDS)
Elapsed Time (minutes)
0
100
200
300
400
500
600
-5
0
5
10
15
20
25
30
Drawdown (feet)
8,500
8,400
8,300
8,200
8,100
8,000
7,900
7,800
7,700
7,600
7,500
TDS (mg/L)
Step 1
Step 2
Step 3
● Drawdown
● TDS



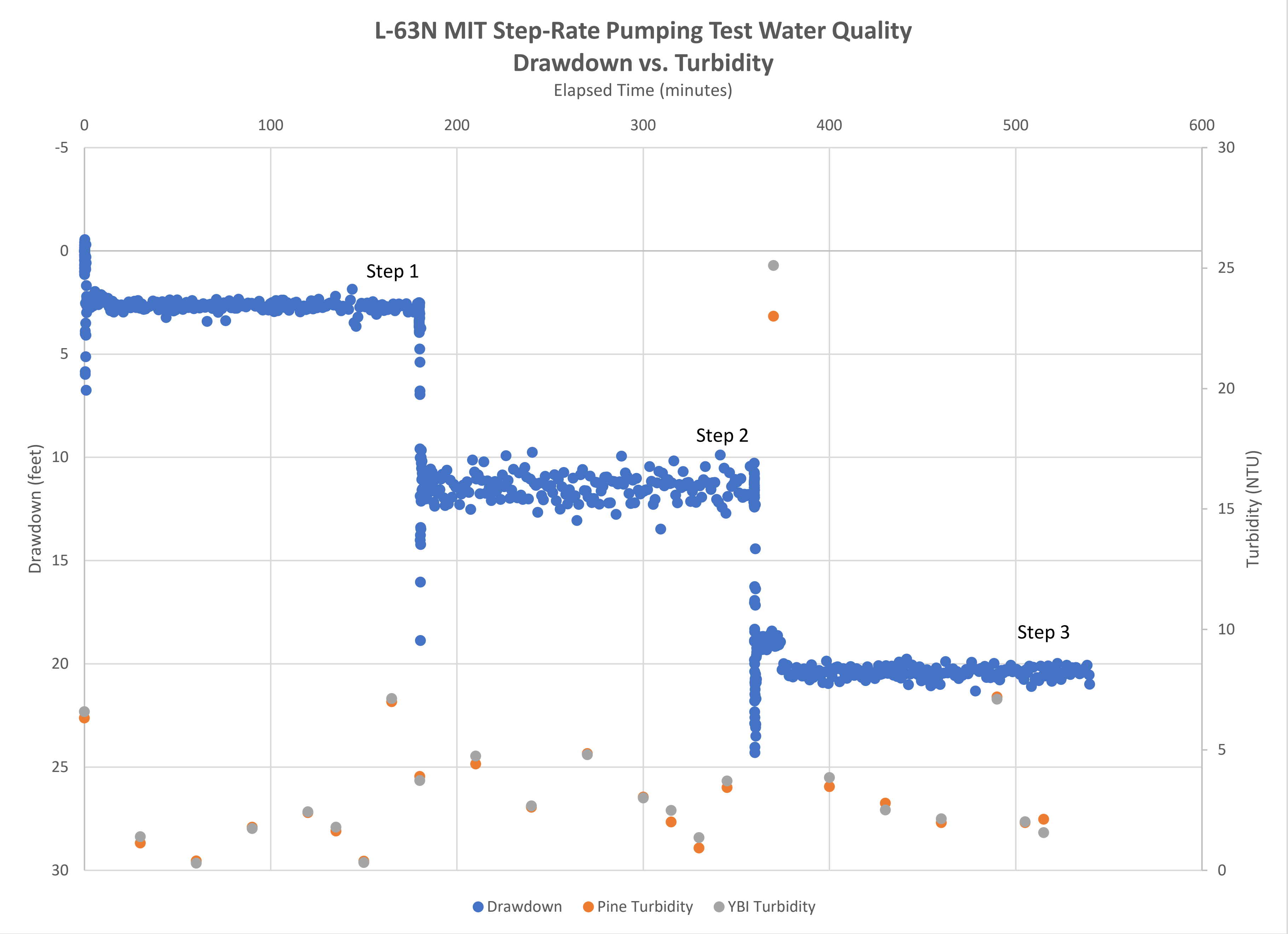
L-63N MIT Step-Rate Pumping Test Water Quality
Drawdown vs. Specific Conductance
Elapsed Time (minutes)
0
100
200
300
400
500
600
Drawdown (feet)
-5
0
5
10
15
20
25
30
Specific Conductance (mS/cm)
14
12
10
8
6
4
2
0
Step 1
Step 2
Step 3
● Drawdown
● Specific Conductance


L-63N MIT Step-Rate Pumping Test Water Quality
Drawdown vs. pH
Elapsed Time (minutes)
0
100
200
300
400
500
600
-5
0
5
10
15
20
25
30
Drawdown (feet)
9
8
7
6
5
4
3
2
1
0
pH (std. units)
Step 1
Step 2
Step 3
● Drawdown
● pH


L-63N MIT Step-Rate Pumping Test Water Quality
Drawdown vs. Temperature
Elapsed Time (minutes)
0
100
200
300
400
500
600
-5
0
5
10
15
20
25
30
35
30
25
20
15
10
5
0
Drawdown (feet)
Temperature (° Celsius)
Step 1
Step 2
Step 3
● Drawdown
● Temperature



L-63N MIT Step-Rate Pumping Test Water Quality
Drawdown vs. Salinity


L-63N MIT Step-Rate Pumping Test Water Quality
Drawdown vs. Turbidity
Elapsed Time (minutes)
0
100
200
300
400
500
600
-5
0
5
10
15
20
25
30
Drawdown (feet)
30
25
20
15
10
5
0
Turbidity (NTU)
Step 1
Step 2
Step 3
● Drawdown
● Pine Turbidity
● YBI Turbidity

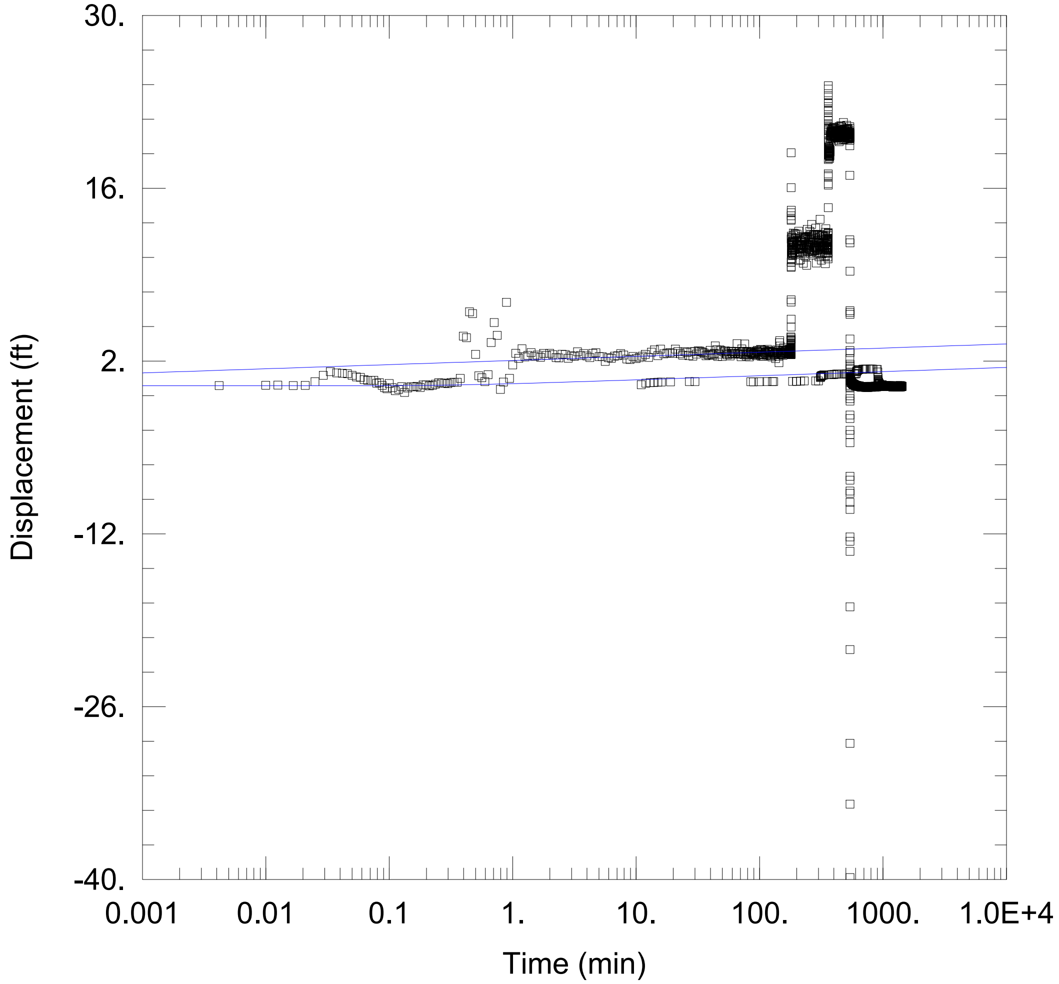
APPENDIX K

AQTESOLV Transmissivity Curve Matching (Graphical)

Appendix K

K.1 AQTESOLV TRANSMISSIVITY CURVE MATCHING (GRAPHICAL)

K.1.1 First Run



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Main Theis 1.aqt
Date: 04/20/20 Time: 16:30:44

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

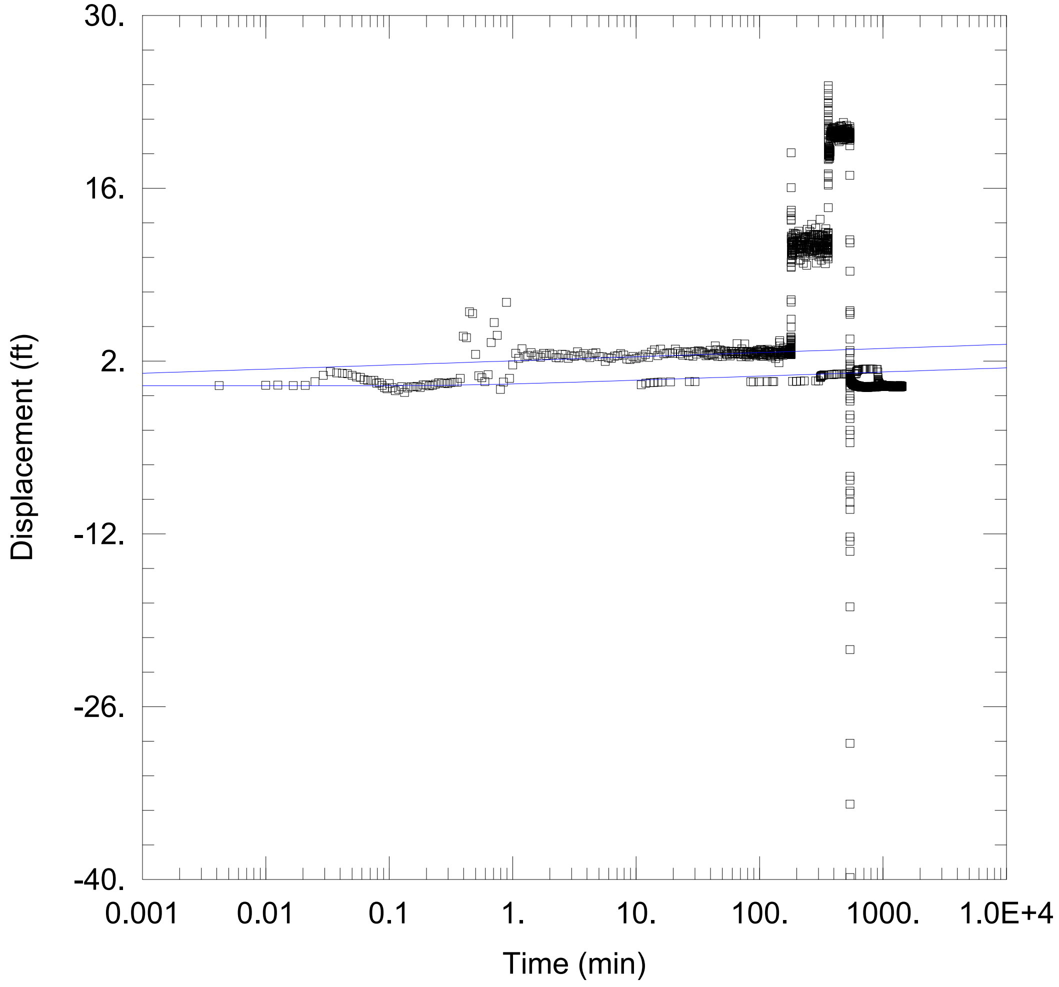
Observation Wells

Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 2.282E+5 ft^2/day
S = 0.0002884
Kz/Kr = 1.
b = 432. ft



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Main Theis Step.aqt
Date: 04/20/20 Time: 16:29:20

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

Observation Wells

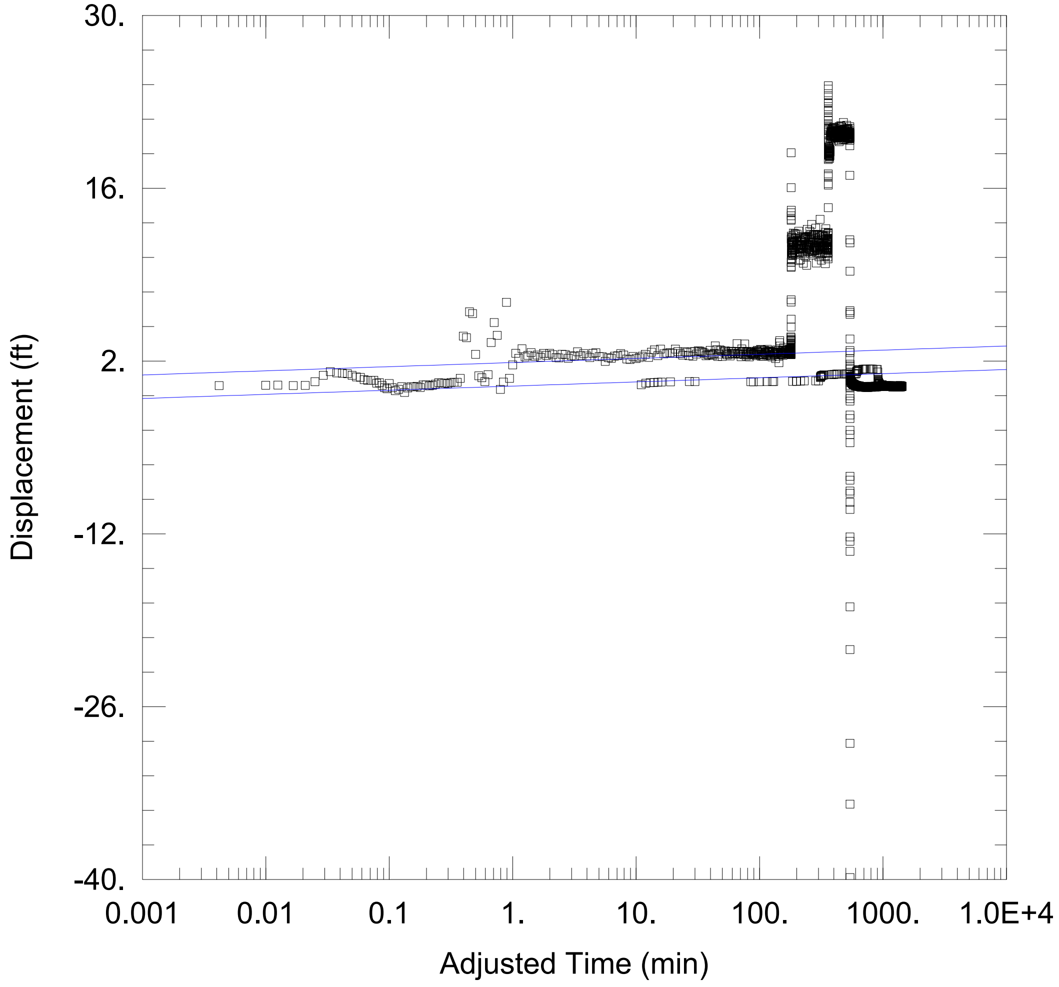
Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Step Test)

T = 2.282E+5 ft^2/day
Sw = 0.
P = 2.

S = 0.0003548
C = 0. min^2/ft^5



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Main CJ.aqt
Date: 04/20/20 Time: 16:32:42

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

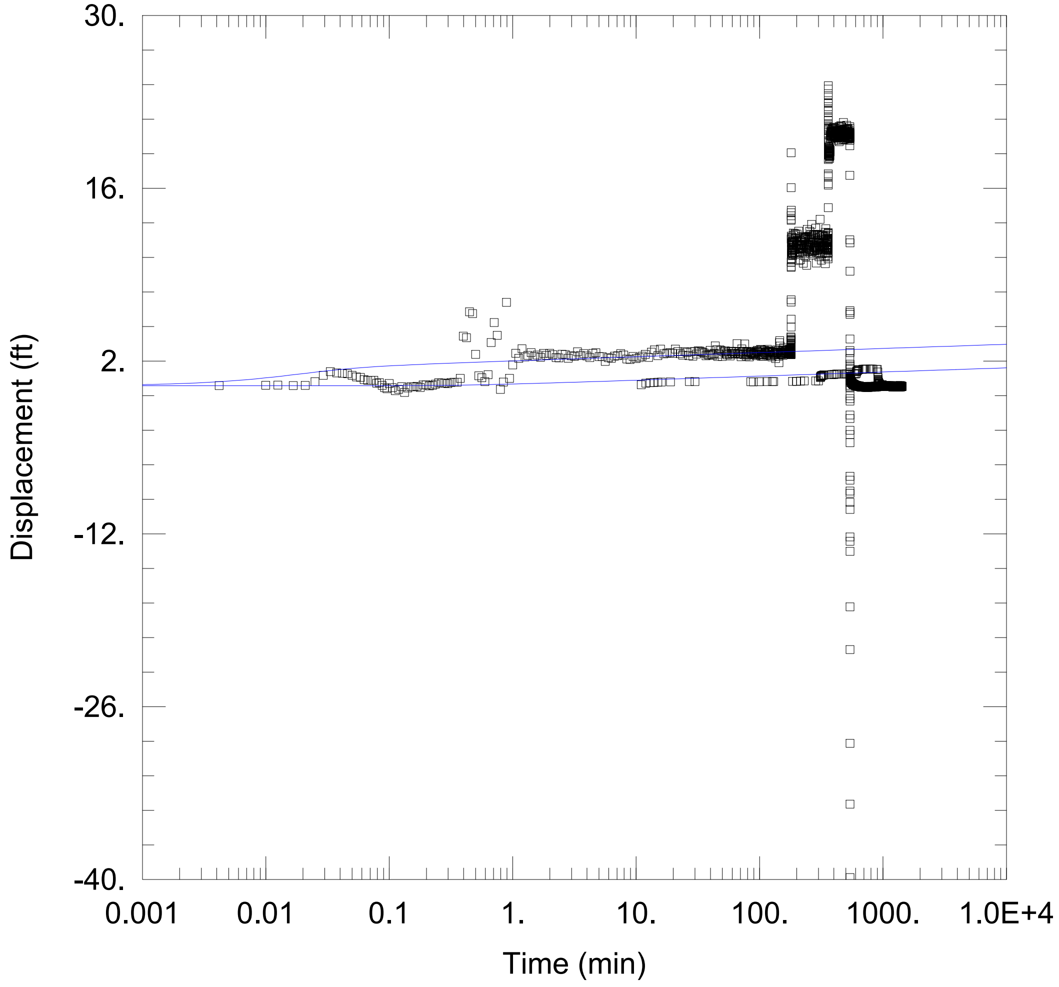
Observation Wells

Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Jacob

T = 2.282E+5 ft^2/day
S = 0.0009016



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Main PC.aqt
Date: 04/20/20 Time: 16:31:19

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

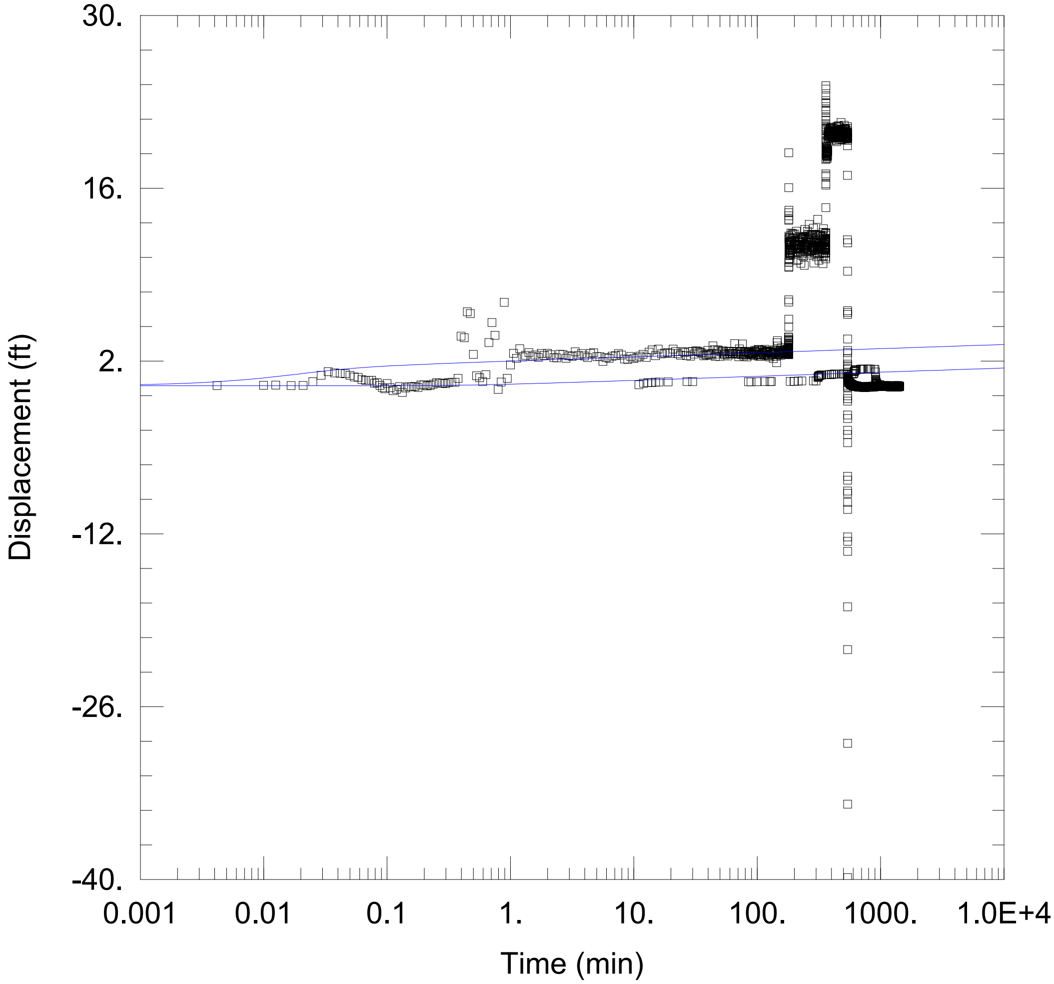
Observation Wells

Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined Solution Method: Papadopulos-Cooper

T = 2.282E+5 ft^2/day S = 0.0003548
r(w) = 1. ft r(c) = 1. ft



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Main DB.aqt
Date: 04/20/20 Time: 16:32:18

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

Observation Wells

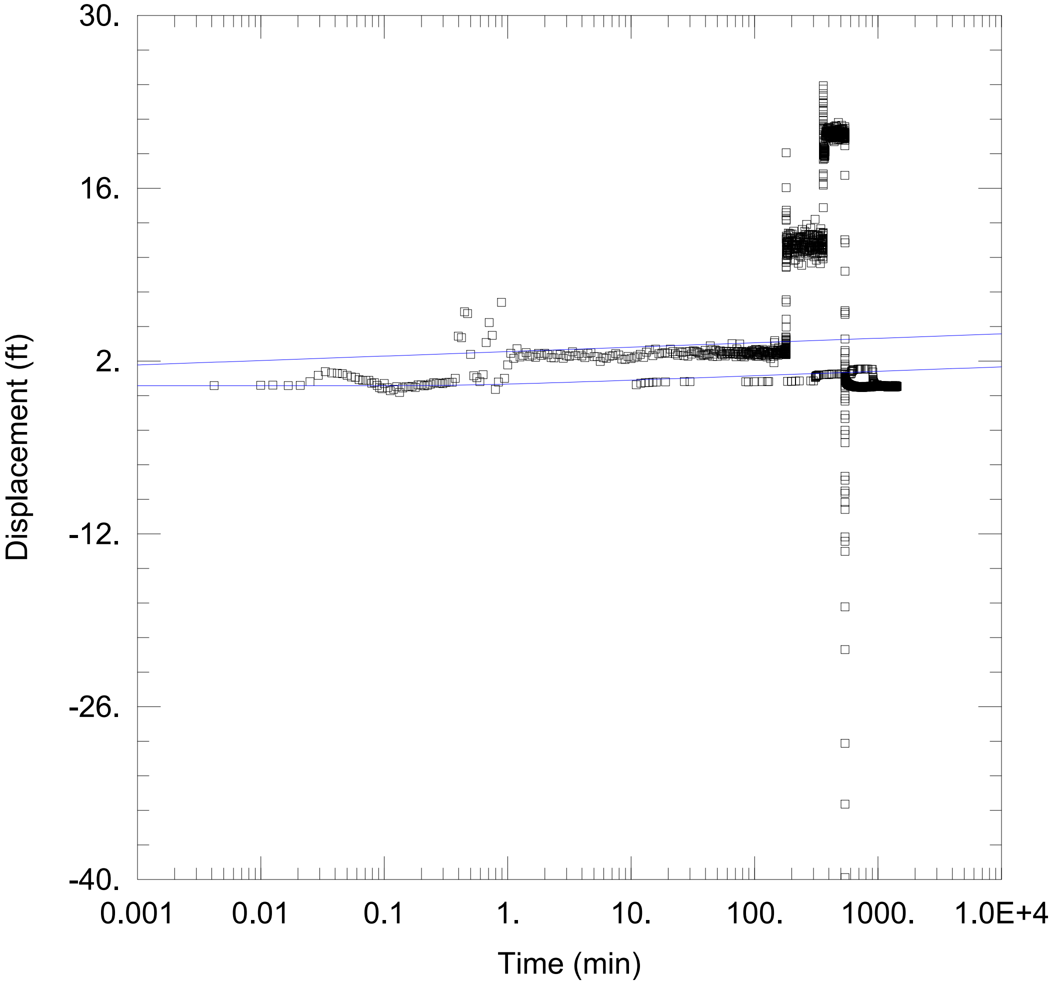
Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined
Solution Method: Dougherty-Babu

T = 2.282E+5 ft^2/day
S = 0.0003936
Kz/Kr = 1.
Sw = 0.
r(w) = 1. ft
r(c) = 1. ft

K.1.2 Second Run



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Sw Main Theis Step.aqt
Date: 04/20/20 Time: 16:26:02

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

Observation Wells

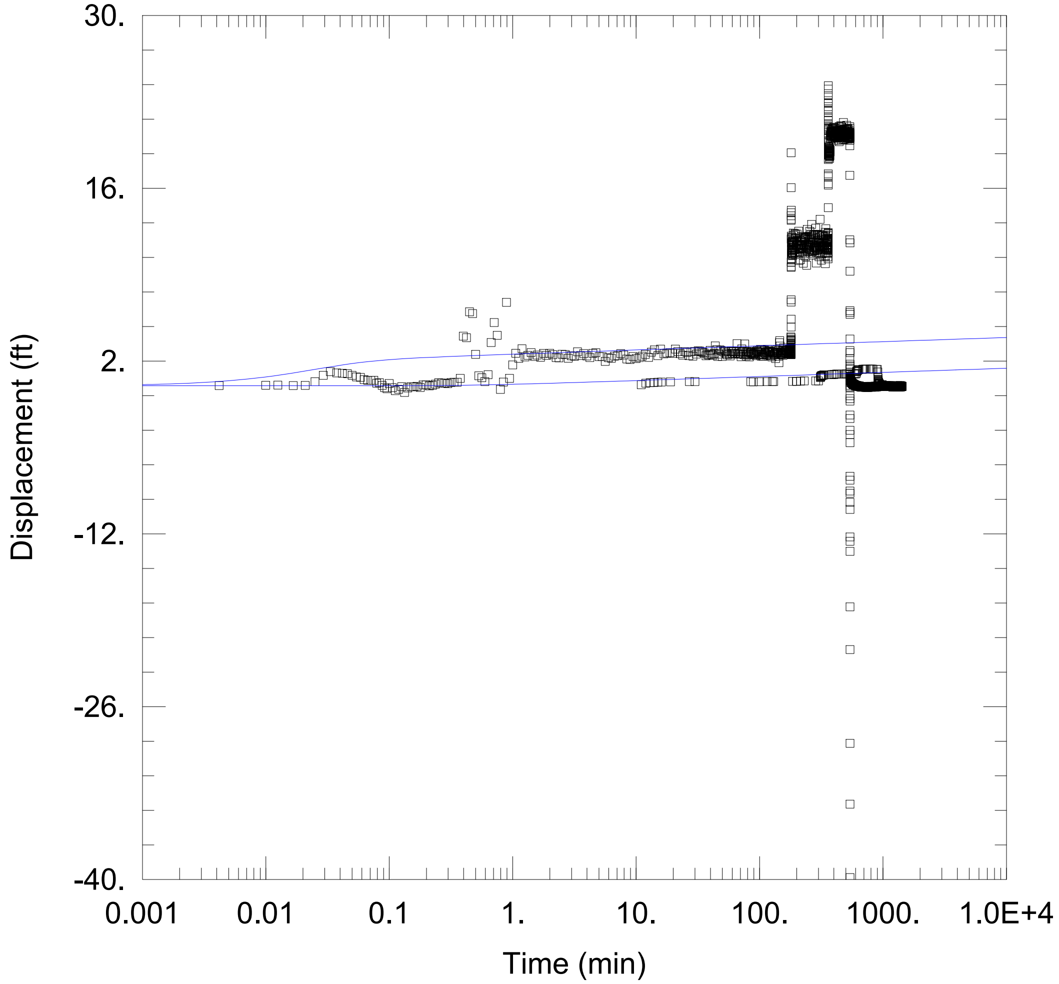
Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Step Test)

T = 2.121E+5 ft^2/day
Sw = 1.995
P = 2.

S = 0.0003981
C = 0. min^2/ft^5



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Sw Main DB.aqt
Date: 04/20/20 Time: 16:27:20

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

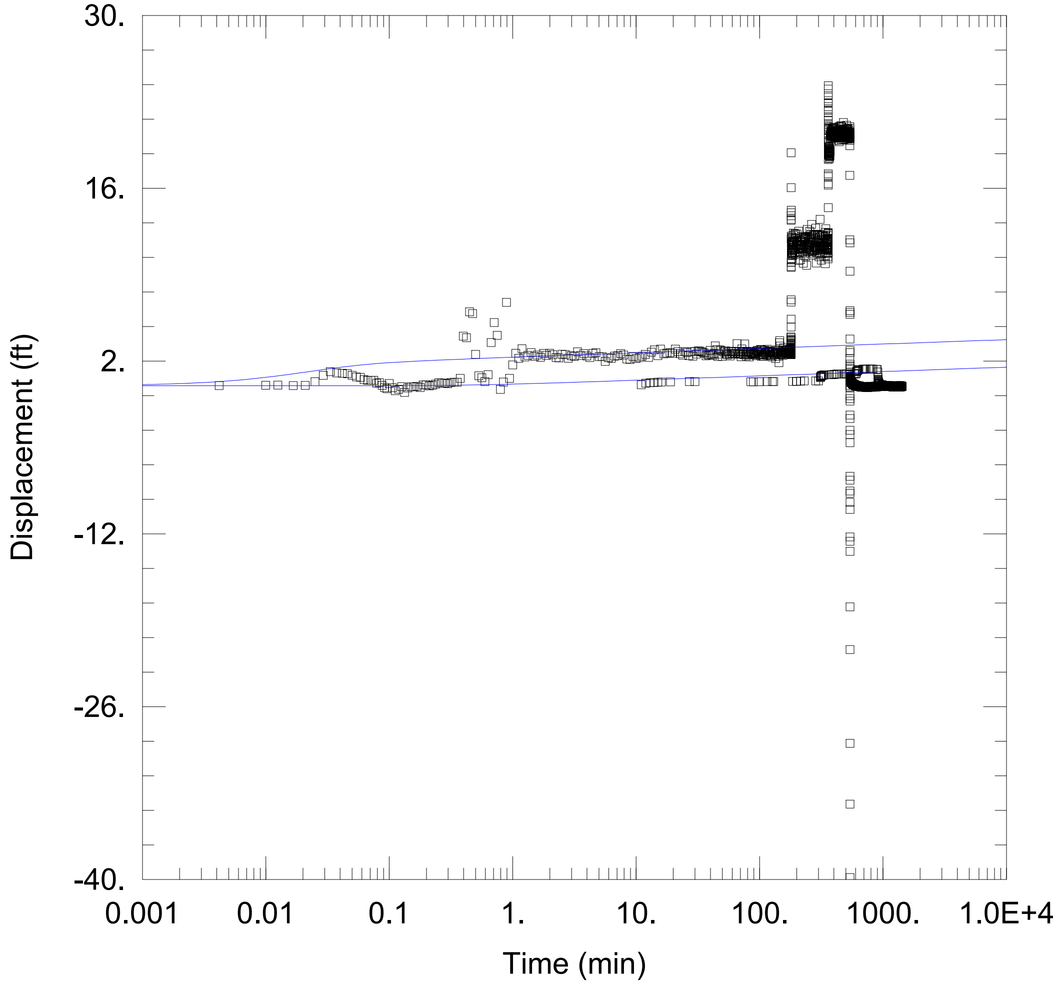
Observation Wells

Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined
Solution Method: Dougherty-Babu

T = 2.282E+5 ft^2/day
S = 0.0004365
Kz/Kr = 1.
Sw = 1.995
r(w) = 1. ft
r(c) = 1. ft



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Rw Main PC.aqt
Date: 04/20/20 Time: 16:27:47

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

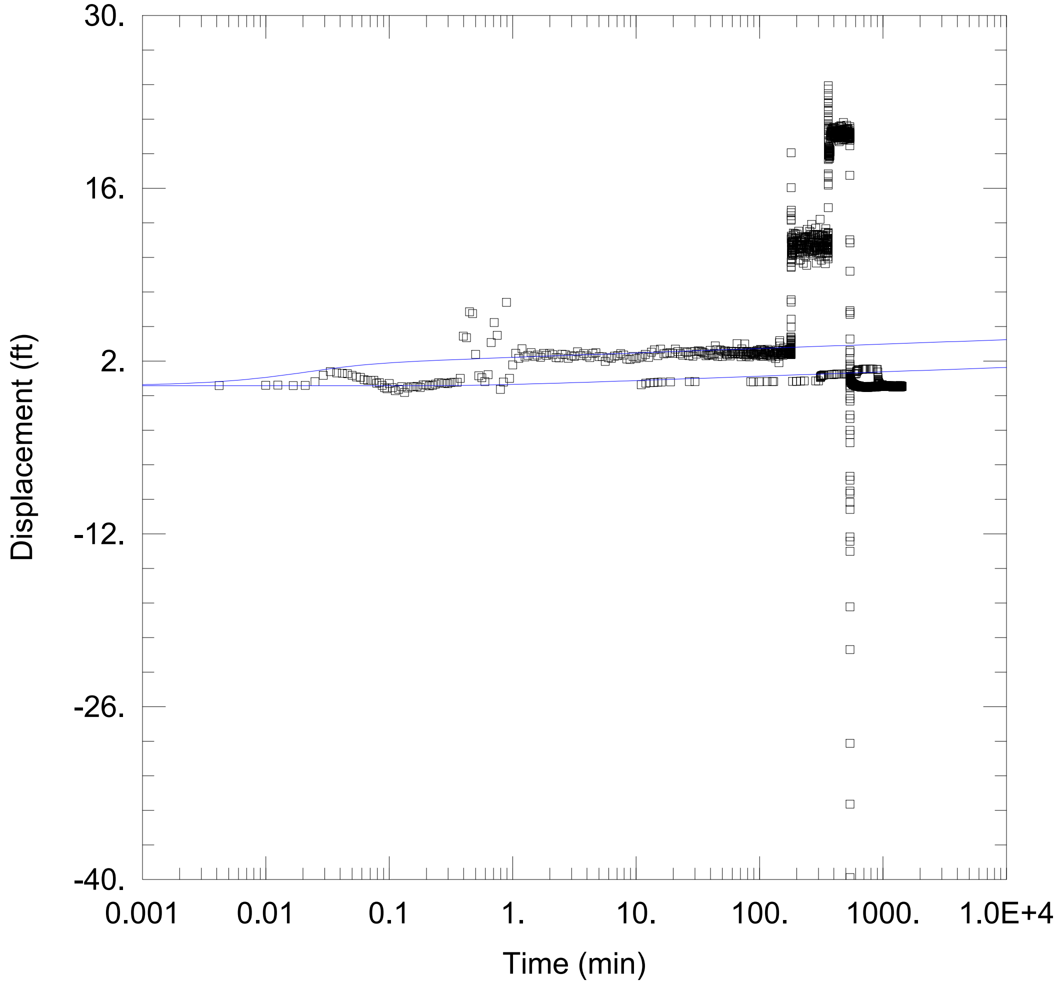
Observation Wells

Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined Solution Method: Papadopulos-Cooper

T = 2.165E+5 ft^2/day S = 0.0003936
r(w) = 0.49 ft r(c) = 1. ft



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Rw Main DB.aqt
Date: 04/20/20 Time: 16:45:08

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

Observation Wells

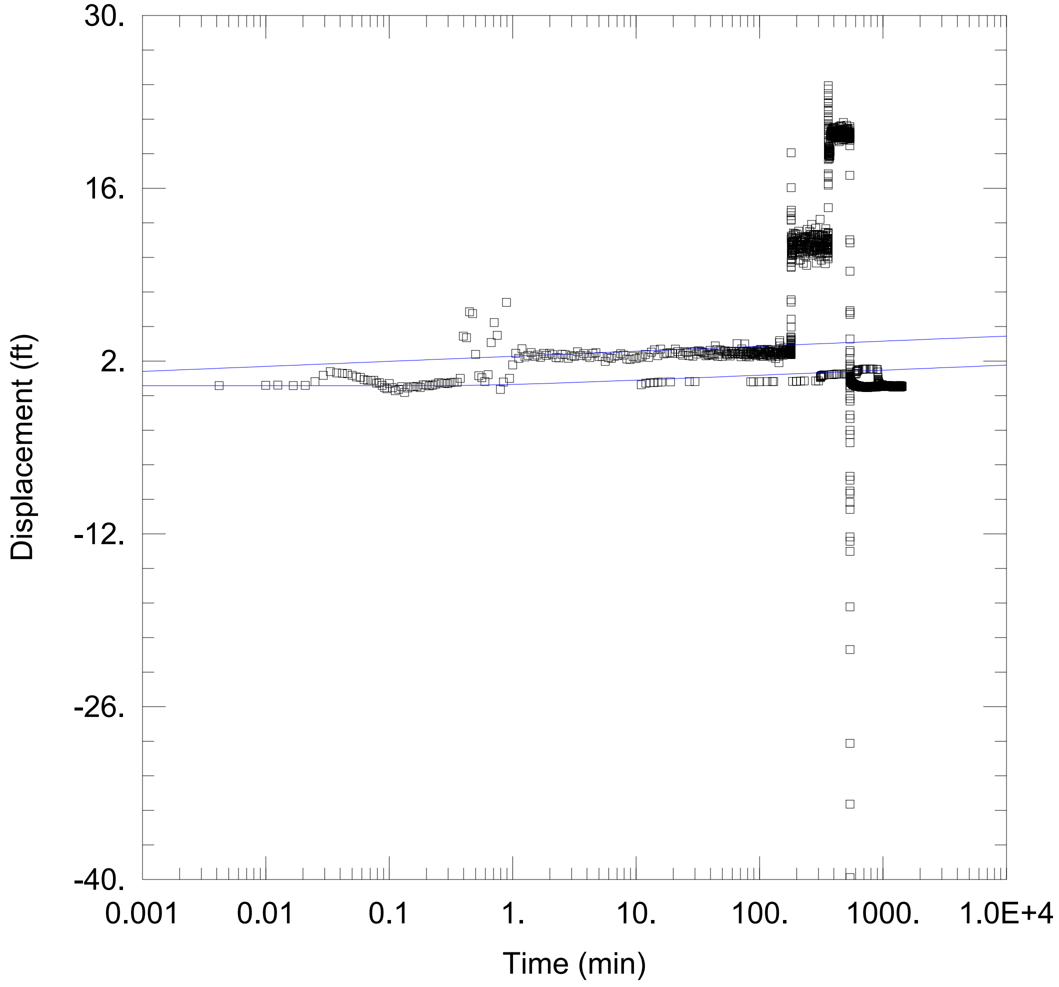
Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined Solution Method: Dougherty-Babu

T = 2.147E+5 ft^2/day
Kz/Kr = 1.
r(w) = 0.49 ft

S = 0.0004842
Sw = 0.
r(c) = 1. ft



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells C Main Theis Step.aqt
Date: 04/20/20 Time: 16:33:50

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

Observation Wells

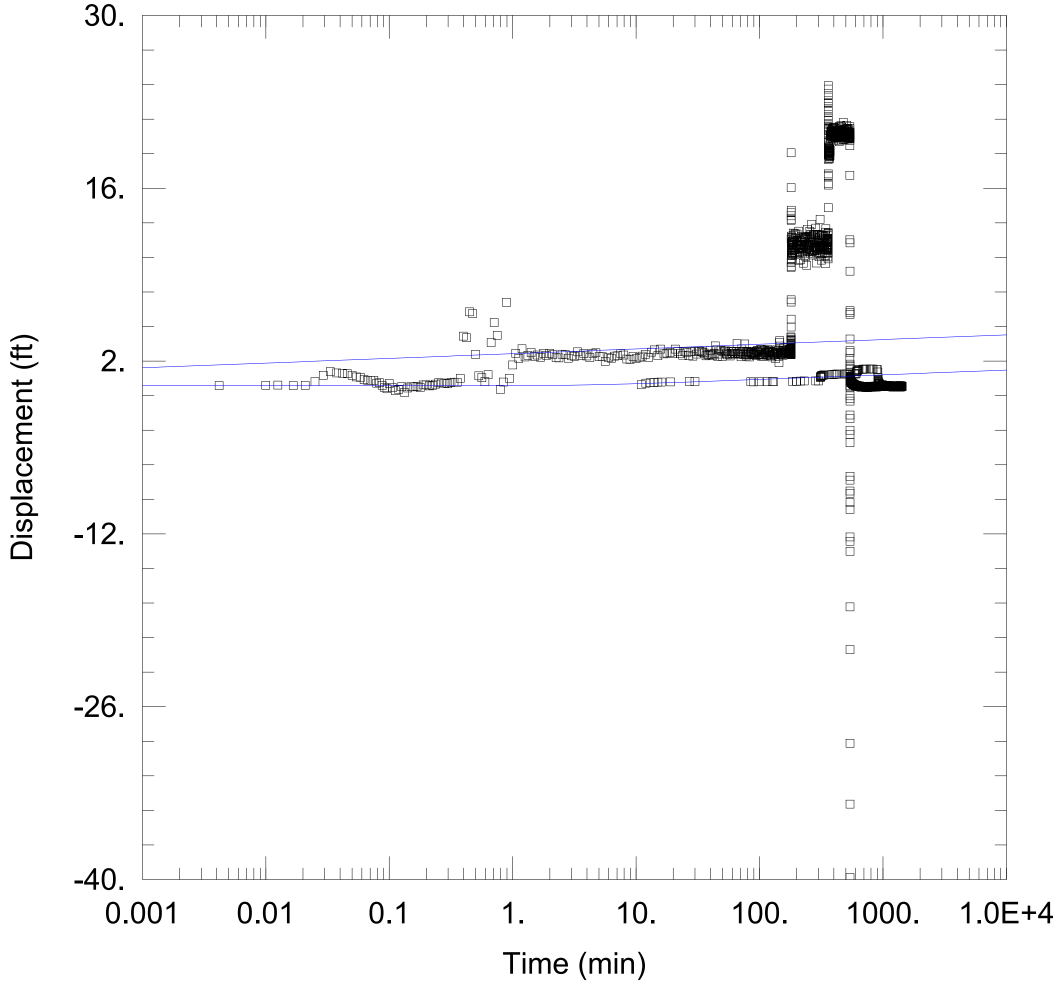
Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined
Solution Method: Theis (Step Test)

T = 1.871E+5 ft^2/day
S = 0.0005012
Sw = 0.
C = 3.0E-7 min^2/ft^5
P = 2.

K.1.3 Third Run



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Combo Main Theis Step.aqt
Date: 04/20/20 Time: 16:33:08

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

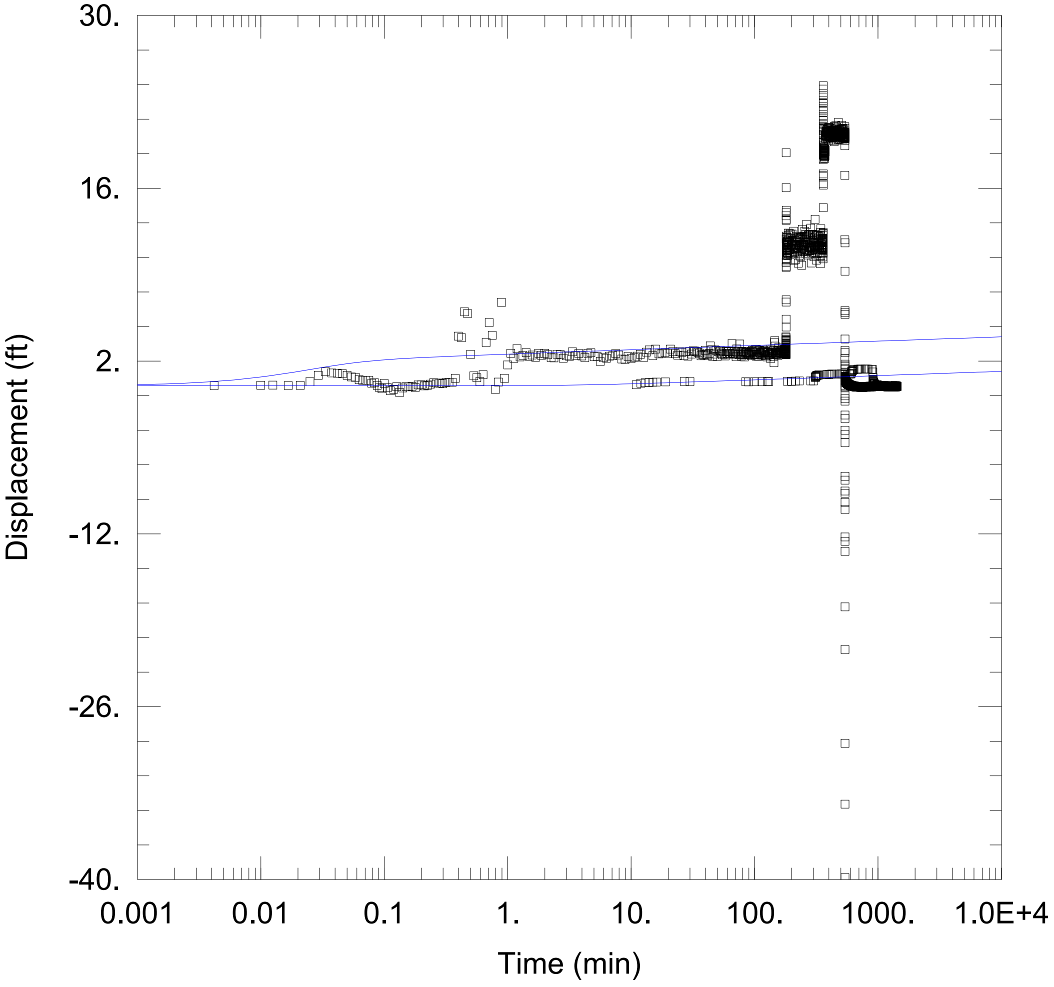
SOLUTION

Aquifer Model: Confined

Solution Method: Theis (Step Test)

T = 2.005E+ ft^2/day
Sw = 1.995
P = 2.

S = 0.003126
C = 3.0E-7 min^2/ft^5



WELL TEST ANALYSIS

Data Set: C:\Users\nsharma\Documents\L-63N MIT Step Test\Both Wells Combo Main DB.aqt
Date: 04/20/20 Time: 16:33:27

PROJECT INFORMATION

Company: Stantec
Client: SFWMD
Location: Okeechobee, FL
Test Well: L-63N ASR
Test Date: 3/23/2020

AQUIFER DATA

Saturated Thickness: 432. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
ASR	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ ASR	0	0
□ ow	142	683

SOLUTION

Aquifer Model: Confined Solution Method: Dougherty-Babu

T = 2.2E+5 ft^2/day
Kz/Kr = 1.
r(w) = 0.49 ft

S = 0.00319
Sw = 1.995
r(c) = 1. ft

APPENDIX D:

APPLICATION OF HIGH DEFINITION 2D AND 3D SEISMIC TESTS FOR CHARACTERIZATION OF THE FLORIDAN AQUIFER SYSTEM IN THE LAKE OKEECHOBEE AREA PROJECT REPORT

Project Report

Application of High Definition 2D and 3D Seismic Tests for Characterization of the Floridan Aquifer System in the Lake Okeechobee Area

Submitted to:
Bob Verrastro, P.G.
Principal Hydrogeologist
South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33406

Submitted by:
Hughbert Collier, Ph.D., P.G.
Senior Vice President
Collier Consulting, Inc.
590 East South Loop
Stephenville, TX 76401

Report by:
Finn B. Michelsen, P.G.
Sr. Geophysicist

John Jansen, P.G.
Sr. Geophysicist/Hydrogeologist

COLLIER
CONSULTING

Table of Contents

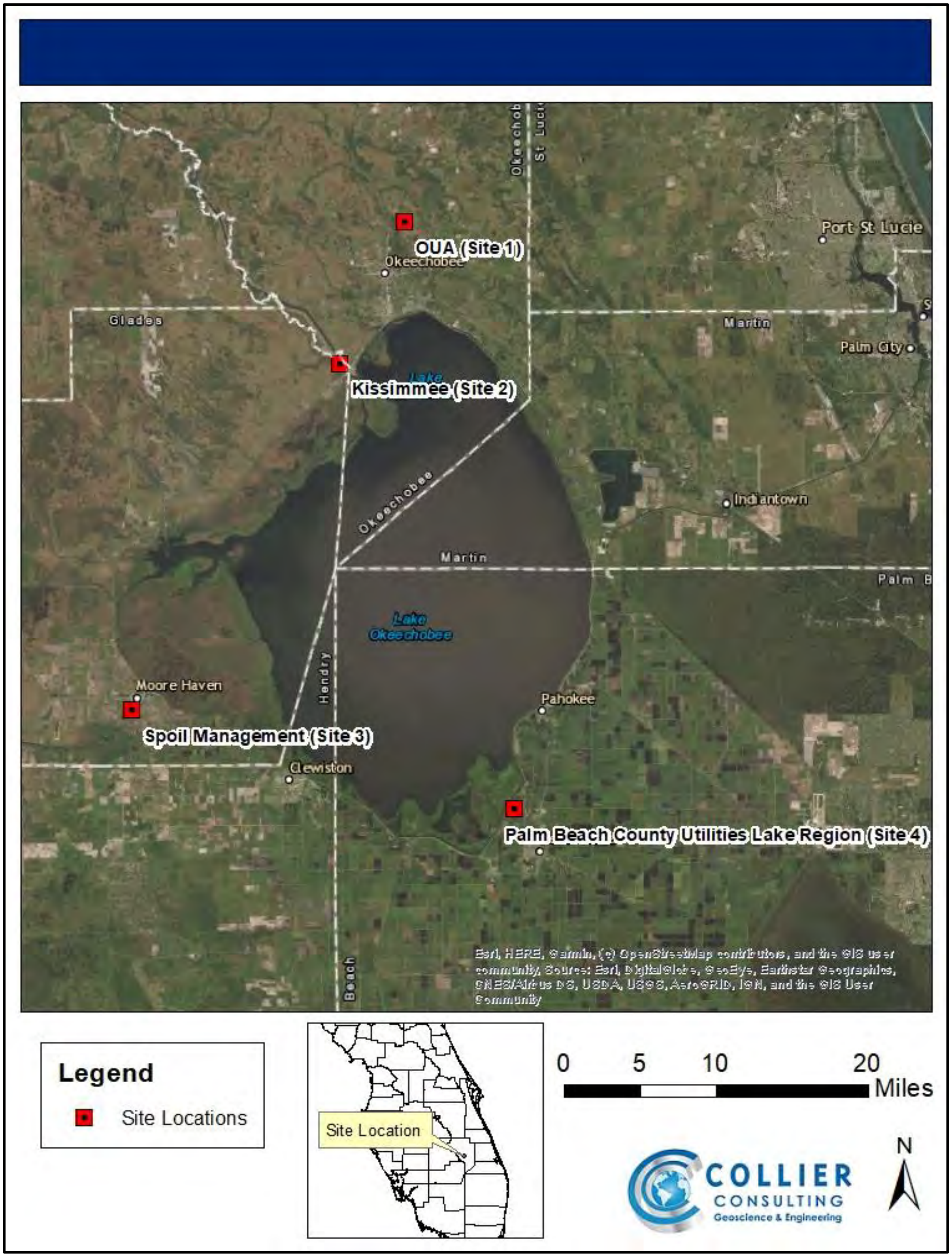
6.0 APPENDIX

1.0 Introduction

Under contract to South Florida Water Management District (Contract No. 4600003869), Collier Consulting Inc. (CCINC) was commissioned to perform a "Proof of Concept" application for acquisition and processing of high resolution seismic data at candidate site locations for construction of wells within the Floridan Aquifer System (FAS) around the Lake Okeechobee area. As part of the plan the District identified a need for improved geologic characterization of the FAS in terms of stratigraphic and hydro-geologic structure. High resolution 2D and 3D seismic acquisition, data processing, and seismic modeling methods, originally developed for oil and gas exploration, have been successfully adapted for high definition mapping and characterizing shallow geology. The "Proof of Concept" 2D and 3D seismic test program represents a qualitative performance evaluation of high resolution seismic data acquisition and processing methods to characterize formations within the Upper and Lower FAS. In addition, the program was designed to evaluate the potential to delineate karst systems and structures that can provide hydrogeologic information concerning the flow of groundwater between major permeable zones within the Floridan aquifer. The 2D and 3D results were compared to evaluate whether 3D significantly improves the geologic delineation.

The sites selected for seismic testing included Okeechobee Utility Authority (OUA), Kissimmee, Spoil Management Area (near Moore Haven), and the Palm Beach County Lake Region Area. Figure 1 shows the sites that were selected for the test seismic surveys.

The geophysical method used for this survey is seismic reflection. Seismic reflection records the travel time of seismic waves generated by a surface energy source to a geologic horizon along wave-field ray paths that are reflected off geologic interfaces and return to the surface. Seismic reflection provides very detailed images of the subsurface geology to depths ranging from a few hundred feet to thousands of feet bgs. It is different than seismic refraction, which uses longer wave paths of energy that travel along formation boundary interfaces and radiate seismic energy back to the surface as refracted head waves. Seismic refraction surveys are not capable of mapping geologic layers with seismic velocities that are lower than the overlying layer. Moreover, the depth of investigation for refraction surveys is one-fourth to one-fifth of the maximum active seismic line length, and is therefore limited with respect to application.



Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1: Location of Lake Okeechobee seismic test sites

CCINC initiated mobilization of equipment and personnel to Okeechobee, Florida in preparation for commencement of field work on December 3, 2018. Based on logistics requirements, the support for operations and equipment was setup and stationed in Okeechobee, and at the Okeechobee Utility Authority (OUA) Facility. Seismic data acquisition operations were performed December 3 – 19, 2018, and from January 3 – 7, 2019.

1.1 Seismic Survey Test Objectives

Area borehole data and other hydrogeologic information used for planning the installation and operation of FAS wells indicated the need for additional geophysical information to provide better geomorphological and geo-structure delineation for characterization of the FAS, the top of which is reported to be approximately 1,000 feet below ground surface (fbgs). The Boulder Zone, the lower member of the Oldsmar formation, is a karstic formation that exhibits various complex stratigraphic and structural attributes. In addition, SFWMD identified the need to delineate the formation boundaries and geo-stratigraphic and structural attributes associated with the overlying upper and lower Floridan Aquifer systems, especially with respect to the potential for stratigraphic viability, identifying faults, vertical channels, fracture zones, and other structural attributes that could potentially affect planning, installation, and long term operation of FAS wells at the selected test sites.

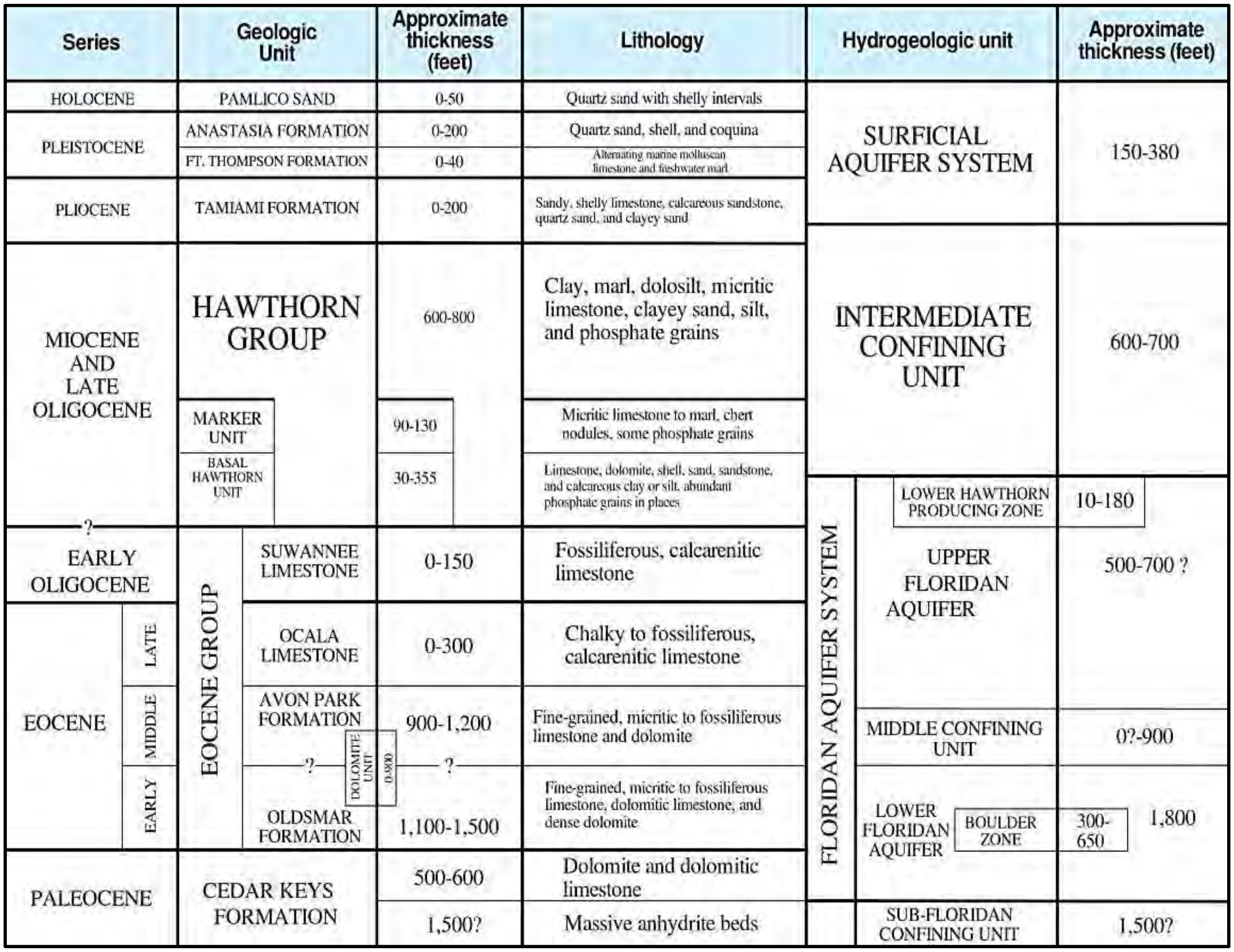
Based on the objectives for testing the application of 2D and 3D seismic methods, CCINC staff reviewed various historical sources of geologic and hydrogeologic information concerning the FAS. Design of the seismic survey programs were based on the following criteria:

1. Acquisition of P-wave seismic data that achieved depth objectives.
2. Expected complexity of the FAS in terms of the P-wave velocity structure; diffraction noise, peg-leg multiples, seismic energy dispersion.
3. Acquisition and processing of seismic data with sufficient signal and spatial resolution to delineate general geologic lithology; use available well log data to correlate approximate lithology with major seismic reflector horizons.
4. Maximum desired seismic signal and spatial resolution, with signal bandwidth between 10 and 100 Hertz; vertical and horizontal resolution of approximately 25 feet.
5. Use of seismic equipment that was cost effective, and portable enough for efficient field operations on 2D and 3D seismic surveys.

To achieve the desired seismic survey test objectives, the 2D and 3D surveys were designed using source and receiver geometries appropriate for processing and producing the required data spatial resolution.

1.2 Area Stratigraphy and Hydrogeology

The principal hydrogeologic formations present in the seismic test area, from youngest to oldest, include the Surficial Aquifer (*Pamlico Sand, Anastasia Formation, Ft Thompson and Tamiami Formations*) the Hawthorn Group Confining Unit (*Peace River and Arcadia formations*), the Upper Floridan Aquifer System (*Suwanee & Ocala Limestones*), the Middle Floridan (*Avon Park*), and the Lower Floridan Aquifer (*Oldsmar*) and underlying Cedar Keys formations. Figure 2 is a generalized stratigraphic column that summarizes the major geologic and hydrogeologic units in Palm Beach County, which is generally typical of the rest of the survey area in the vicinity of Lake Okeechobee with some changes in unit thickness and the absence of minor units in some areas.



Series		Geologic Unit		Approximate thickness (feet)	Lithology	Hydrogeologic unit		Approximate thickness (feet)
HOLOCENE		PAMLICO SAND		0-50	Quartz sand with shelly intervals	SURFICIAL AQUIFER SYSTEM		150-380
PLEISTOCENE		ANASTASIA FORMATION		0-200	Quartz sand, shell, and coquina			
		FT. THOMPSON FORMATION		0-40	Alternating marine molluscan limestone and freshwater marl			
PLIOCENE		TAMIAMI FORMATION		0-200	Sandy, shelly limestone, calcareous sandstone, quartz sand, and clayey sand			
MIOCENE AND LATE OLIGOCENE		HAWTHORN GROUP		600-800	Clay, marl, dolosilt, micritic limestone, clayey sand, silt, and phosphate grains	INTERMEDIATE CONFINING UNIT		600-700
			MARKER UNIT	90-130	Micritic limestone to marl, chert nodules, some phosphate grains			
			BASAL HAWTHORN UNIT	30-355	Limestone, dolomite, shell, sand, sandstone, and calcareous clay or silt, abundant phosphate grains in places	FLORIDAN AQUIFER SYSTEM	LOWER HAWTHORN PRODUCING ZONE	10-180
?								
EARLY OLIGOCENE		EOCENE GROUP	SUWANNEE LIMESTONE	0-150	Fossiliferous, calcarenitic limestone		UPPER FLORIDAN AQUIFER	500-700 ?
EOCENE	LATE		OCALA LIMESTONE	0-300	Chalky to fossiliferous, calcarenitic limestone			
	MIDDLE		AVON PARK FORMATION	900-1,200	Fine-grained, micritic to fossiliferous limestone and dolomite		MIDDLE CONFINING UNIT	0?-900
			DOLOMITE UNIT	0-900				
			?	?				
	EARLY		OLDSMAR FORMATION	1,100-1,500	Fine-grained, micritic to fossiliferous limestone, dolomitic limestone, and dense dolomite		LOWER FLORIDAN AQUIFER	1,800
							BOULDER ZONE	300-650
PALEOCENE		CEDAR KEYS FORMATION		500-600	Dolomite and dolomitic limestone			
				1,500?	Massive anhydrite beds		SUB-FLORIDAN CONFINING UNIT	1,500?

Figure 2: Generalized Stratigraphic Column for Study Area (Source: Reese and Memberg, 2000)

The Holocene and Pleistocene Surficial Aquifer System (SAS) units range in thickness from about 0 to 250 feet, and consist mainly of sand, clay, coquina, and organic matter.
Underlying the Surficial Aquifer is the Miocene Hawthorn Group, which is divided into Peace River Formation and Arcadia Formations. The Hawthorn Group is between 200 and 800 feet thick and consists of silty to sandy clay with thin shell beds and basal limestone beds. In addition, limestone

and coarse sand units can occur in the formation west of Lake Okeechobee. The Hawthorn Group forms a semi-confining unit between the SAS and the underlying FAS, referred to as an Intermediate Confining Unit. The Lower Hawthorn Production Zone lies beneath the Intermediate Confining Unit in the Basal Hawthorn Group. It is between 10 to 180 feet thick and forms the upper part of the Upper Floridan aquifer.

Beneath the Hawthorn Group lies the Early Oligocene Suwannee Limestone, and Eocene Ocala Limestone formations. The Suwannee is a thin, discontinuous 0 to 150 ft. thick phosphatic limestone that lies above the Ocala Limestone. The Ocala Limestone is 0 to 300 feet thick. These two units, along with the Lower Hawthorn Production Zone and the upper part of the Avon Park formation, comprise the Upper Floridan aquifer.

The Avon Park formation includes the Middle Confining and Middle Floridan Aquifer Units, which underlie the Ocala Limestone. The unit sequences were deposited during the Middle Eocene Age, and ranges in thickness from 500 to 1,200 feet. The upper part of this unit forms the base of the Upper Floridan aquifer. Within the upper 100 to 300 feet of the Avon Park formation, layers of dense limestone and dolomite form a semi-confining unit between the Upper and Lower Floridan aquifers called the Middle Confining Unit. The lower 400 to 900 feet of the Avon Park formation consists mainly of dolomite, dolomitic limestone, limestone, and some gypsum, forming an upper permeable zone within the Lower Floridan aquifer.

The Oldsmar formation underlies the Avon Park formation. It is 600 to 1,800 feet thick and forms the lower section of the Lower Floridan aquifer system. Lithologically, it consists of indurated crystalline dolostone that grades to alternating limestone and dolostone sequences. Depth to the Oldsmar Formation in the Lake Okeechobee region can range from 1,850 fbgs to 2,700 fbgs. Below 1,850 fbgs anhydrite and gypsum are often present within the dolostone sequence. The lower 300 to 600 feet of the Oldsmar formation contains the Boulder Zone, a zone of discontinuous and highly permeable fractured or cavernous limestone-dolomite structures. Similar zones can also be present in the upper part of the Oldsmar Formation. Beneath the Oldsmar formation is the Paleocene Age Cedar Keys formation. The Cedar Keys formation consists of layers of dolomite and anhydrite, and is the lower confining unit at the base of the Lower Floridan aquifer; the sub-Floridan Confining Unit.

1.3 Seismic Survey Equipment

For recording of 2D and 3D seismic data, CCINC used the Geospace Technologies GSX cable-less seismic system. The GSX is designed for cable-free and radio-free seismic data recording. The self-contained GSX Land Based Recorder unit includes 1 to 4 channels of 24-bit A/D digitization, an integrated high sensitivity GPS receiver, built-in test signal generator, up to 32 GB per channel of non-volatile solid-state data storage, and a high-speed data port.

The unit is housed in a sealed case, with input connectors for battery and geophones.

Geospace GSX Seismic System

To propagate sufficient seismic energy for generation of signal reflections from the required target depths, and to produce data with a 10 to 100 Hertz bandwidth, CCINC elected to use the XLR8-2000 Accelerated Impact Source (AIS) system. In addition to performance, the XLR8-2000 is more economical and efficient than other seismic energy source systems. The XLR8 is designed to minimize impact on the environment and surface or subsurface infrastructure.

XLR8 Accelerated Impact Source (AIS)

The CCINC XLR8-2000 AIS was equipped with the Geospace Source Data Recorder (SDR) unit**,** GPS, Hammer "Hit" Sensor, and Source Signature Geophone. The SDR records the hammer hit time based on the GPS receiver clock to monitor and record in real-time the accurate control "time-break" (seismic zero-time). The SDR also records in real-time the GPS X, Y, and Z coordinates for each of the source (SRC) stations. GSX and XLR8-2000 seismic equipment information and specifications are attached to this report in APPENDIX 1.

1.4 Seismic Line Geometry and Data Recording Parameters

The 2D and 3D seismic survey geometry and recording parameters were determined on the basis on SFWMD project objectives and plans for the Lake Okeechobee area, and on model analysis of geology and hydrogeology information. For the OUA (Site #1) and Kissimmee (Site #2) 2D seismic survey geometry, CCINC used a 2D two-line swath survey; swath configuration can improve attenuation of seismic signal back-scatter associated with fracture zones.

2D Seismic Swath Geometry for OUA and Kissimmee Sites

Seismic Line Lengths : 2 lines (1 mile each line)
Geophone Interval : 50 ft. (Type: GS-One single 10 Hz)
Seismic Receiver Line Separation : 50 ft.
Center Source Line Length : 1 line (1 mile)
Source Line Offset from Receiver Lines : 25 ft.
Source Point Interval : 100 ft. (5 hits per SRC station @450-550 psi)
Recording Sample Rate : 1 millisecond
Record Length : 3 seconds (SEGY Format)
Data Acquisition Filters : 2 HZ Low-Cut, High-Cut Open

For the Kissimmee 2D swath line an additional seven (7) SRC roll-on/roll-off extension points were added to increase Common Depth Point (CDP) fold coverage near RCVR line end.

For the Lake Region 2D seismic survey, obstacles and environmental constraints prevented using the two-line swath configuration. In addition, the planned 2-mile seismic lines along State Road 80 and State Road 715 (NW 16th-17th Street) were divided into two 1-mile segments because of road intersections. The gap between line segments is equivalent to 10 receiver stations (~ 450 ft.).

2D Seismic Line Geometry for State Road 80 and State Road 715

Seismic Line Lengths : 4 lines (1 mile each line)
Geophone Interval : 50 ft. (Type: GS-One single 10 Hz)
Source Line Lengths : 4 lines (1 mile each line)
Source Point Interval : 100 ft. (5 hits per SRC station @ 350-400 psi)
Recording Sample Rate : 1 millisecond
Record Length : 3 seconds (SEGY Format)
Data Acquisition Filters : 2 HZ Low-Cut, High-Cut Open

Figures 3a, 3b, and 3c are plots of the locations for seismic receiver lines (RCVR) and AIS source (SRC) stations for OUA (Site #1), Kissimmee (Site #2), and the four seismic line segments for the Lake Region (Site #4 – State Road 80 and State Road 715) respectively.

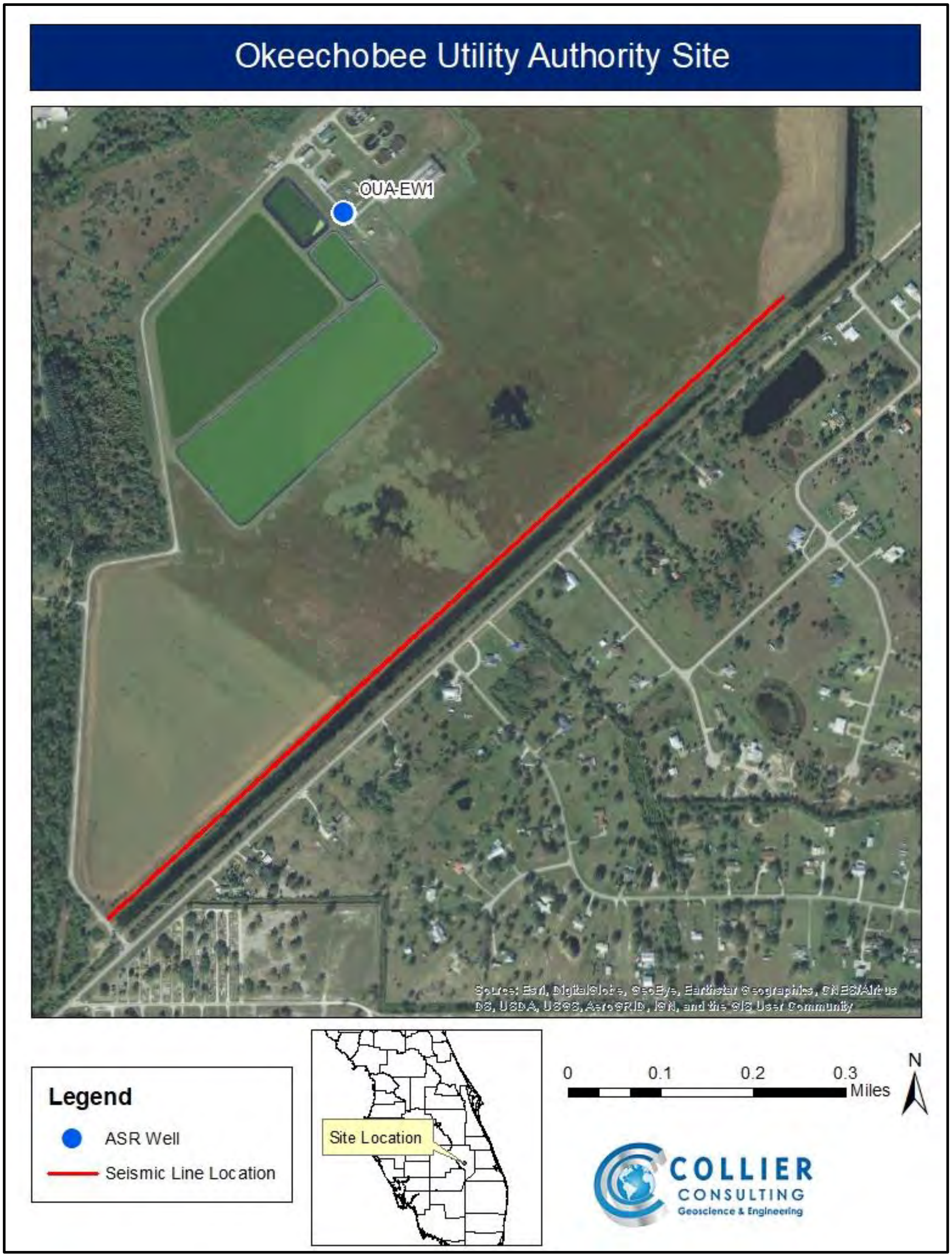
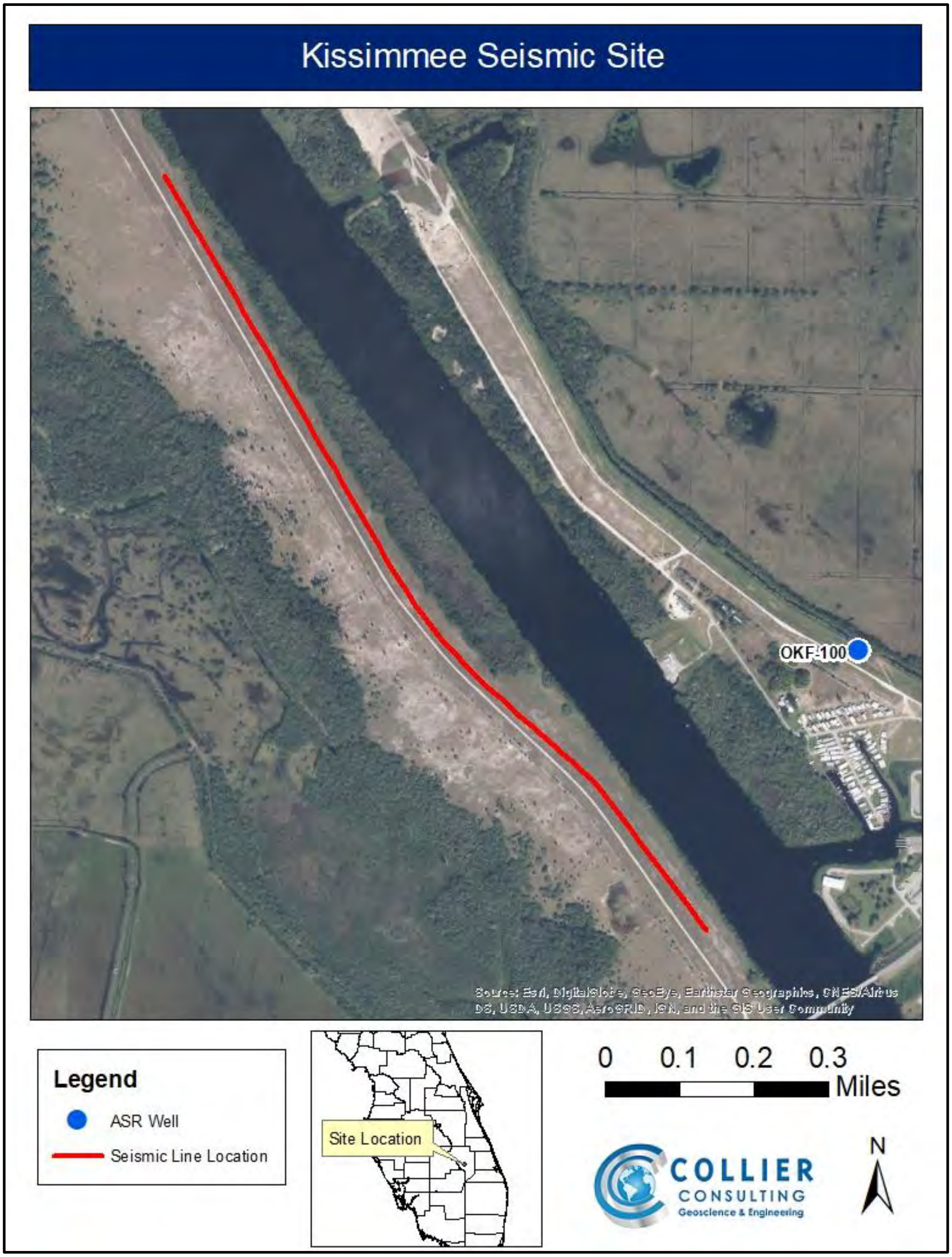
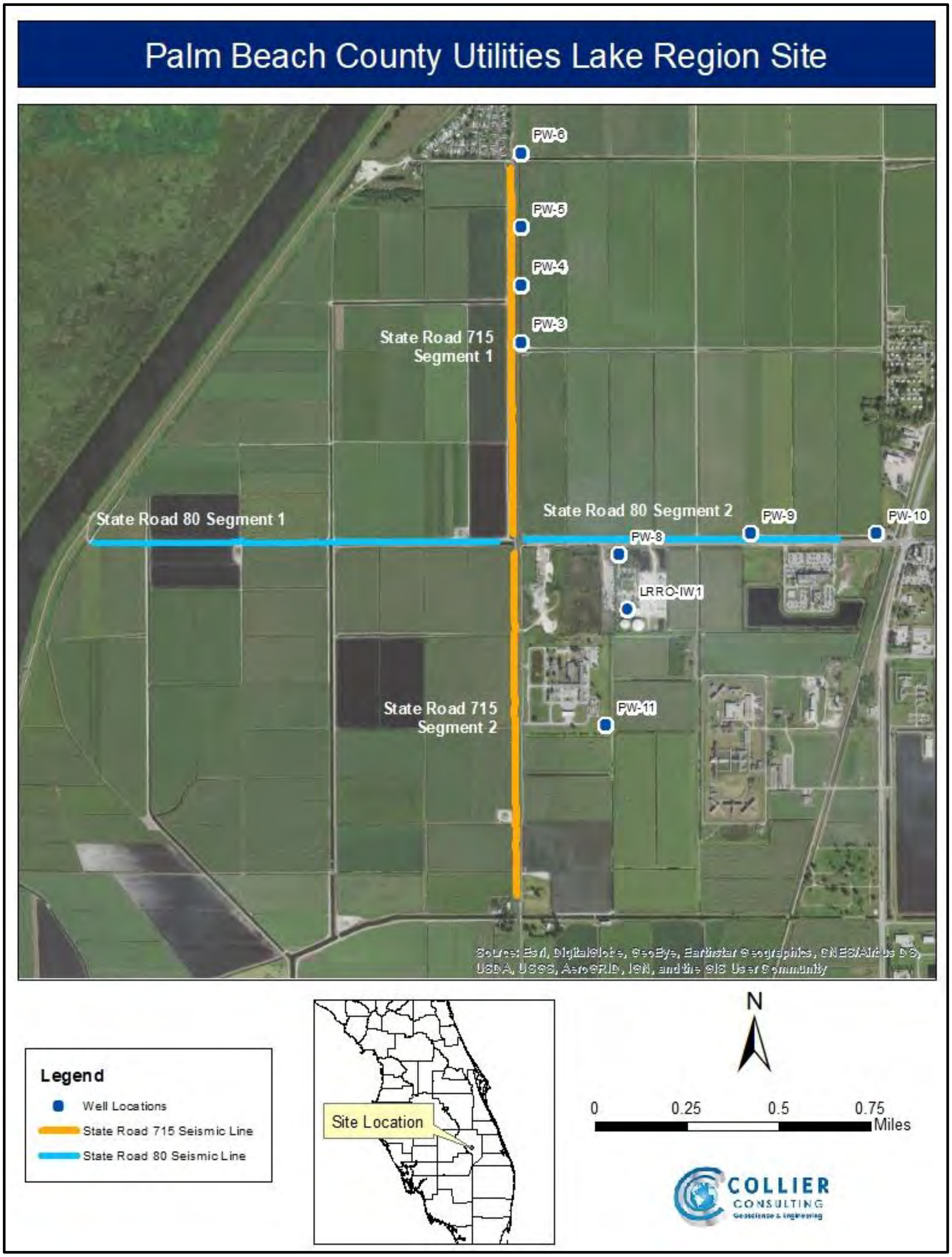


Figure 3a: OUA 2D seismic line location map.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3b: Kissimmee 2D seismic line location map.



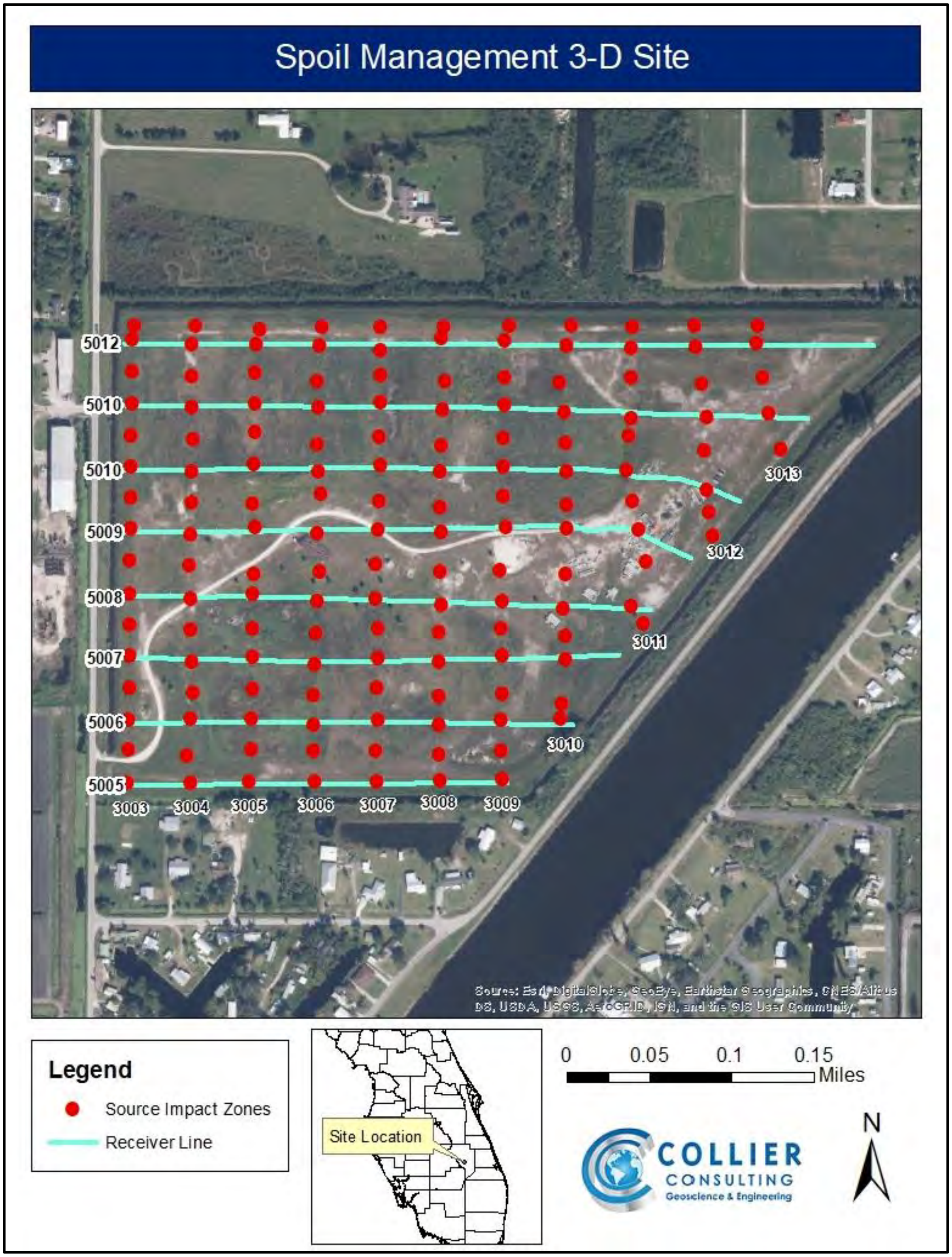
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3c: Palm Beach County Lake Region seismic line location map.

3D Seismic Grid Geometry for Spoil Management Area (Site #3)

CCINC field crew acquired seismic data for 3D processing at the Spoil Management Site #3 using an orthogonal grid of RCVR and SRC lines. The original 2D seismic swath plan was aborted because the deployment of GSX RCVR units was limited to CDP coverage of no more than 0.5 miles. An alternative 3D grid design provided sufficient maximum SRC-to-RCVR offset and CDP bin azimuthal distribution, which was needed to generate seismic data with adequate CDP fold within the targets depth range. Figure 4 presents the 3D RCVR and SRC seismic survey grid.

Number of RCVR Lines : 8 (east-west orientation, 5006 – 5012)
RCVR Line Spacing : 200 ft.
Number of SRC Lines : 11 (north-south orientation, 3003 - 3013)
SRC Line Spacing : 200 ft.
Geophone Interval : 50 ft. (Type: GS-One single 5 Hz)
Source Point Interval : 100 ft. (5 hits per station @ 350-400 psi)



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4: Spoil Management 3D survey grid design.

Geodetic coordinates for all Spoil Management 3D seismic survey RCVR and SRC coordinates are given in Appendix 2.

Seismic data recording parameters for the 3D survey were the same as used for the 2D swath seismic surveys; 1 millisecond sample rate, 3 second record length, 2 HZ low-cut and open high-cut filters.

1.5 Geodetic Survey Control

Geodetic survey control was established for all 2D and 3D RCVR and SRC lines using the Trimble R8 GPS system. The control survey points consisted of X, Y, Z coordinates for all RCVR and SRC line end points, and where possible, survey points at every 500 feet along each line. Final geodetic post processing and post-plots used all survey control points, and all recorded GSX and XLR8-2000 GPS coordinates. The Coordinate Projection System used for data processing and the generation of all RCVR and SRC stations is NAD 83 State Plane Florida East FIPS0901. Seismic RCVR and SRC station coordinates for all 2D and the 3D survey are presented in Appendix 2.

Trimble R8 GPS Receiver

2.0 Seismic Instruments and Data Acquisition QA/QC

The GSX data recording units require data survey parameter programming prior to deployment. During programming, all internal circuits are fully tested in accordance with manufacturer guidelines. In addition, batteries are charged and geophones performance tested prior to project mobilization. Once programmed, all required GSX data recording units are deployed using a GSX Line Viewer to record station ID, GSX GPS locations, and GSX unit operating status. Both the AIS and GSX seismic recording instruments were checked and inspected daily.

2.1 XLR8-2000 Accelerated Impact Source Performance

Critical to producing 2D and 3D high resolution seismic data is energy source performance. As part of the XLR8 AIS setup process, testing is performed to determine the optimum energy output and “shot stack” requirements. Given the desired seismic data frequency resolution needed for producing high-resolution seismic sections from processing, the required source signal frequency bandwidth must be between 12 – 96 Hertz. A shot stack count of five (5) ground impacts, operating at 450 psi, was more than sufficient to meet the specified recording of data with a frequency bandwidth 12 to 96 Hertz. Figure 5 is a power spectrum (dB value versus frequency) determined from pre-survey field testing.

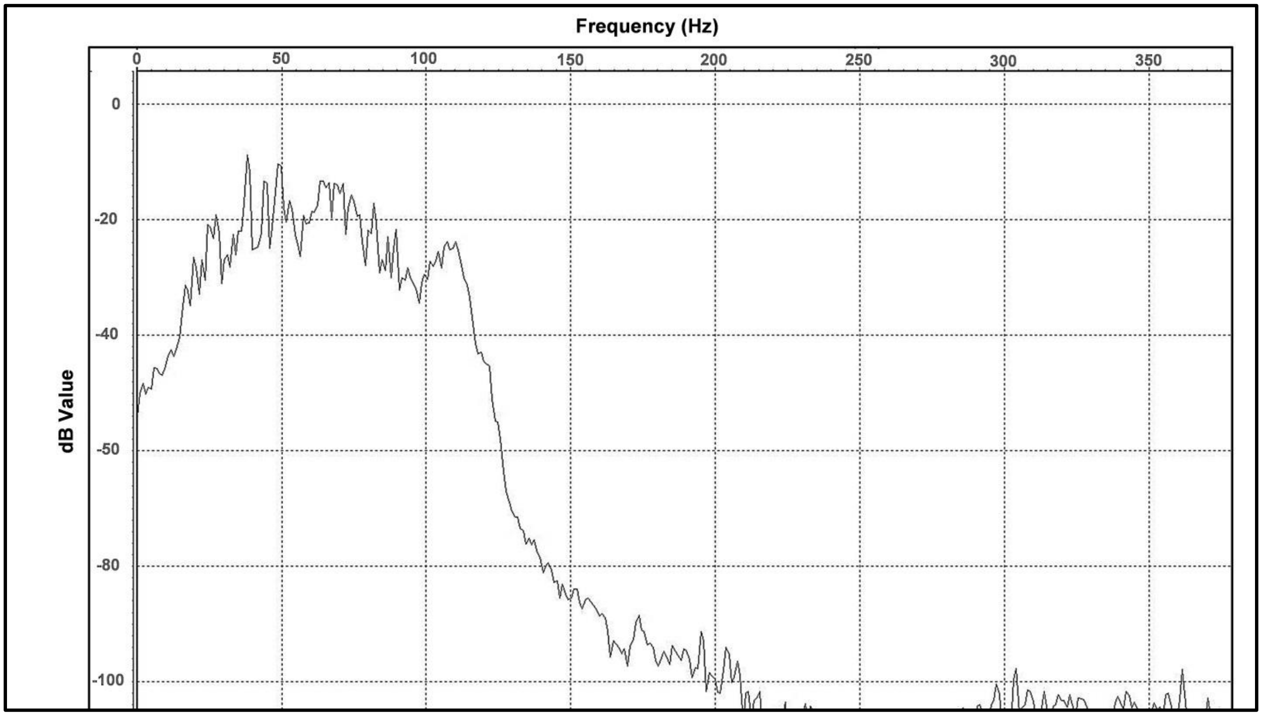


Figure 5: Raw unfiltered AIS amplitude versus frequency spectrum showing good seismic frequency content between 10 Hz and 125 Hz.

The seismic frequency bandwidth achieved for all 2D and 3D seismic data acquired exceeded minimum requirements. Using advanced Bandwidth Extension (BWE) source signal processing, which improves source signature signal-to-noise, balances and flattens the frequency spectrum, the actual usable seismic data bandwidth used in processing was 12 Hz to 130 Hz. Figure 6 is the final AIS Power Spectrum with BWE.

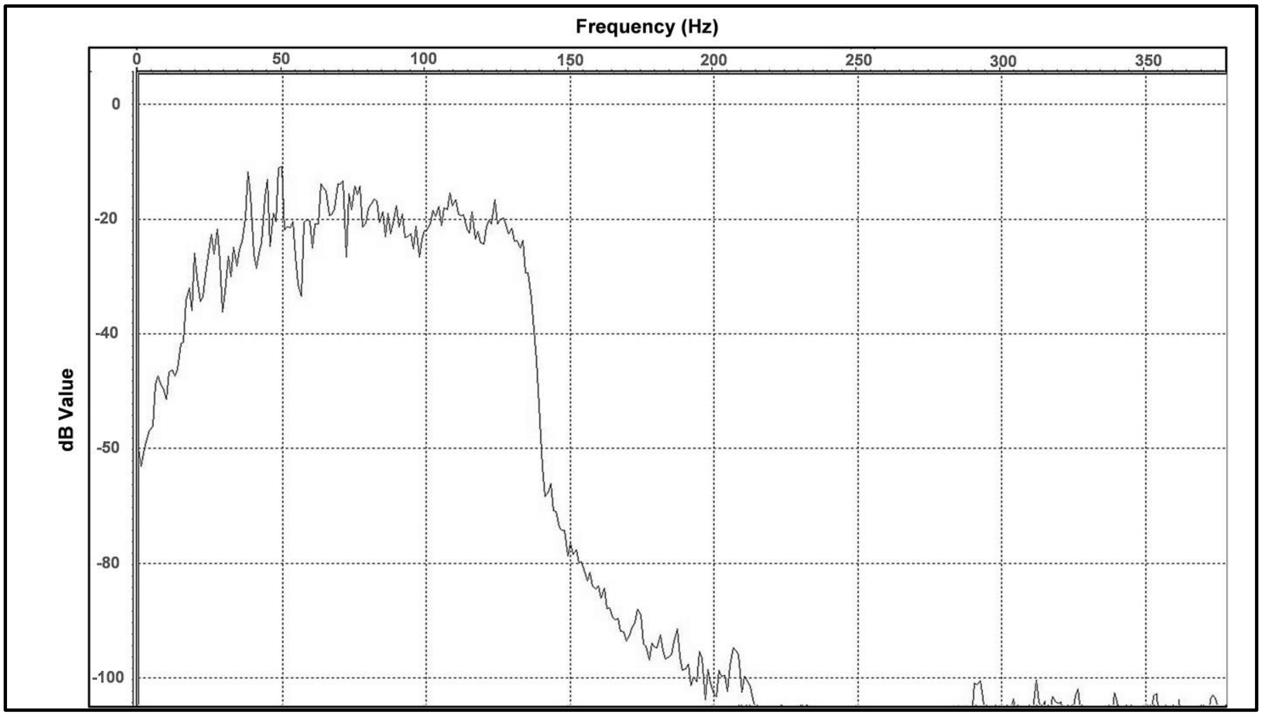


Figure 6: Final AIS frequency bandwidth used in processing all SFWMD 2D and 3D seismic data after application of Bandwidth Extension.

2.2 Seismic Data Quality

The Geospace GSX is a very reliable, efficient, and environmentally friendly seismic system. It has been in use by the oil and gas exploration industry for more than ten years, on 2D and 3D seismic projects requiring thousands of GSX seismic channels deployed. Like all cable-free seismic systems, it does not provide for real-time viewing of raw data during acquisition operations. Seismic data from each line is available for viewing only after the GSX units are retrieved from the field, data harvested, and output in SEGD or SEGY standard formats. On seismic projects where only a small number of GSX seismic channels are deployed on short survey lines, the field geophysicist will perform data QA/QC after data from each seismic line is complete, data harvested and formatted. A complete review of all raw unprocessed seismic records is typically performed after the first seismic line is complete, mainly for inspection and evaluation of data quality.

Figure 7 is a raw unfiltered “stack” seismic record from OUA Line 5001, source station 1067 (center of RCVR line). Automatic Gain Control is applied for trace amplitude balancing, and the record length shown is a full 3 seconds. Figure 8 is a test CDP stack section to evaluate optimal data filter parameters and seismic reflection horizon continuity. Both Figures 7 and 8 are representative examples of industry standard geophysics QA/QC data analysis, performed to confirm survey design acquisition parameters, data quality, and GSX data recording performance.

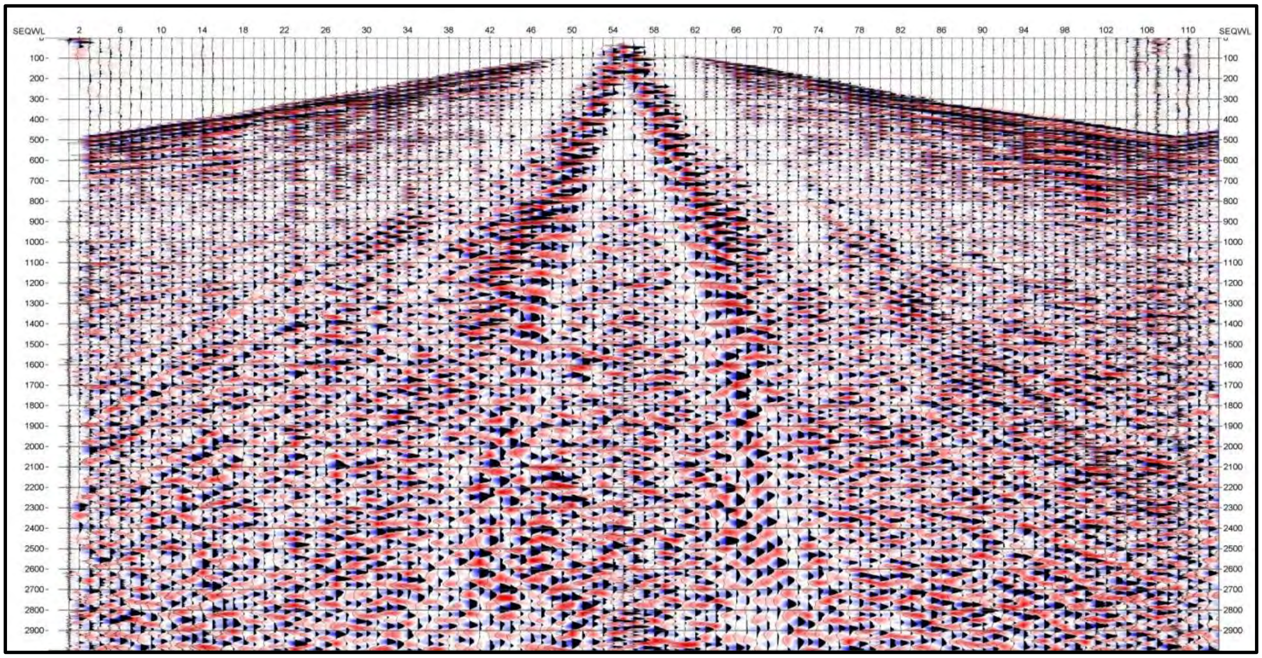


Figure 7: Unfiltered Automatic Gain Control (AGC) stack shot gather from OUA 2D seismic line 5001, source station 1067 (3 second record length, 1-mile RCVR line).

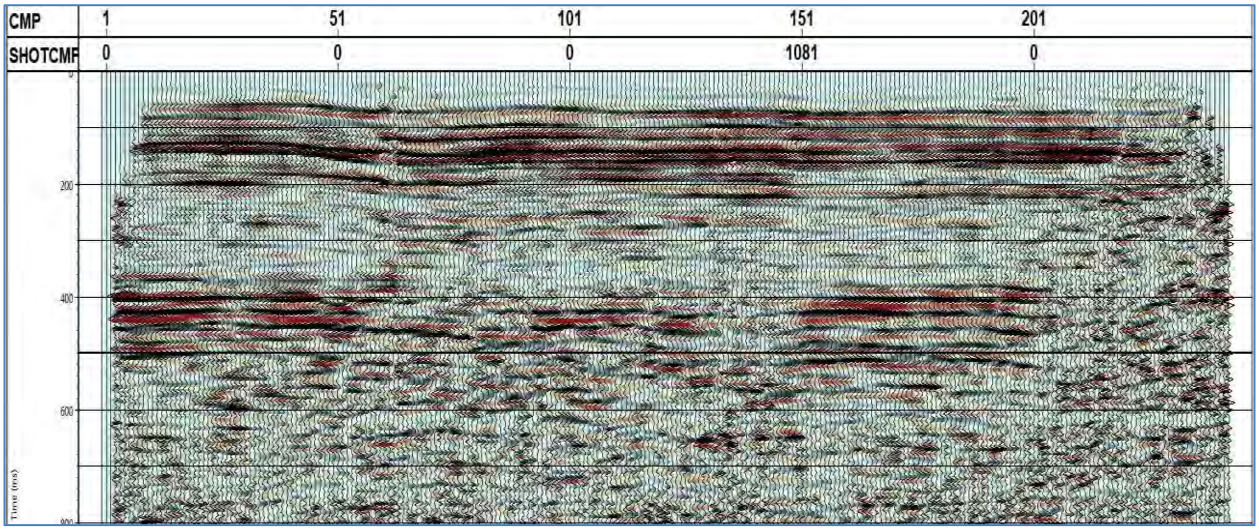


Figure 8: Preliminary 2D seismic CDP stack section (1-mile seismic line) for QA-QC of data filter parameters and overall seismic reflection quality.

3.0 2D and 3D Seismic Data Processing

Upon completion of data acquisition operations and pre-processing QA/QC, all 2D and 3D seismic and geodetic data were sorted and archived for delivery to the processing center. All geodetic survey data received post-processing analysis to compare and correlate Trimble R8 control survey data with the GSX and AIS GPS data. Maximum RCVR and SRC GPS station position error was ~ +/- 2-3 feet.

All P-wave seismic data processing work was performed using the Vista™ 2D and 3D Seismic Data Processing program. Following comprehensive testing and analysis of data processing algorithms a final processing flow was designed.

General Seismic Data Processing Flow

1. Reformatting
2. Geometry / Trace Edit / Trace First Break Picks
3. Time Variant Logarithmic Scaling
4. Pre-filter 12 HZ - Out
5. Noise Reduction by Adaptive Subtraction
6. Surface Consistent & Source Signature Deconvolution, Shot and Receiver
   Operator = 220 ms. Lag = 1 ms.
7. Spectral Balance
8. Datum Statics Datum = Sea Level
9. Refraction Statics
   A. Vista 2-Layer Modeling
   B. GeoTomo Tomographic Modeling
10. Automatic Surface Consistent Reflection Statics: 2 Passes
11. NMO/Mute
12. Noise Reduction by Radon Filter and Rank Reduction
13. DMO / Linear Noise Removal
14. White Noise Suppression by Principle Component Modeling
15. Final CDP Stack
16. Bandwidth Extension (BWE)
17. Migration
18. AGC
19. TVF

0-0.300 Sec.	20-120 HZ
0.45-0.65	20-96
0.80-1.5	20-84

Collier Consulting used the following additional advanced data processing techniques on the 2D and 3D high resolution seismic projects:

- Source Signature Deconvolution is applied using the recorded source signature wavelet for each source position, rather than through statistical derivation.

- Source Signature Bandwidth Extension is applied in order to flatten and balance the amplitude-frequency spectrum of the energy source seismic wave field. This maximizes the usable seismic bandwidth in processing and improves overall data resolution.
- Rather than use statistically derived velocity analysis to correct for near-surface statics, Collier Consulting used full waveform time and wave-field inversion processing to generate continuous vertical and horizontal tomography velocity data to accurately correct for both

refraction and reflection statics. The application of more accurate near surface velocity data significantly improves signal and spatial resolution and eliminates the need for excessive spectral seismic data smoothing.

- Seismic tomography processing was also performed to aid with conversion from seismic time to depth domain, which can then provide better correlation between the non-linear seismic depth scale and synthetic seismographs. Since the geophysical well logs used to generate synthetic seismographs were from wells at great distances from the seismic test sites, predictive modeling was performed to derive a local regional average time-to-depth tomography velocity transfer function; used to reference off-site geophysical logs to seismic ties in depth and time. Figure 9 plots the two-way travel-time (TWT) versus depth to compare the modeled time-depth velocity curve and time-depth picks for the synthetic seismographs. The plot shows excellent correlation, and validates the use of time-depth seismic velocity modeling and correlation with the derived well log synthetic seismographs.

- Principal Component Analysis was applied as an additional advanced processing step to de-noise and improve overall signal-to-noise on the 2D seismic data sets. In addition to improvements on further noise attenuation, signal decomposition and constrained pattern recognition is performed to reduce seismic artifacts caused by diffractions and anomalous reflections generated by rock fracture systems.

The2D and 3D data processing flow were developed on the basis of careful QA/QC tests with raw data files, as well as processing tests to determine best processing steps parameters. The final processing flow is fairly basic, but adds a few advanced steps that are unique to CCI for generating high-definition 2D and 3D panels that can be used for future specialized data attributes processing and analysis that is focuses on a more comprehensive characterization and interpretation of the Floridan Aquifer System.

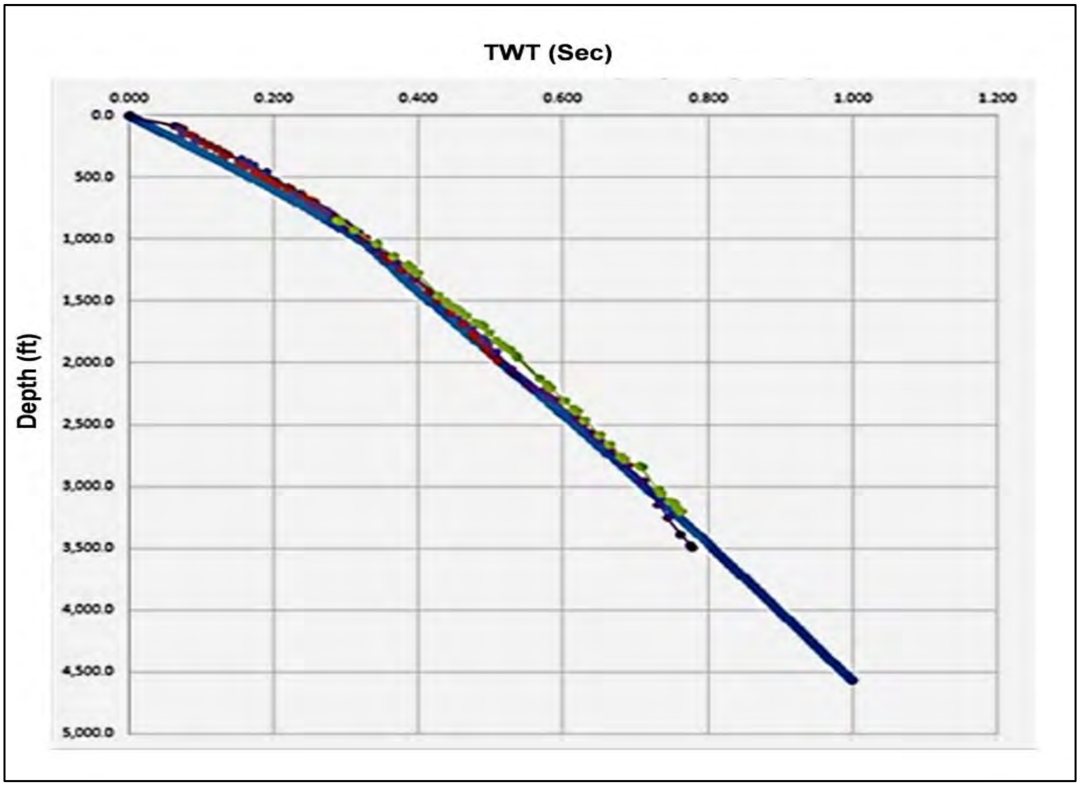


Figure 9: Plot of TWT versus depth comparing time-depth velocity modeling to time-depth synthetic seismograph.

3.1 Synthetic Seismographs

The Synthetic Seismographs that are used to tie site lithology to seismic reflectors in the depth domain were generated using geophysical well log data and lithology information from the Labelle, OUA, and Lake Region injection wells, all obtained from the SFWMD DBHYDRO database. Geophysical log data was selected for modeling of the local regional lithology and generation of synthetic seismographs, because of their nearest proximity to the seismic survey sites and quality-completeness of the log data. In addition to the logs from these well sites, the geophysical logs from a well located in Clewiston was also reviewed and compared with Labelle IW-1 well log data. Figures 10a, 10b, and 10c are the synthetic seismographs for OUA-EW1, Labelle IW-1, and LRRO-IW1, generated using the Ornsby Method (60 Hz center frequency). The synthetic curve picks and lithology correlation tie to seismic reflection data is based on the modeled time-depth-velocity analysis, and lithologic information for each well location.

Valid sonic log (DT) data for OUA-EW1 started at 804 feet BGS. For the Labelle EW-1 geophysical log runs, the sonic log started recording at a depth of 118.5 feet and stopped at 2,011.5 feet BGS. The time-depth average area velocity modeling, along with additional lithologic information, was used to infill the missing sonic log data, and to aid with tie-in to seismic data from each of the seismic test sites. The gamma and resistivity logs were also included in the generation of synthetic seismographs, but only for QC correlation purposes.

A correlation was made to the noted depth of the Underground Source of Drinking Water (UDSW) depth at each well. The USDW is based on water quality and not a stratigraphic unit. However, there was a distinct reflection event at the USDW depth on each log, suggesting that there may be a stratigraphic feature that controls the mixing of water quality in the formation. We referred to this event as the USDW marker and used it for time depth conversion because it was a consistent reflector with a known depth identified on each log.

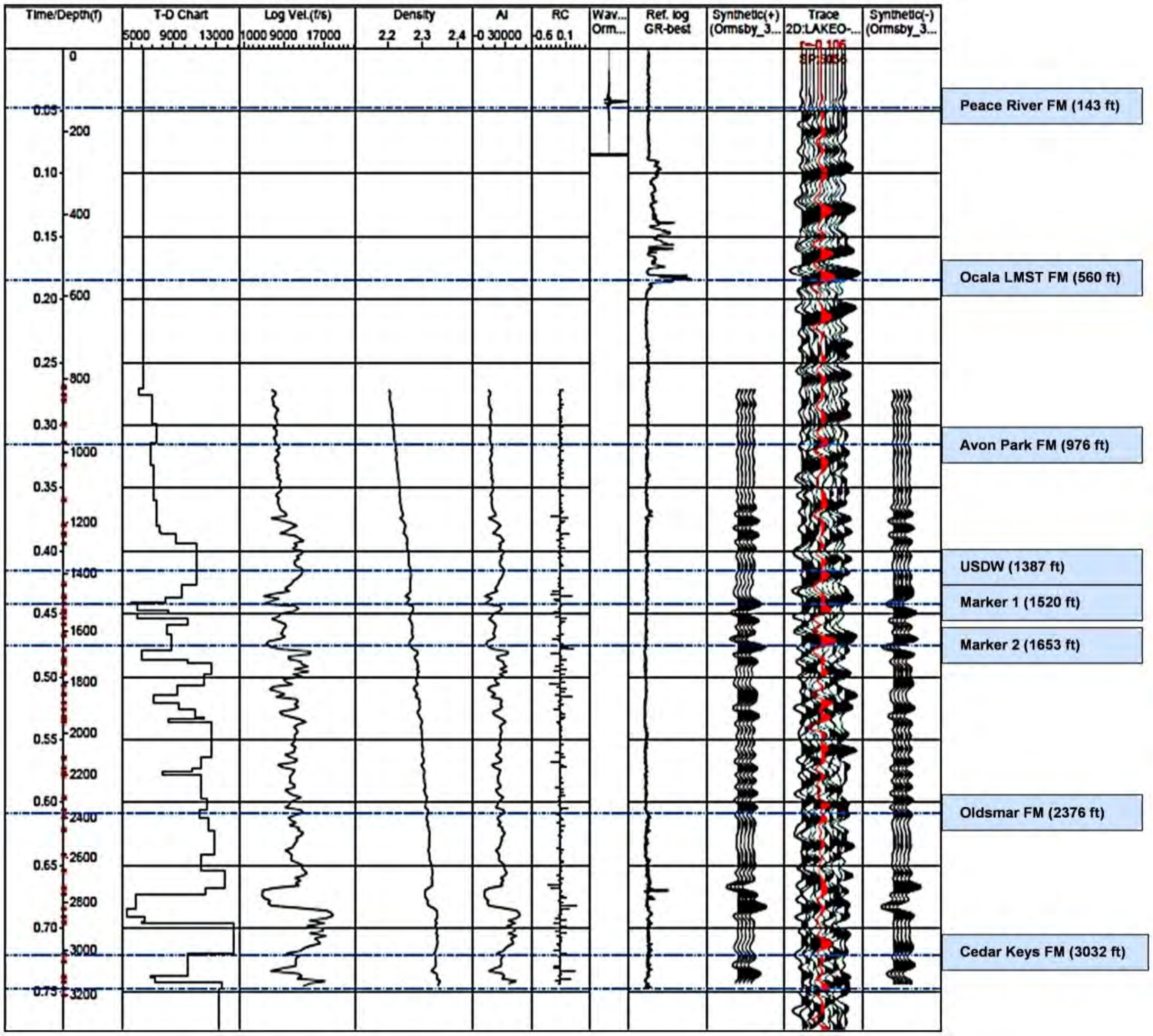


Figure 10a: OUA-EW1 synthetic seismograph tied to OUA 2D seismic data.

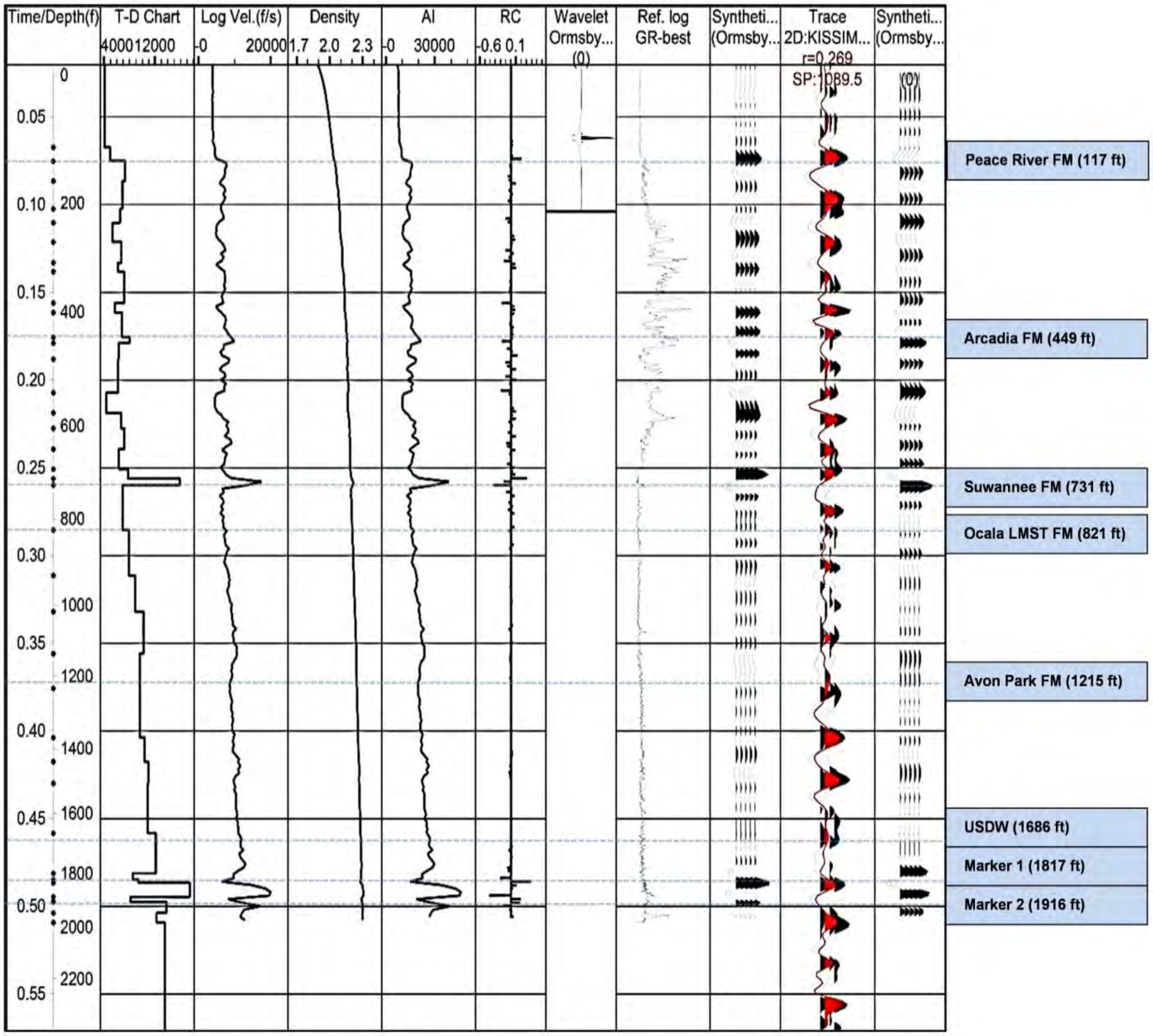


Figure 10b: Labelle IW-1 synthetic seismograph tied to Kissimmee 2D seismic data.

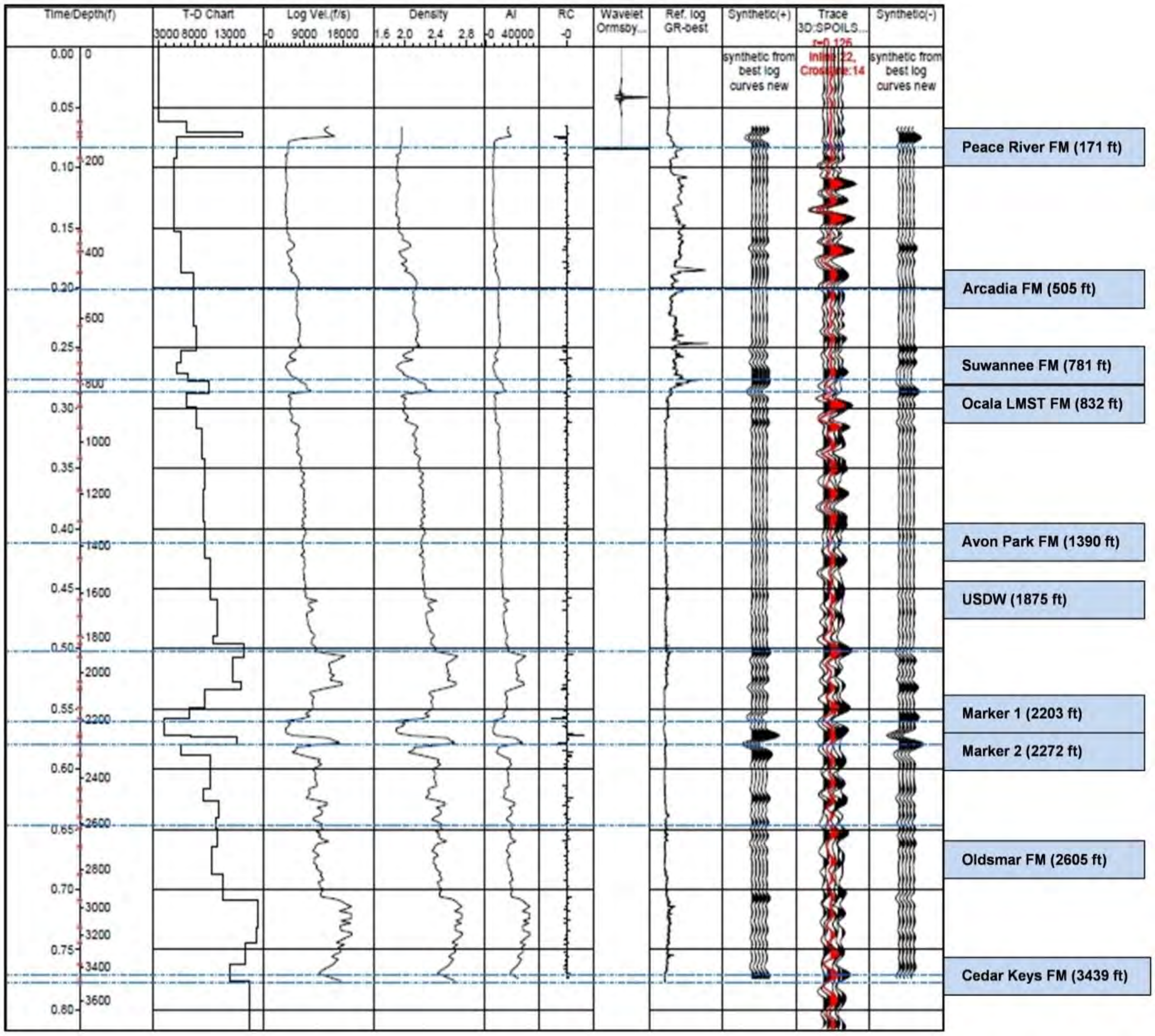


Figure 10c: Lake Region LRRO-EW1 synthetic seismograph tied to Spoil Management seismic data.

Using the final synthetic seismograph, seismic correlation ties, and area P-wave velocity models for each of the seismic test sites, a set of depth-time-velocity tables were generated, which includes both average and interval velocity. Tables 1a, 1b, and 1c are the final depth, time, and velocity versus depth information derived from the synthetic seismograph to seismic data ties for the OUA, Kissimmee, Palm Beach Lake Region, and Spoil Management sites.

Establishing an accurate time, depth, and P-wave velocity relationship using the synthetic seismograph to seismic trace correlation for each of the test sites is critical to interpretation of the 2D and 3D data. The TWT on seismic data does not have a linear relationship to depth because the P-wave velocity does not increase linearly. To generate a common time-depth scale for each of the seismic test sites, an area P-wave velocity model is derived from the synthetic seismograph analysis, from which the time and depth can be used to pick formation reflection horizons that fit with well log lithology. The approximate depth error using this modeling and velocity transfer function method is +/- 15 feet.

Table 1a: Time to depth conversion for the OUA-EW1 Well log tied to Seismic Line 5001.

OUA-EW1 Lithology-Velocity				
Formation	**Depth to Formation Top Elevation BGS (feet)**	**Average Velocity (feet/sec)**	**Interval Velocity (feet/sec)**	**Formation Top (milliseconds)**
Peace River Formation	143	5967	6097	48
Suwannee Limestone	Absent			
Ocala Limestone	580	6064	6390	184
Avon Park Formation	976	6199	8184	314
USDW	1387	6679	10004	415
Oldsmar Formation	2376	7811	11546	608
Cedar Keys	3032	8399	10396	722

Table 1b: Time to depth conversion for the Labelle-IW-1 Well log tied to Seismic Line 5004.

Labelle IW-1 Lithology-Velocity				
Formation	**Depth to Formation Top Elevation BGS (feet)**	**Average Velocity (feet/sec)**	**Interval Velocity (feet/sec)**	**Formation Top (milliseconds)**
Peace River Formation	117	3082	6639	76
Arcadia Formation	449	5108	6718	178
Suwannee Limestone	731	5629	7020	260
Ocala Limestone	821	5754	9074	285
Avon Park Formation	1215	6529	10418	372
USDW	1686	7289	11490	463
Oldsmar Formation	2673	8740	13514	612
Cedar Keys	3210	9289	13514	691

Table 1c: Time to depth conversion for the LRRO-IW1 well log and tied to the Spoil Management Site.

LRRO-IW1 Lithology-Velocity				
Formation	**Depth to Formation Top Elevation BGS (feet)**	**Average Velocity (feet/sec)**	**Interval Velocity (feet/sec)**	**Formation Top (milliseconds)**
Peace River Formation	171	4413	5688	84
Arcadia Formation	505	5679	7375	200
Suwannee Limestone	781	5705	9245	270
Ocala Limestone	832	6096	8898	287
Avon Park Formation	1390	6278	10754	412
USDW	1875	7497	11280	502
Oldsmar Formation	2205	8078	9887	646
Cedar Keys	3439	8943	13460	770

3.2 Regional Geologic Correlation

Figure 11a shows the location of wells (OUA-EW1, Labelle-IW1, LRRO, IW1) in the study area that provided geophysical well log data required for developing regional cross-section ties between site seismic synthetic seismograms lithology, and sites stratigraphy. Figure 11b is the cross-section that was developed to show regional correlations of the major formations in the study area using the geophysical well logs. Figure 11b illustrates that the Peace River through Suwannee formations are generally horizontal with uniform thickness along the line of section but the Ocala though Cedar Keys formations thicken significantly to the south, west, and east. Understanding of the well log correlations and seismic litho-stratigraphic relationship is important for interpretation of the seismic data for test sites 2D and 3D seismic data.

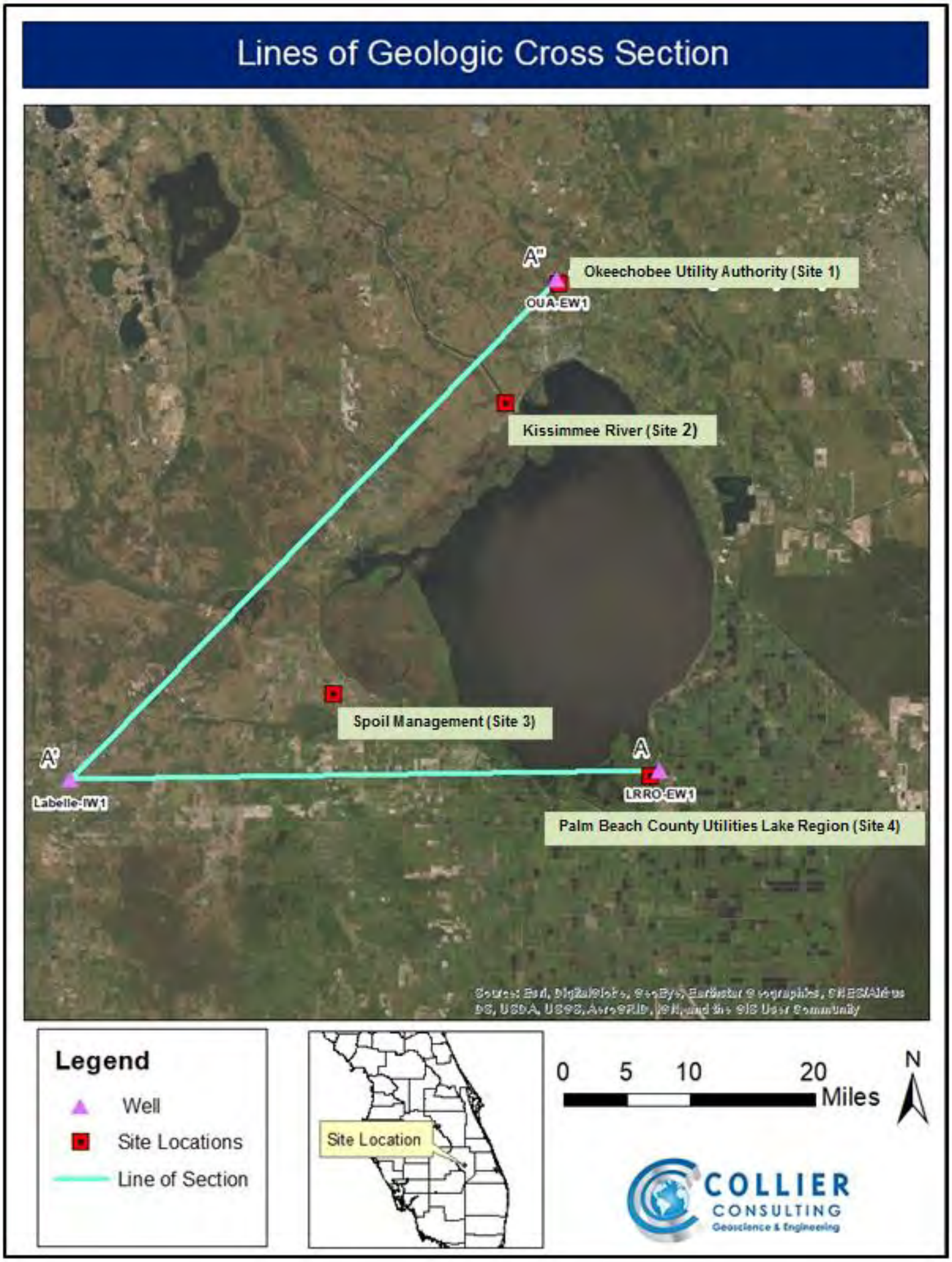


Figure 11a: Cross-Section lines from regional well logs.

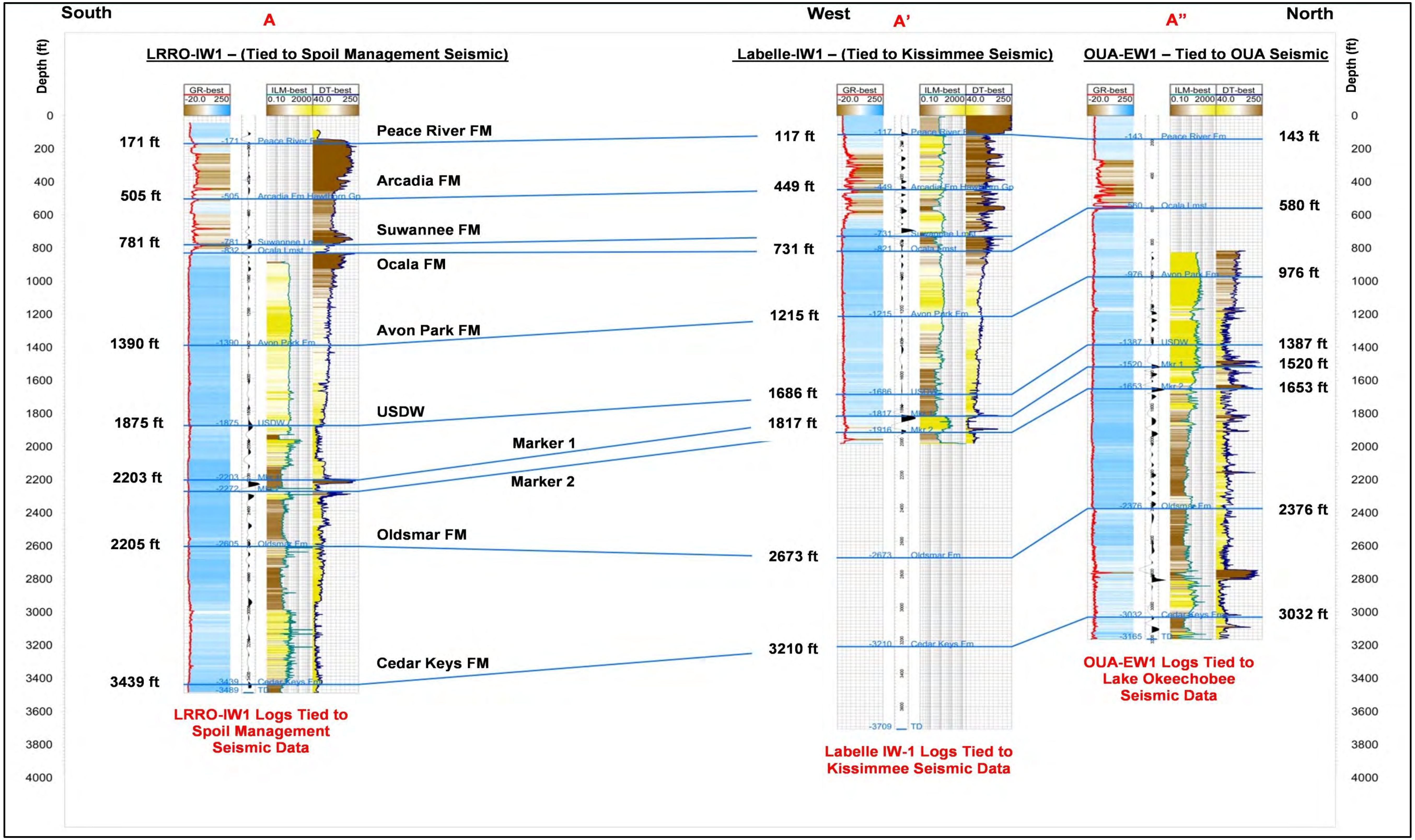


Figure 11b: Correlation of regional well logs LRRO-IW1, Labelle-IW1, OUA-EW1 across study area.

4.0 RESULTS/INTERPRETATION

This project was intended to be a demonstration of the ability of CCI proposed reflection seismic method to image the stratigraphy and structure of the Floridan Aquifer System (FAS), and also to evaluate seismic characterization of the Boulder Zone. While the seismic sections are in themselves proof that the survey was able to image the stratigraphy and structure of the geology to depth below the Boulder Zone, a more comprehensive level of seismic attributes processing and interpretation is necessary to fully appreciate the full spectrum of geologic and hydrogeologic information provided by the data. We have provided a brief interpretation of selected stratigraphic and structural elements of the data. However, the level of detail in the data is quite high and suitable for interpretation for multiple purposes. We have limited our interpretation to focus on features we believe to be most relevant to the current needs of SFWMD, namely the major formations and features that may affect the permeability of aquifer confining units and their effects on the hydraulic attributes of the FAS wells. Other entities may be more interested in other aspects of the geology, such as stratigraphic changes or depositional environments.

In addition, more advanced forms of data analysis, such as attribute processing, are available that can extract subtle but significant patterns from the data that can greatly facilitate the identification of structural and stratigraphic details. While this type of analysis was not part of our scope of work, we included some limited examples of simple attribute processing to demonstrate the power of the methods. A more detailed interpretation including more sophisticated attribute processing would improve the level of detail that can be extracted from the data and make the data useful for more purposes. A brief discussion of our limited interpretation is provided below.

NOTE: While the Ocala Limestone is recognized as a separate geologic unit, distinguishable from the overlying Suwannee and top of underlying Avon Park, the interpretations for this report we include the Ocala as part of the FAS hydrogeologic system.

4.1 Site 1, Okeechobee Utility Authority Plant 2D Seismic

Figure 12 presents an un-interpreted and interpreted seismic section for the line near the Okeechobee Waste Water Treatment Plant (OUA Line 5001 acquired in swath configuration as lines 5001 and 5002). The OUA injection well was installed in 2009 and is completed in a highly transmissive interval of the Boulder Zone, between the depths of 2,765 to 3,200 feet bls. The section shows generally parallel, horizontal reflectors in the Hawthorn Group, suggesting largely intact bedding in these units. A few truncations and seismic amplitude variations are apparent on the reflectors, indicating some lateral changes in stratigraphy and possible minor faulting. A broad sag feature is evident in the Hawthorn Group near the center of the OUA 2D seismic line. The sag feature overlies an apparent collapse structures deeper in the OUA seismic section (~ 1,000 to 2400 feet), which suggests this two or more periods of active subsidence before, and after deposition of the Hawthorn formation.

The Upper Avon Park formation has weaker reflectors, suggesting this unit is somewhat denser and stratigraphically homogeneous relative to the Hawthorn formation. Some minor changes in amplitude and offsets of reflectors are apparent, suggesting the presence of some stratigraphic changes, possible small karst features, and minor faulting.

The reflectors are stronger in the Middle and Lower Avon Park Formation suggesting more stratigraphic layering in this unit. The general pattern of this interval suggests normal faults stepping down into collapse structures near the base of the unit. A large sag feature is present in the center of the line as shown by the red ellipses. This feature contains numerous disrupted reflectors that step down into apparent collapse features deeper in the section. Most of the fractures do not propagate upward beyond the Middle Avon Park Formation, suggesting it is likely to be an effective confining unit in this area.

The Boulder Zone is characterized by sub-parallel and parallel reflectors with numerous zones of discontinuous vertical offsets. Significant amplitude variations along reflector horizons are identified, suggesting a mix of intact stratigraphy and broken chaotic zones of voids and probable and faults and related fractures. The chaotic and disturbed seismic characterization is consistent with the known geophysical well log and core log information of the Boulder Zone.

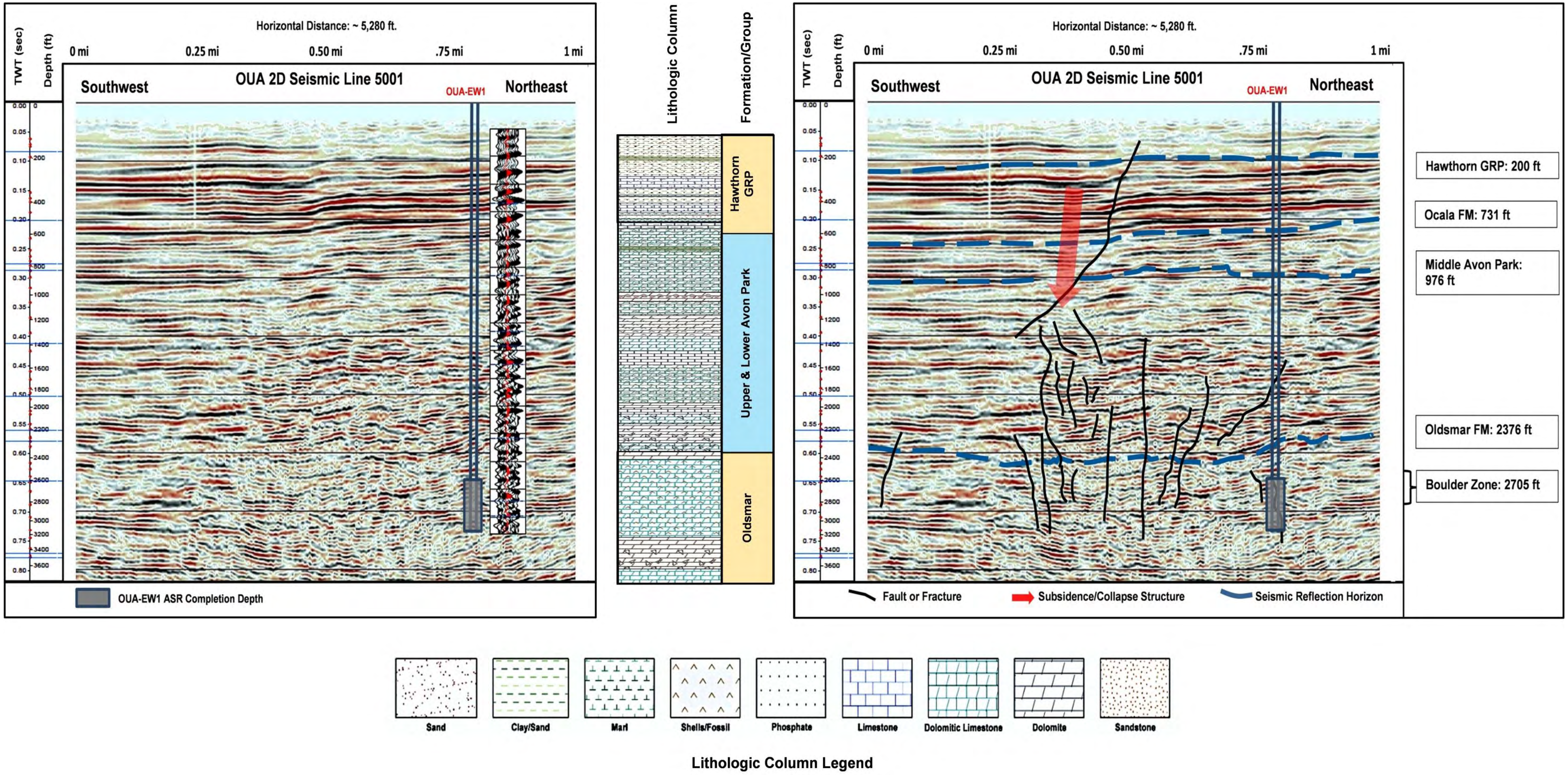


Figure 12: Un-interpreted and preliminary interpretation of the 2D seismic section for OUA Line 5001.

4.2 Site 2, Kissimmee River, 2D Seismic

Figure 13 presents an interpreted seismic section for the Kissimmee seismic line 5004. The Kissimmee 2D seismic data was acquired in swath configuration, consisting of two separate receiver lines (5003 and 5004) deployed parallel at 50 ft separation. In processing, data from each of the two receiver lines was compared for repeatability with respect to data quality and seismic reflection character. Further processing to compensate for “out of the plane” artifacts was also evaluated, and Principal Component corrections applied to de-emphasize non-reflector noise.

Data for these seismic lines was acquired in close proximity to the ASR pilot project constructed as part of the Comprehensive Everglades Restoration Program. Seismic section 5004 shows generally parallel, horizontal reflectors in the FAS and Hawthorn Group, suggesting largely intact bedding in these units. A few truncations and amplitude variations are apparent on the reflectors suggesting some lateral changes in stratigraphy and possible minor faulting. A broad sag feature is evident in the reflectors in the Hawthorn Group in the southeast half of the line. The sag feature overlies an apparent collapse feature deeper in the section, which suggests this area experienced active subsidence following deposition of the Hawthorn formation.

The Upper Avon Park formation has much weaker reflectors, suggesting a denser homogeneous unit. Some changes in amplitude and offsets of reflectors are apparent suggesting the presence of some stratigraphic changes, possible karst features and faulting. Two large sag features are present as shown by the red ellipses. These features contain numerous faults and dipping and disrupted reflectors that step down into apparent collapse features deeper in the section.

The reflectors are stronger in the Middle and Lower Avon Park Formation suggesting more stratigraphic layering in this unit. The reflectors are broken with a general pattern of stepping downward to the west of the section. Some horizontal reflectors lap onto dipping reflectors, suggesting deposition onto a subsiding structure. The general pattern of this interval suggests normal faults stepping down into collapse structures near the base of the unit, with a general trend of greater subsidence to the southeast half of the line. The Boulder Zone is characterized by discontinuous reflectors with dips and offsets and with significant amplitude variations along reflectors, suggesting a more chaotic mix of intact stratigraphic sections broken up by large fracture zones or voids.

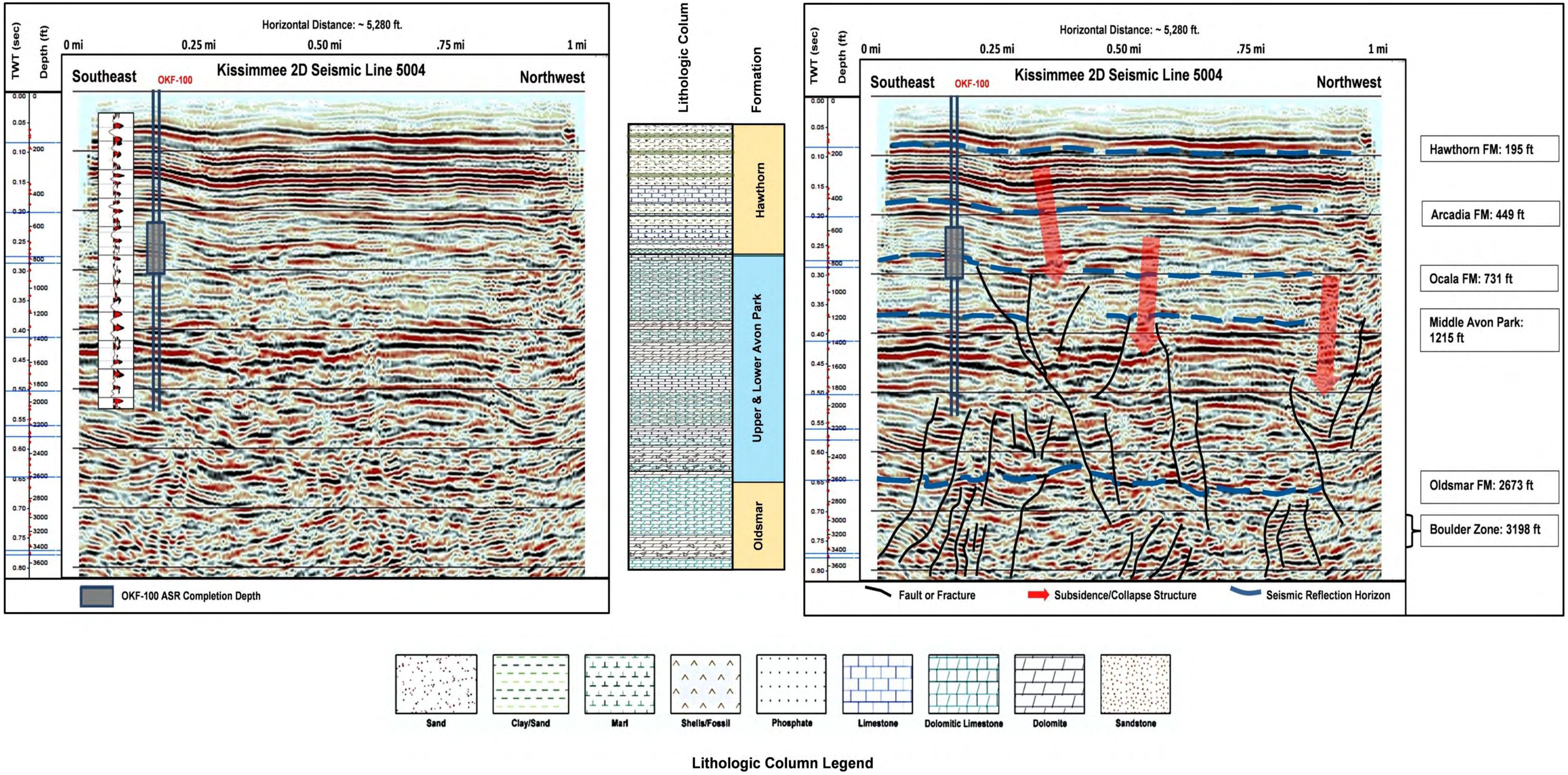


Figure 13: Un-interpreted and preliminary interpretation of the 2D seismic section for Kissimmee Line 5004.

4.3 Site 3, Spoil Management Site, 3D Seismic

The data for the Spoil Management site was collected as a 3D survey using a grid pattern for the source and receiver lines as shown on Figure 4. The survey was collected in 3D partly to obtain the required depth of investigation and partly to demonstrate the improvement in resolution that 3D acquisition can provide.

The Spoil Management site is approximately 55 acres, and would not allow a 2D line that was long enough to image deeper portions of the FAS. 3D data acquisition can provide greater penetration with less maximum source-receiver offset than a 2D survey. In addition, 3D acquisition collects data from multiple azimuths along and in between survey lines. The reflection data is processed as a data volume of all the receiver and source lines (data cube) rather than as separate 2D profiles. This places reflected energy into the proper spatial relationship and reduces smearing that occurs from out of plane reflections in traditional 2D surveys. By acquiring the data in 3D, we were able to image the subsurface to greater depths and at much higher resolution than could have been obtained by a 2D line.

Figure 14 is a plot of the survey geometry and fold density of coverage generated for the Spoil Management 3D survey. The source and receiver line locations were placed to maximize the fold (density of common depth points in the reflection data) in the target exploration depth zone across the site to provide high spatial resolution (20 to 114 fold) 3D data.

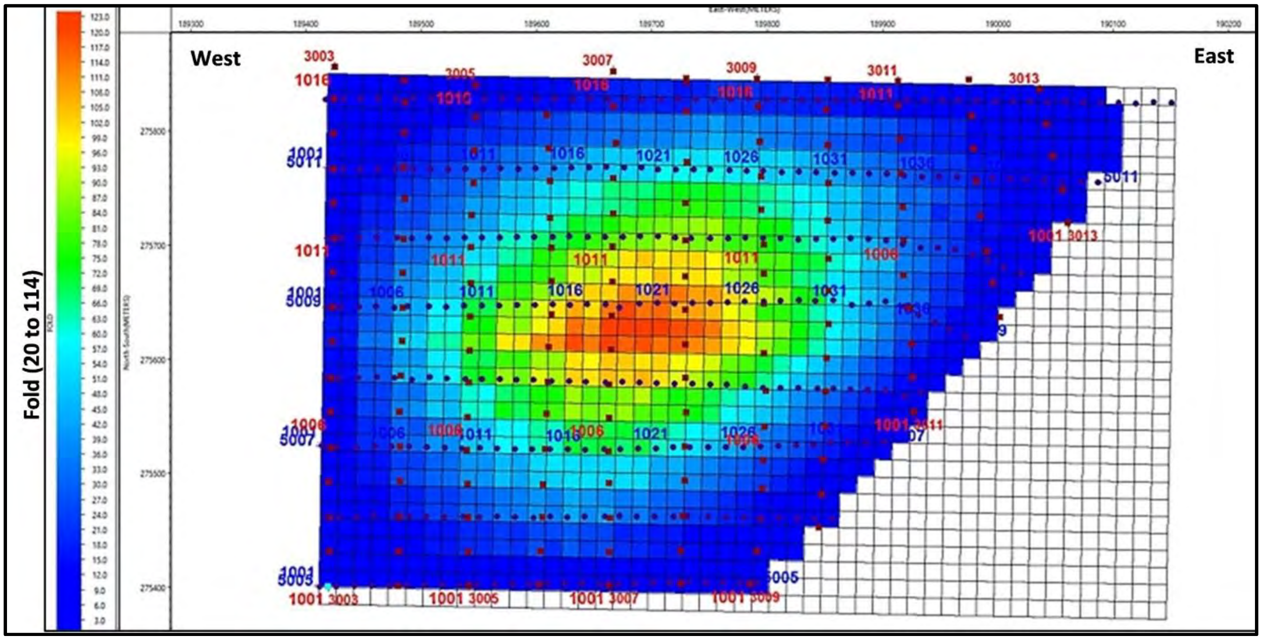


Figure 14: Source and receiver line layout with data fold coverage for Site 3, Spoil Management Site, 3D seismic.

Figure 15 is a sample seismic section extracted from the 3D data cube along a crossline (perpendicular to the receiver lines) that illustrates the improvement in resolution and data quality provided by 3D acquisition. The major formation tops are marked to make it easier to see where specific reflection packages lie within the stratigraphic sequence. In comparison to the 2D lines acquired at the other three sites, the seismic data from the Spoil Management Site shows good seismic reflection continuity, and subtler changes in amplitude and character along each reflector. Subtle stratigraphic relationships, such as on-lapping and off-lapping reflectors, and bisecting or truncating reflectors are evident. These features can be interpreted to understand the detailed stratigraphic and structural relationships between the units, and infer the depositional environment of the sequences. The 3D reflection data is generally cleaner with better overall signal-to-noise, and can show more detail than the 2D lines.

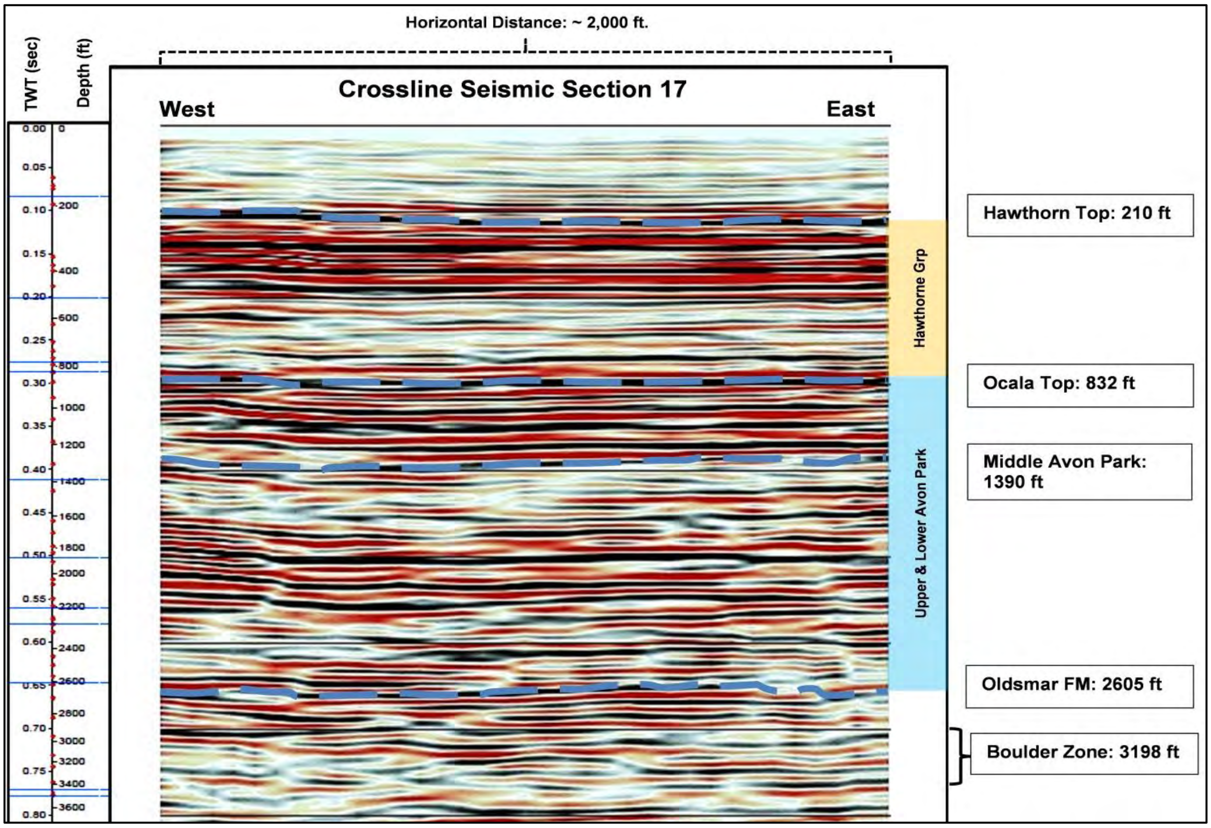


Figure 15: Interpreted crossline 17, from Site 3, Spoil Management Site, 3D seismic.

Figure 16 shows two interpreted crossline seismic sections for two lines located approximately 200 feet apart within the 3D data cube. A low cut filter has been applied and the color scale of the plots has been modified to fit frequency vs impedance to improve the visual contrast. The section shows generally parallel, horizontal reflectors in the upper Hawthorn Group, suggesting largely intact bedding in these units. The lower part of the Hawthorn Group has weaker reflectors suggesting this interval is denser and more homogeneous.

The Upper Avon Park formation has stronger reflectors, suggesting more distinct layering on this interval. Some changes in amplitude and offsets of reflectors are apparent suggesting the presence of some stratigraphic changes, possible karst features.

The reflectors are more discontinuous in the Middle and Lower Avon Park Formation suggesting more stratigraphic or structural changes in this unit. Two large subsidence features are present as shown by the red arrows. These features contain numerous small subsidence fringe faults, characterized by indications of dipping and vertically disrupted reflectors that step downward into apparent collapse features deeper in the section.

The Lower Avon Park and Oldsmar Formations are more intensely disrupted. The general pattern of this interval suggests normal faults stepping down into collapse structures near the base of the unit, with a general trend of greater subsidence to the southeast half of the line. The Boulder Zone is characterized by strong but discontinuous reflectors with dips and offsets and with significant amplitude variations along reflectors, suggesting a mix of intact stratigraphic sections broken up by fractures or voids.

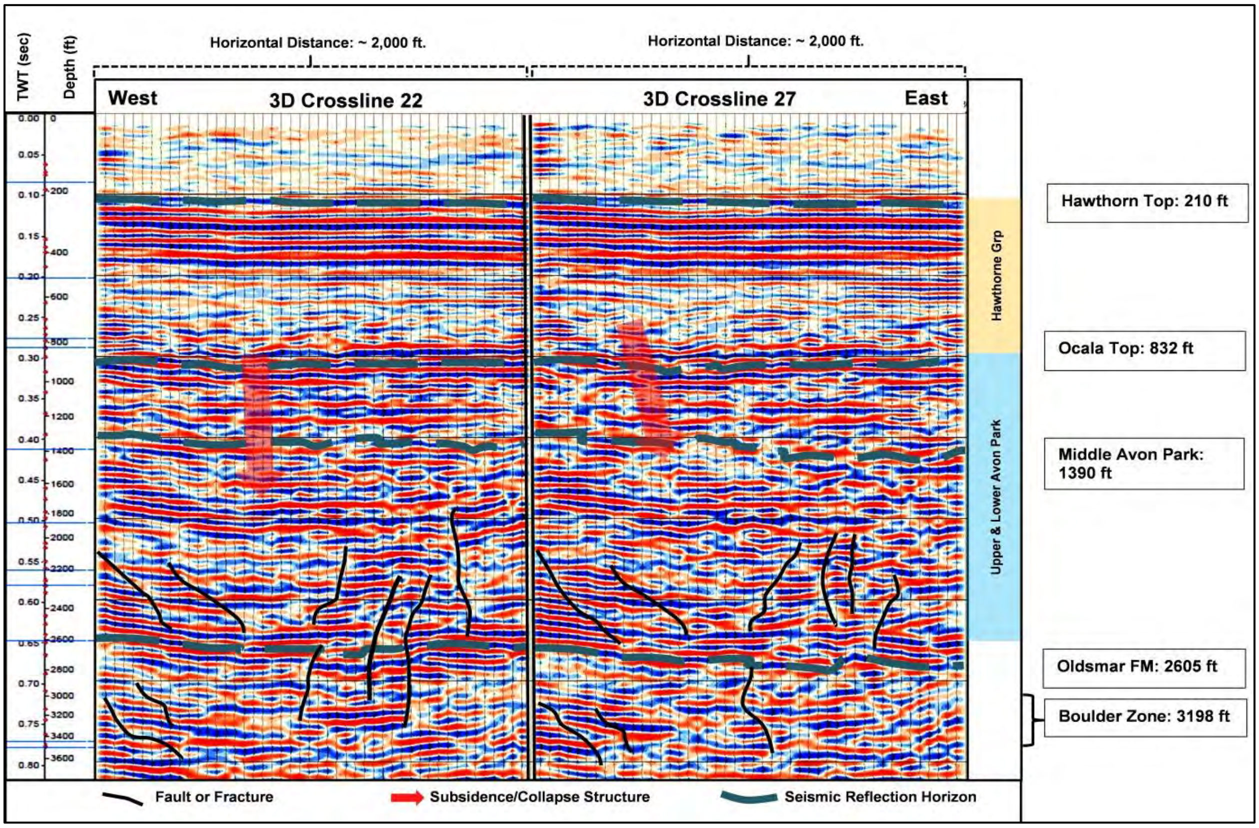


Figure 16: Interpreted crosslines 22 and 23 with color scale enhancement and band pass filtering, Site 3, Spoil Management Site, 3D seismic.

Figures 17 through 20 are depth slice elevation maps for the tops of the Arcadia, Ocala, Middle Avon Park and Oldsmar Formations, derived from two-way travel time (TWT) to depth conversion processing using TD-Velocity Inversion. The depth-slice surfaces show a prominent subsidence feature at each formation top. The subsidence structure appears more prominent at greater depth, and shifts south - southwest with increasing depth. Figure 21 is a stacked plot of the time surfaces for the Arcadia, Ocala, Suwanee, Avon Park, and Oldsmar formation tops extracted from the 3D data cube. The increase in depth and translation to the southwest of the sag feature is apparent in the stacked surfaces. The shape of the formation surfaces suggests a collapse structure into a deeper feature that has been active through the period of deposition of the units.

A limited attribute processing analysis was applied to the 3D data cube to illustrate how variations in the wavelets along reflectors can be used to highlight structural and stratigraphic features that are not apparent to the human eye. Figure 22 shows the results of a composite attribute complied from amplitude, frequency and velocity variations of the wavelets selected to emphasize voids and karst features. The plot shows the position of larger voids beneath the site as blue to yellow and red small bodies in the space between formation horizons. The voids and karst feature attributes are largely absent from the Hawthorn Group and more prevalent in the Lower Avon Park and Oldsmar Formations. These features would be promising drilling targets for high volume injection wells. Similarly, they would be features to avoid for applications where turbulent flow or mixing was undesirable, such as for an ASR storage zone, or where the integrity of a confining unit was critical, such as an injection zone below a water production zone. With more attributes processing these zones could be better defined and ranked in terms of size and probable permeability using other attributes of the wavelets. Other features such as faults, fractures, or lateral stratigraphic changes could also be mapped in three dimensions using attribute processing.

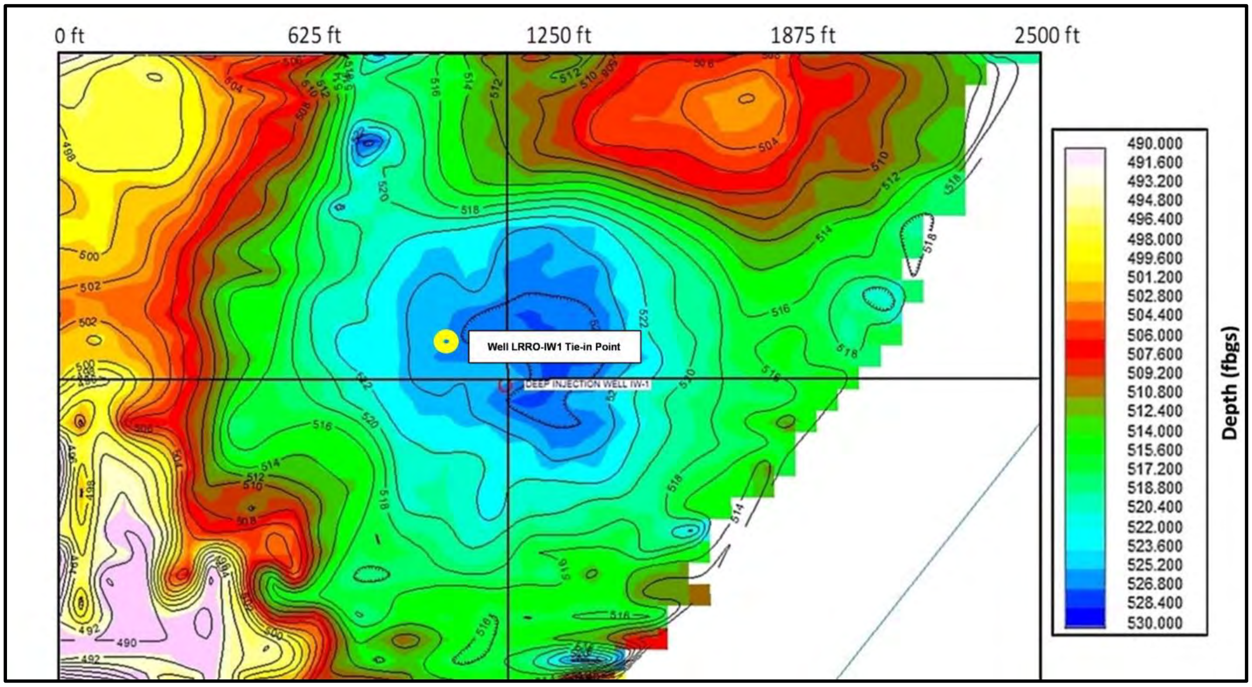


Figure 17: Top of Arcadia Formation from inverted time horizon, Site 3, Spoil Management Site, 3D seismic.

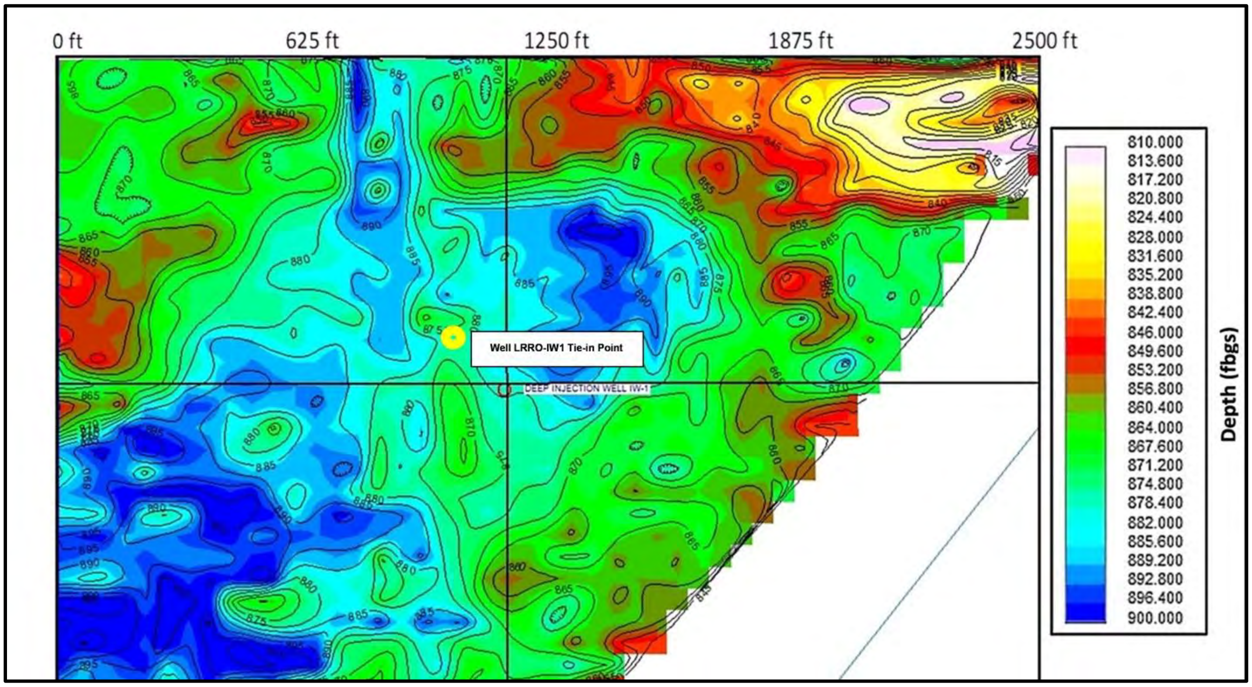


Figure 18: Seismic geomorphology contour map for top of Ocala formation (elevation range: 810 to 990 feet bls), Spoil Management Site 3D seismic.

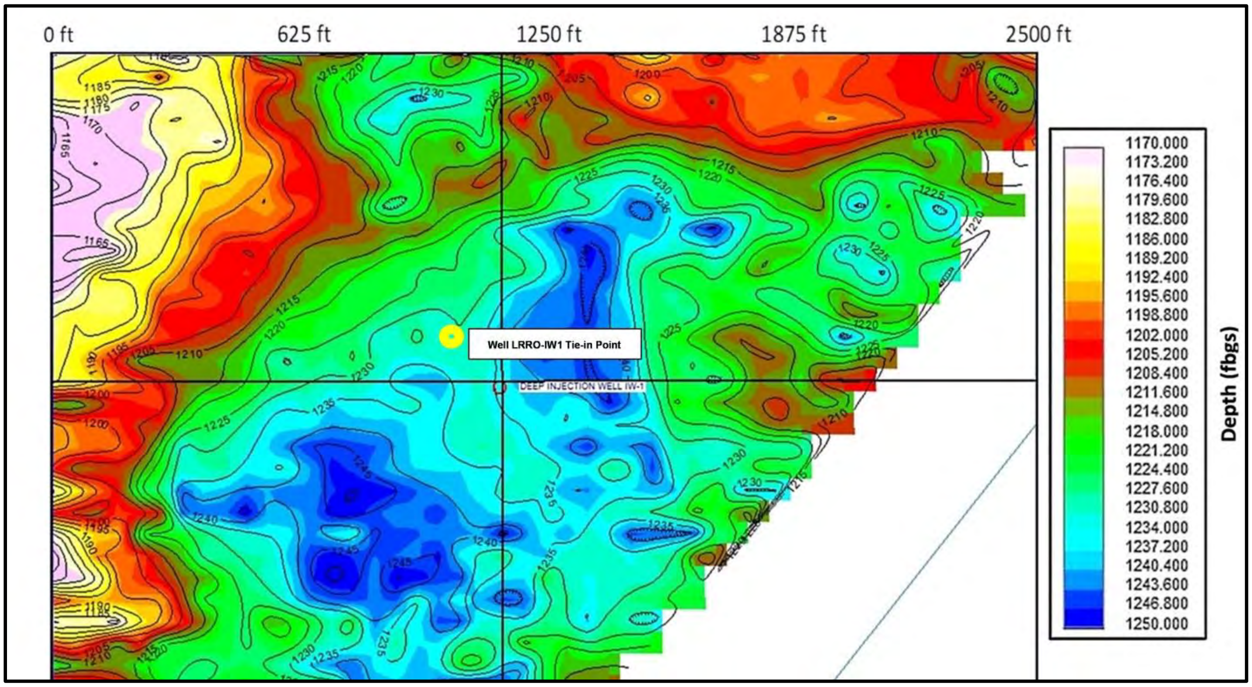


Figure 19: Seismic geomorphology contour map for top of Middle Avon Park (elevation range: 1170 to 1250 feet bls), Spoil Management Site 3D seismic.

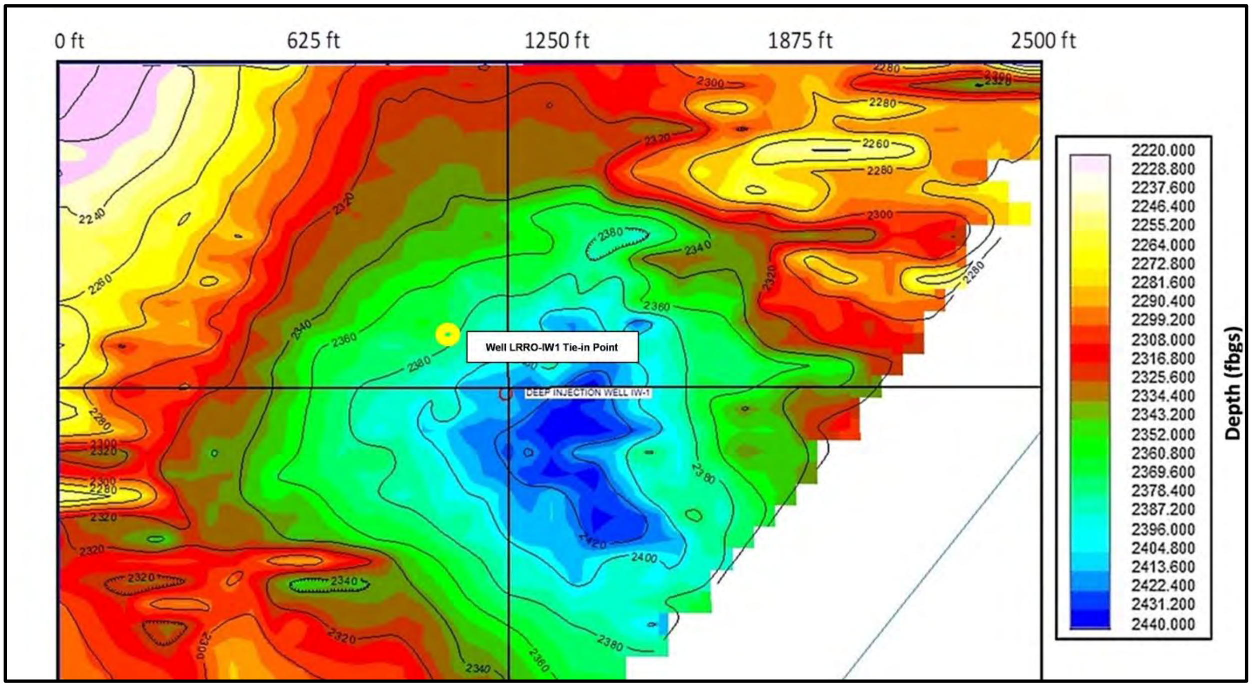


Figure 20: Seismic geomorphology contour map for top of Oldsmar formation (elevation range: 2220 to 2440 feet bls), Spoil Management Site 3D seismic.

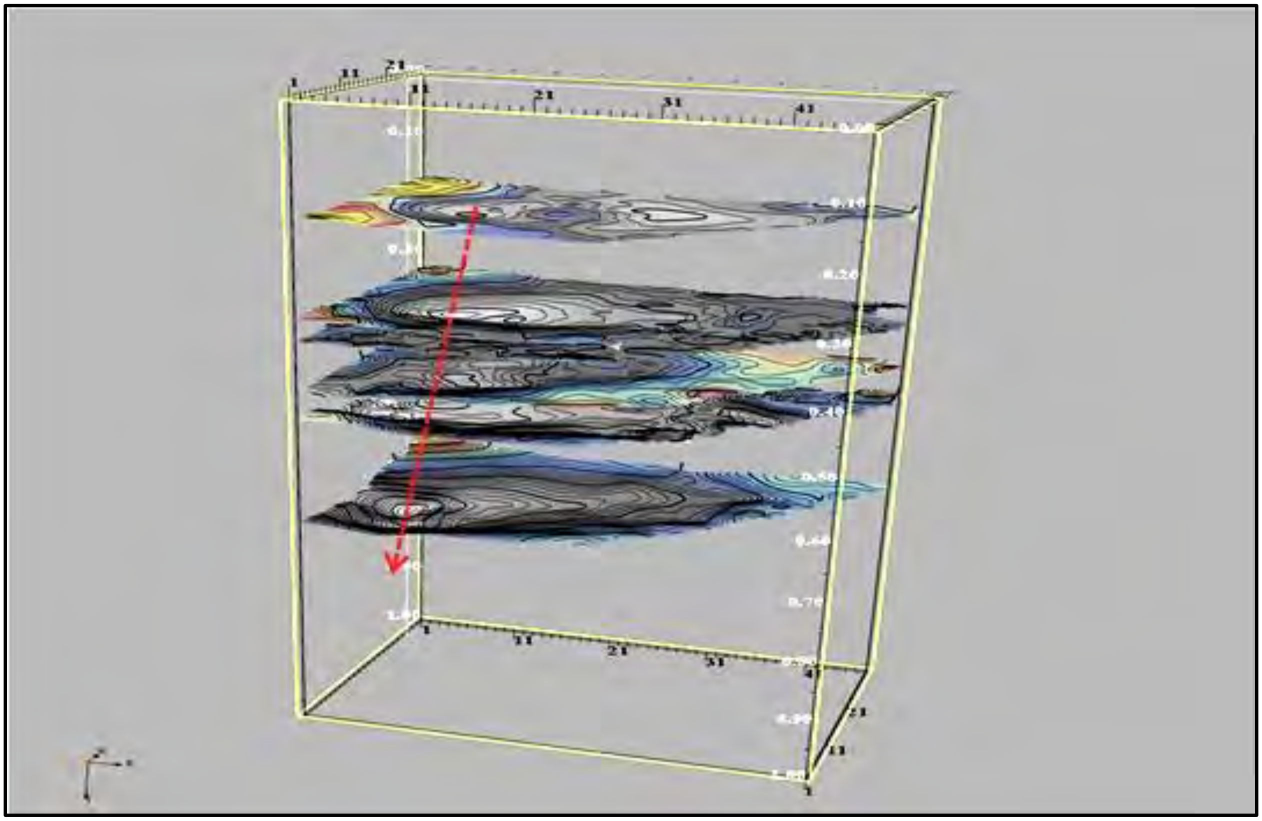


Figure 21: 3D rendering of formation tops from inverted time horizons showing progression of possible remnant collapse structure with depth, Spoil Management Site 3, 3D seismic.

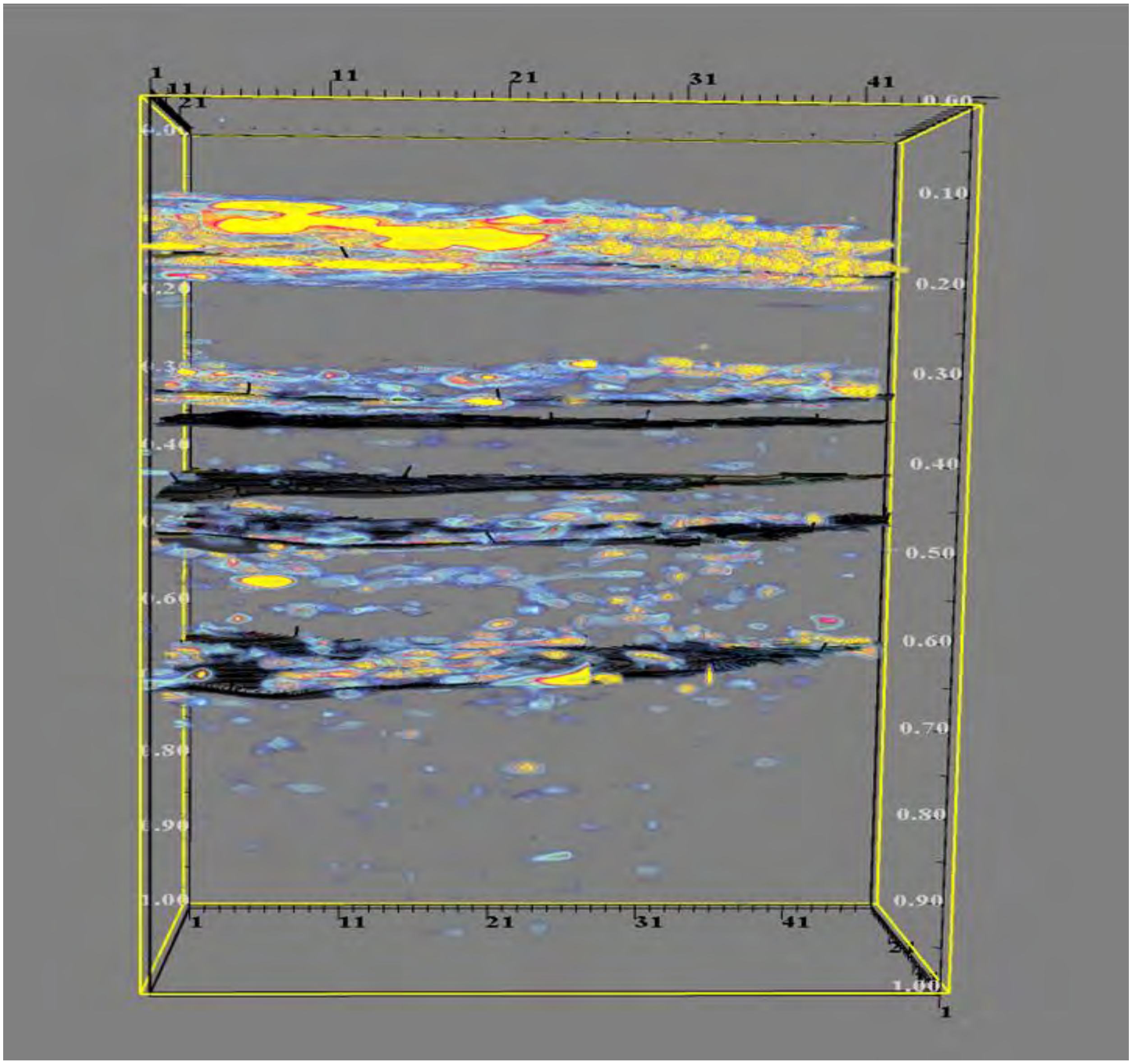


Figure 22: South view of Spoil Management Site 3 3D attributes processing showing voids and karst features within lower Avon Park and Oldsmar formations.

4.4 Site 4, Palm Beach County Lake Region, 2D Seismic

For the Palm Beach County Lake Region (Site 4) 2D seismic program, data was acquired as two lines of 1-mile segments along State Road 80 and State Road 715. The State Road 80 and State Road 715 intersection presented noise and other infrastructure obstacles that prevent layout of geophones across the roads. Undershooting to obtain subsurface coverage below the intersection as the data gap between line segments at 450 to 500 feet was too wide. In addition, there is insufficient roadside shoulder access for deployment of more than one line. The 2D swath configuration (2-receiver line deployment) was not used over Site 4. Each seismic section segment represents data from single receiver lines. Figure 23 shows the individual State Road 80 and State Road 715 seismic segment locations, and area well sites.

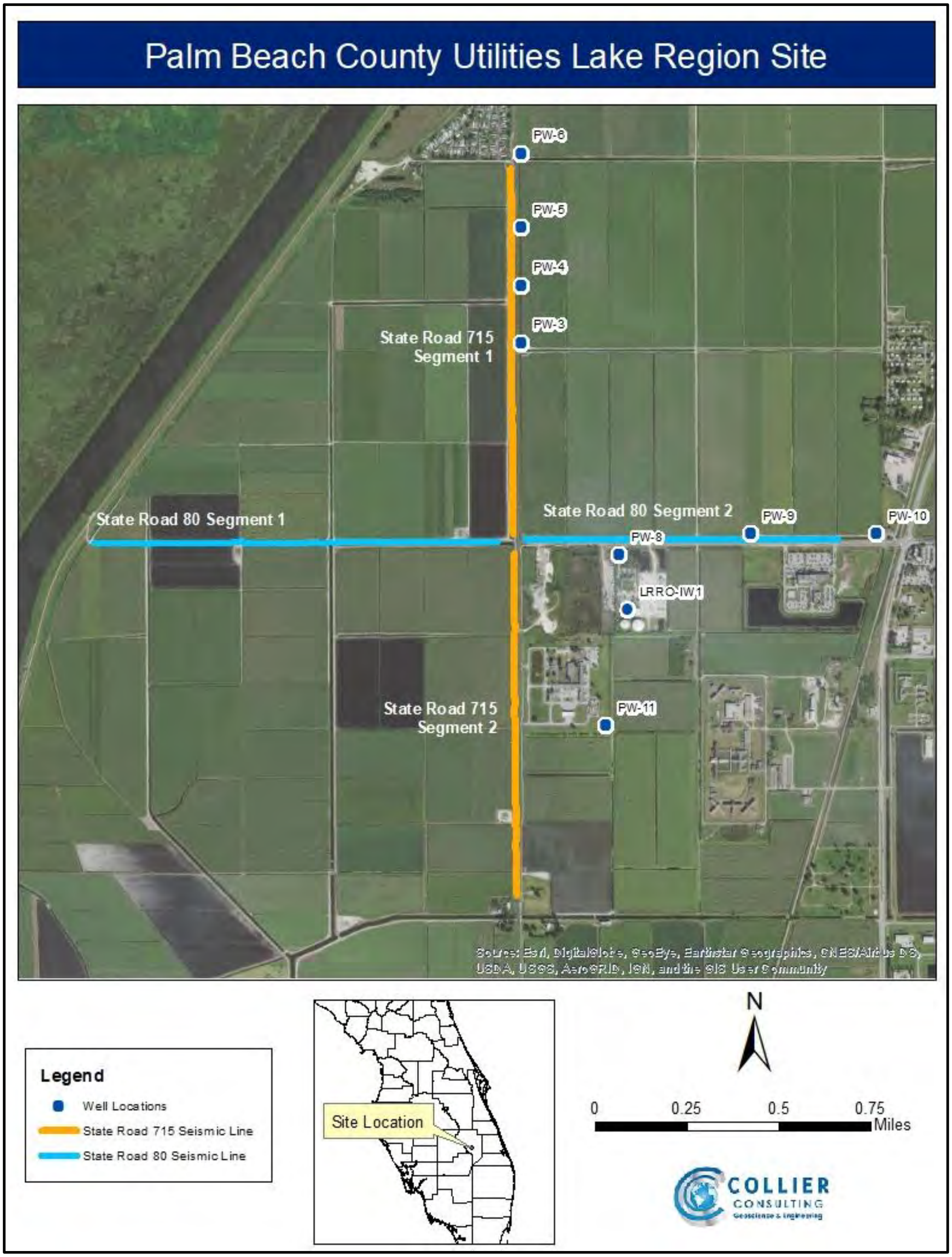


Figure 23: Palm Beach County 2D seismic line map for State Road 80 and State Road 715, west-east and north-south 1-mile Segments 1 and 2.

4.4.1 State Road 80 Segments 1 and 2

Figures 24 and 25 are interpreted seismic sections of the State Road 80, line Segments 1 and 2. In Figure 24 the 1-mile Segment 1 section shows generally parallel, horizontal reflectors in the Hawthorn Group, suggesting largely intact bedding in these units. A few truncations and amplitude variations are apparent on the reflectors suggesting some lateral changes in stratigraphy and possible minor faulting.

The Upper Avon Park formation has much weaker reflectors, suggesting a denser homogeneous unit. Some changes in amplitude and apparent sag features are present suggesting the presence of some stratigraphic changes, possible karst features and faulting. The reflectors are stronger in the Middle and Lower Avon Park Formation suggesting more stratigraphic layering in this unit. The reflectors appear fractured with a general pattern of downward vertical offset to the west of the section. Some horizontal reflectors appear to overlap onto dipping reflectors, suggesting deposition over a subsidence structure. The general pattern of this interval suggests short-normal faults stepping down into collapse structures near the base of the unit, with a general trend of greater subsidence to the western end of the line. The Boulder Zone is characterized by discontinuous reflectors with dips, vertical offsets, and significant seismic amplitude variations along reflectors, suggesting a more chaotic mix of intact stratigraphic sections broken up by large fracture and/or voids. Based on review of geophysical well logs and sample cores (where available), this structure and stratigraphic character is consistent with of the Boulder Zone.

Figure 25 presents the seismic section for the eastern half of the State Road 80 line Segment 2. The general pattern of the reflectors is similar to Segment 1, but the reflectors in the Middle Avon Park appear to be less faulted and more horizontal. The Boulder Zone seismic reflectors appear to be more coherent and continuous, although some strongly dipping reflectors are still observed. The general pattern suggests that the faulting and karstification is less prominent on Segment 2 compared to Segment 1.

Wells 8 and 9 are located next to the seismic line and the well bores have been projected onto the lines. Both wells have experienced increases of about 70 to 75% in EC concentrations, though Well 9 was drilled after Well 8 and had a higher initial EC reading. By 2018, the EC concentration of Well 9 was about 40% higher than Well 8. Both wells are completed in the Upper Avon Park. Well 9 appear to be completed in an area with more vertical faults extending into the Lower Avon Park and Oldsmar Formation. It is possible that these faults are a preferential flow path for higher TDS water causing Well 9 to experience a greater degree of invasion from deeper sources of water which resulted in higher levels of EC and TDS. Some portions of the Upper Avon Park, such as west of Well 8 on segment 2 and the west half of Segment 1 appear to have more continuous reflectors in the Upper Avon Park with fewer faults that extend into the Upper Avon Park from deeper units. These areas may be more favorable for supporting wells with more stable water quality.

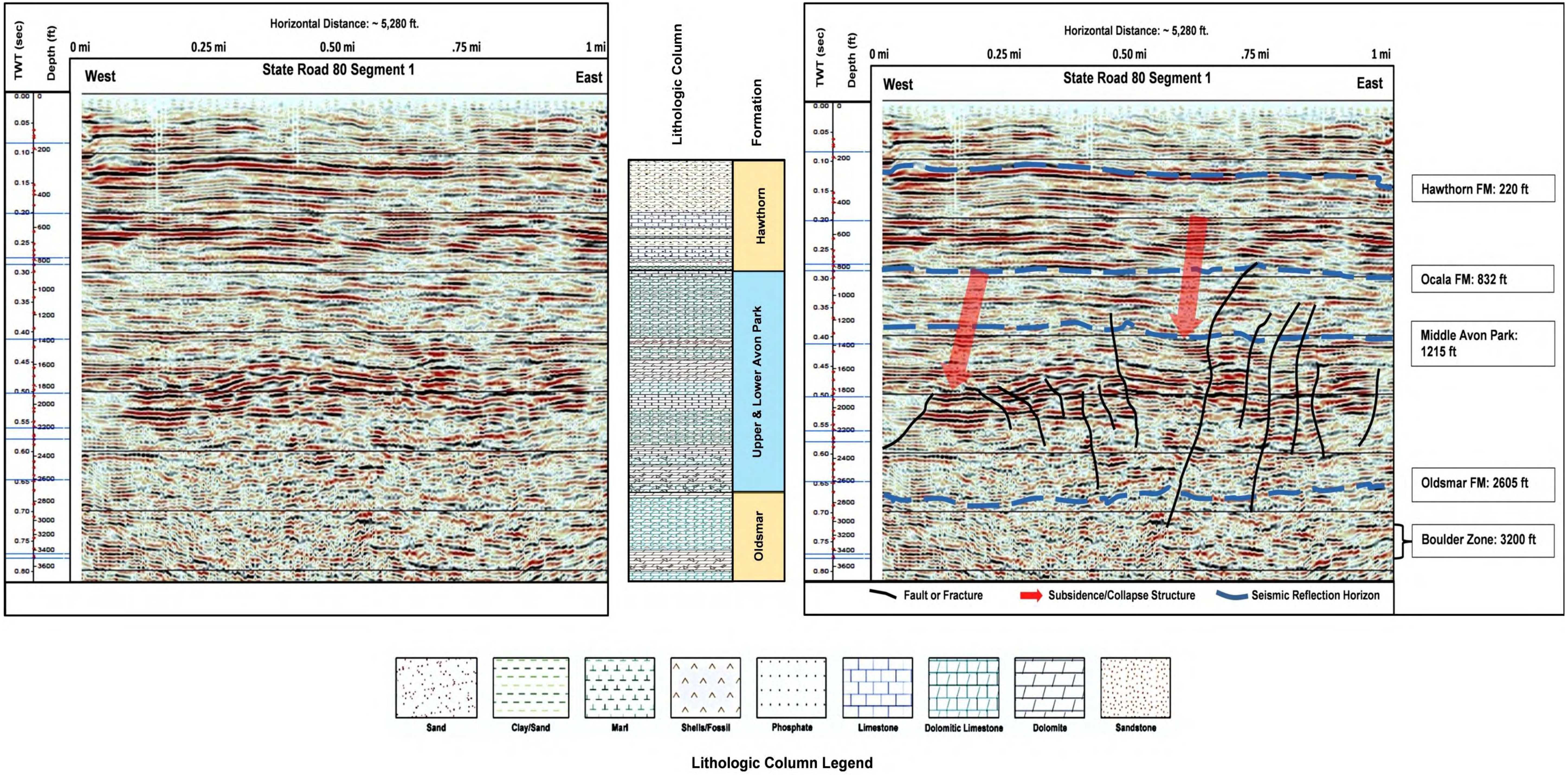


Figure 24: Un-interpreted and preliminary interpretation of the 2D seismic section for State Road 80 (Line 5015), Segment 1, Site 4.

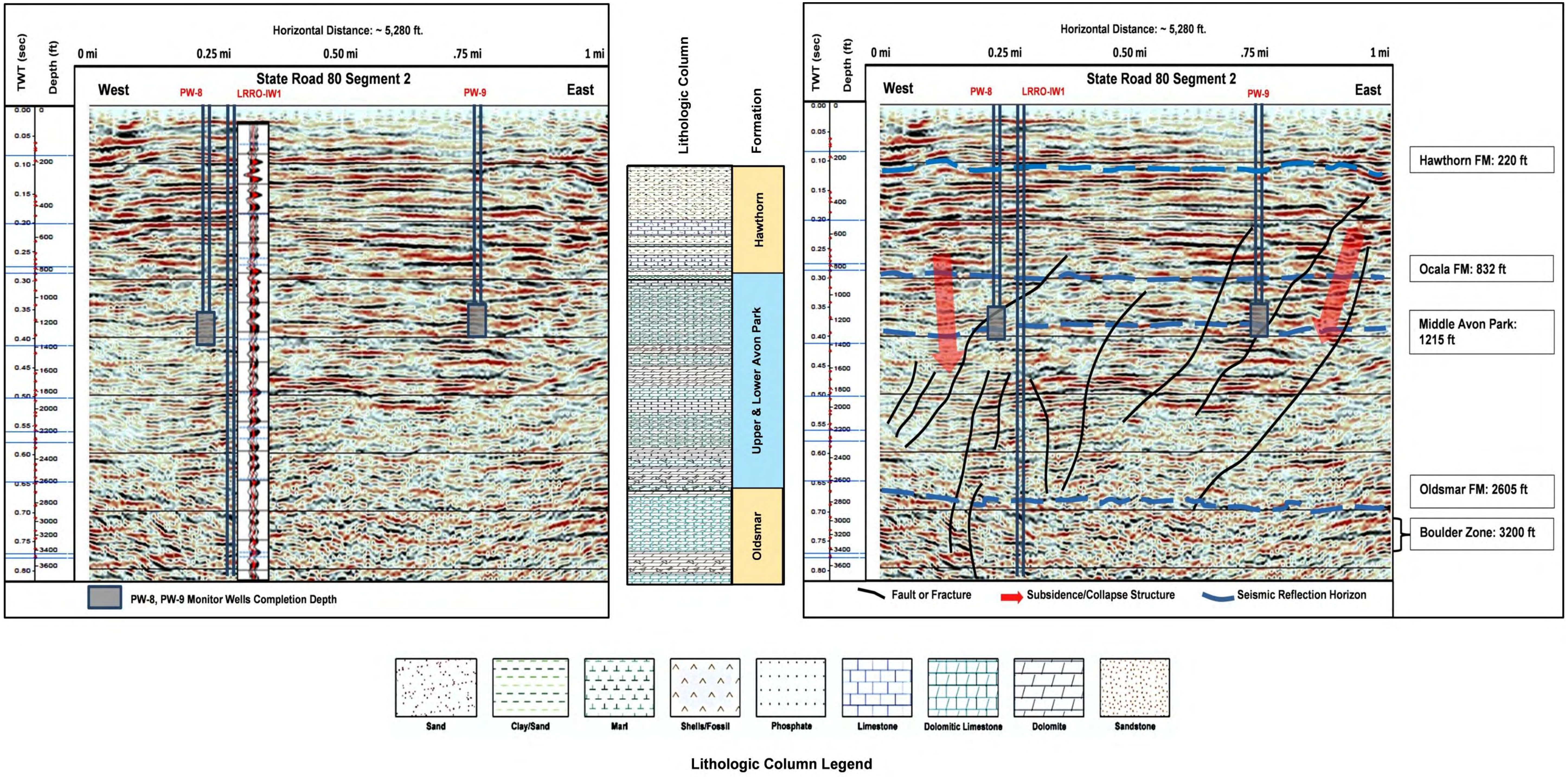


Figure 25: Un-interpreted and preliminary interpretation of the 2D seismic section for State Road 80 (Line 5015), Segment 2, Site 4.

4.4.2 State Road 715, Segments 1 and 2

Figures 26a and 27 are un-interpreted and interpreted (preliminary) seismic sections for State Road 715 seismic line Segments 1 and 2, where Segment 1 is the northern 1-mile segment and Segment 2 is the southern 1-mile segment. The general reflection pattern is similar to the State Road 80 seismic line. However, there appears to be greater lateral reflector discontinuity and amplitude changes within the Hawthorn Group, suggesting that there may be more stratigraphic structure changes and faulting. There are also deeper sag features and dipping reflectors in the Lower Avon Park Formation, especially in the northern one-third of the line. The Boulder zone has a similar reflector patterns as the State Road 80 line.

Wells 3, 4, and 5 are located along this segment and nearby well bore locations are projected onto the seismic section. Well 5 has experienced a more rapid increase in EC and TDS than Wells 3 and 4. Well 5 is located above a zone of dipping and disrupted reflectors in the Middle and Lower Avon Park formation, and adjacent to dipping reflectors in the Upper Avon Park Formation just north of the well. The reflector pattern suggests that Well 5 may be located in a more disturbed portion of the Avon Park Formation, and may have received more rapid upward migration of higher TDS water through faults and fractures within the confining units. Well 4 is located on the south side of an apparent subsidence feature, but is still in a zone of discontinuous and dipping reflectors in the Avon Park Formation. Well 3 is located in a stratigraphic zone that exhibits greater seismic reflection continuity in the Upper and Middle Avon Park Formation. Well 4 appears to have been less impacted by rising EC levels than Well 5, and more so than Well 3. Seismic Segment 1 for State Road 715 appears to indicate that the reflection continuity in the Upper and Middle Avon Park Formation may correlate with more stable water quality in the wells. Based on this assumption, the far southern portion of this segment may be a favorable location for production of better water quality; however, additional seismic attributes analysis and signal processing is needed to guide correlation between the hydrogeologic structures and water quality.

Figure 26b is an enlargement of State Road 715 Segment 1 seismic section between 200 and 550 milliseconds (450ft to 1,800ft depth bsl). Image re-processing was performed to show stratigraphic inter-bedding, and the variability of seismic signal attributes associated with amplitude, frequency, and phase.

Figure 27 presents the seismic section for segment 2, the southern half of the line. The general reflection pattern is similar to the Segment 1. There are stronger apparent faults and subsidence features within the Middle to Lower Avon Park. There is a prominent subsidence feature in the far northern part of the Segment in the Lower Avon Park, but most of the faults and dipping beds do not extend into the Middle and Upper Avon Park. The reflectors in the Middle Avon Park are largely continuous and horizontal on this segment. The Boulder Zone has similar reflector patterns as the State Road 80 seismic data.

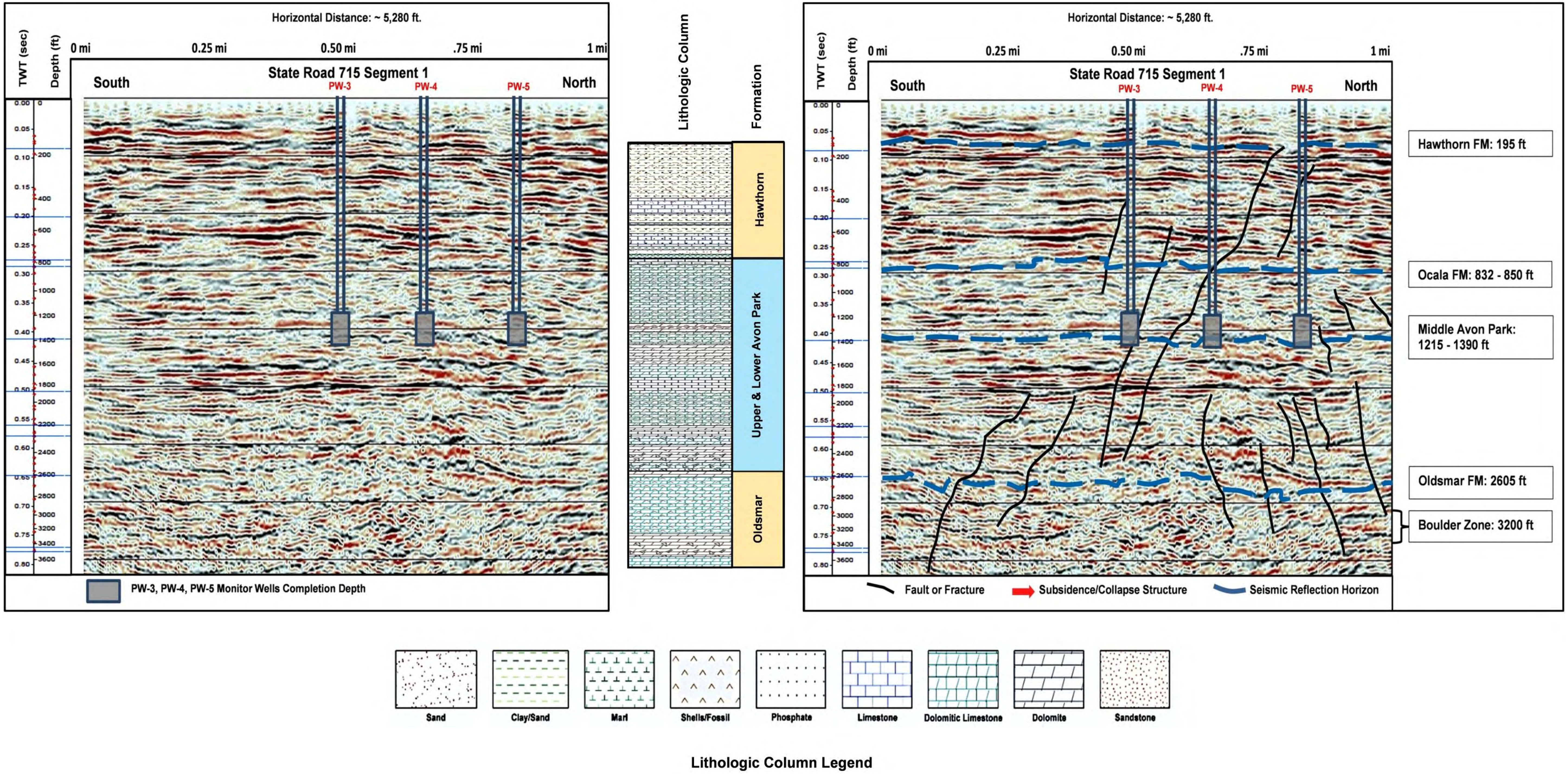


Figure 26a: Un-interpreted and preliminary interpretation of seismic section for State Road 715 Segment 1 (Line 5017),

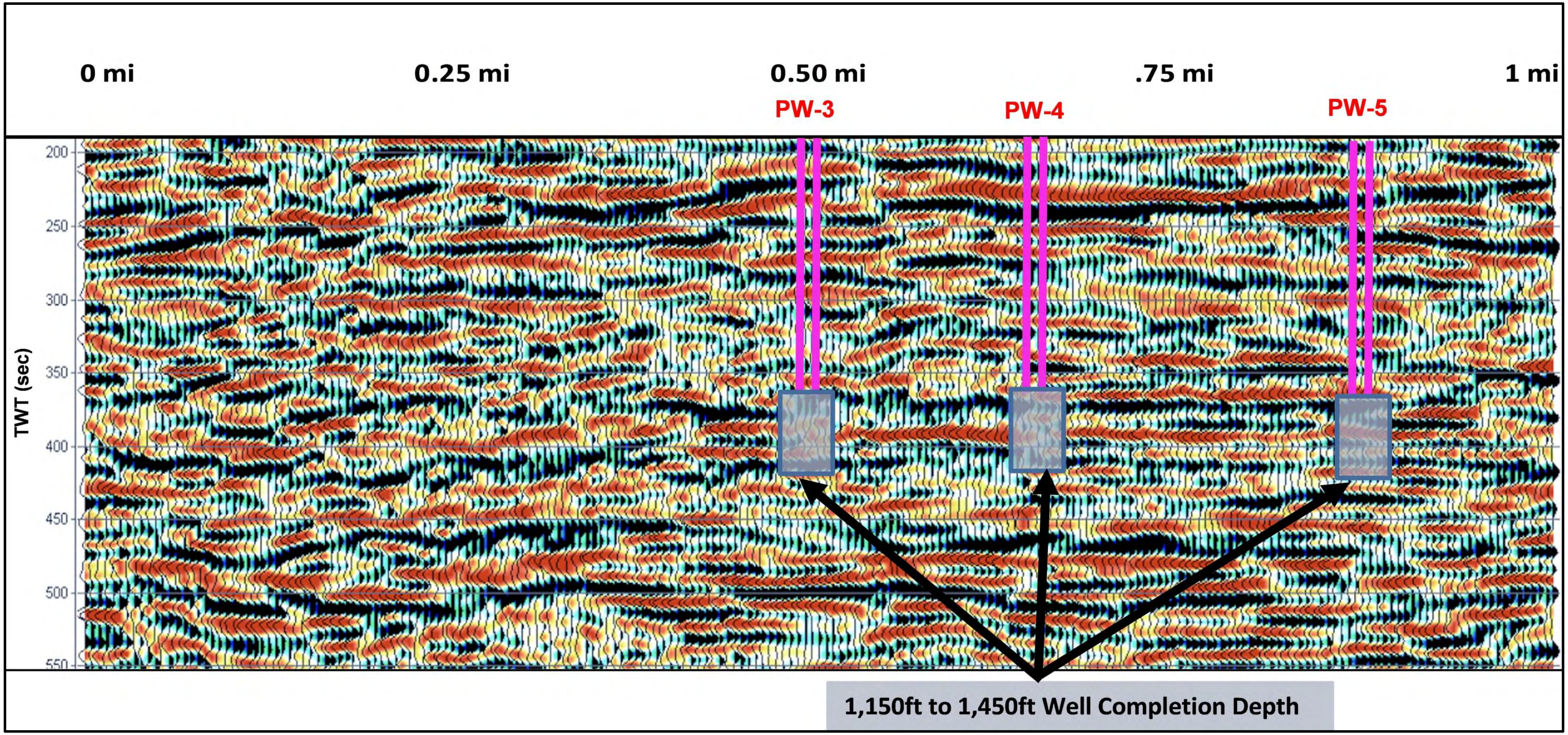


Figure 26b: Re-processing of State Road 80 Segment 1 to generate enlargement of 2D seismic section between 200ms (450ft depth) and 550ms (1,800ft depth). Re-processing includes overlay of seismic traces to enhance seismic reflection attribute changes.

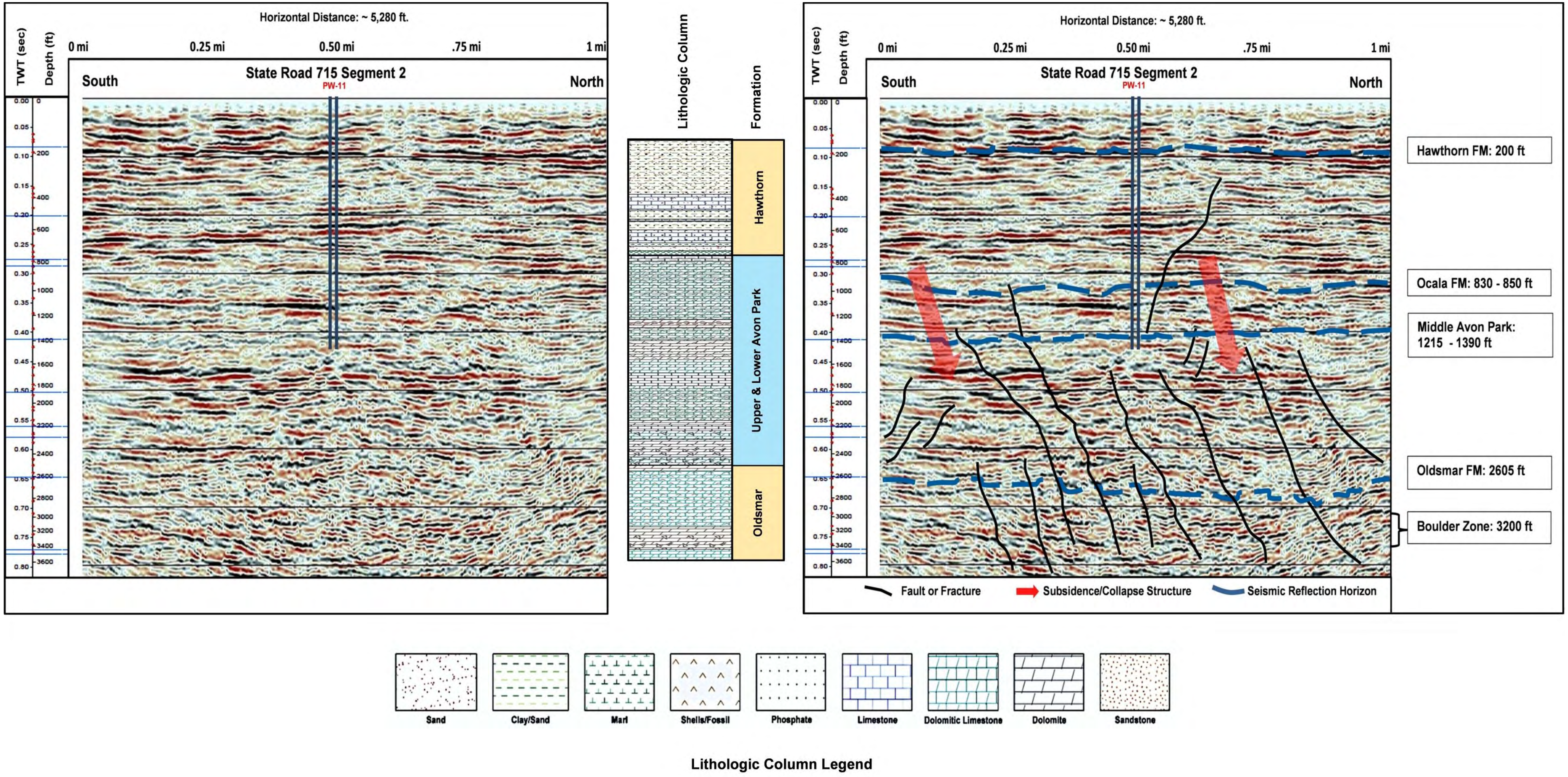


Figure 27: Un-interpreted and preliminary interpretation of seismic section for State Road 715 seismic line (Line 5017), segment 2, Site 4.

4.4.3 PBC WUD Well Field Water Quality Trends

Palm Beach County operates 11 FAS supply wells at the Lake Region Water Treatment Plant (WTP) well field along State Road 715 and State Road 80. The locations of the wells are shown on Figures 3c and 23. The wells were drilled to depths of approximately 1,350 to 1,450 feet bls and are completed at depths of between 950 to 1,450 feet bls in the Upper Avon Park Formation. Some of the wells have experienced increases in chloride and total dissolved solid (TDS) levels over the period of operation of about 20 years.

Figure 28 is a plot of water quality data from the wells that illustrates the change in Electrical Conductivity (EC) over time. EC is a good proxy for salinity, with TDS levels in ppm being approximately 65% of the EC value in uS/cm. Some wells, such as Wells 1, 5, 6 and 7 have seen EC levels in the produced water more than triple in less than 15 years. Other wells, such as Wells 3 and 8 have experienced lower rates of increase over the same period. Well 10 experienced a decline from initially high EC levels to somewhat lower levels. TDS concentrations in these wells can be assumed to have followed similar trends. Chloride concentrations for the period we have data for (2005 to 2015) have also followed similar trends. Wells in close proximity to each other have experienced significant differences in changes in water quality. For example, Wells 3 and 4 are only about 800 feet apart, but Well 3 has experienced only about a 50% increase in EC over the last 10 years while Well 4 has experienced more than a doubling of EC levels. Well 5, located about another 800 feet north of Well 4 experienced a rapid rise in EC, nearly tripling in about 4 years, at which time it was taken offline. Well 11, located along Segment 2 on State Road 715 is projected onto the 2D seismic section in Figure 27. Well 8 indicate one of the smallest increases in EC and TDS in the well field. No data was reviewed for Well 11. The continuity of the reflectors in the Upper and Middle Avon Park Formation suggests that the far southern part of this segment may be a favorable location for more sable water quality.

The Upper Floridan Aquifer typically is characterized by an increase in groundwater TDS concentration with increasing depth. Where present, the hydro-stratigraphic units that comprise the Upper Floridan Aquifer, the basal Hawthorn Unit, Suwannee Limestone, Ocala Group and Avon Park Formation, can exhibit differences in groundwater quality as a result of discrete aquifer zones (flow zones) that can be hydraulically isolated from one another by lower hydraulic conductivity intra and inter aquifer aquicludes and semi-confining units. Often, where an increasing TDS concentration in groundwater with depth in the Upper Floridan Aquifer is present, it may be attributed to the occurrence of multiple layered aquifer and semi-confining zones.

The natural occurrence or absence, due to depositional or diagenetic variations of these aquicludes or semi-confining units, determines the magnitude of groundwater quality variation and hydraulic connection between the discrete aquifer zones under both static and dynamic (groundwater pumping withdrawals) conditions. Occurrences and features that can breach and compromise the semi-confining units, post deposition or formation, include karst, collapse, fracturing or faulting. Vertical upward movement of groundwater from deeper aquifer zones exhibiting higher TDS concentrations occurs across absent or breached semi-confining units into shallower aquifer zones, in response to vertical upward gradients, causing an increase in TDS concentration in the shallower aquifer zones. Vertical upward gradients can cause groundwater to flow across absent or compromised semi-confining unit(s). Increases in TDS concentrations in the Upper Floridan Aquifer in response to groundwater withdrawal may be attributed to this phenomenon. However, where the semi-confining units are present and have not been breached, migration of groundwater from the deeper aquifer zones into the shallower aquifer zones is slower and more limited. Upper Floridan Aquifer groundwater quality, its variation with depth, the presence or absence of discrete aquifer zones, semi-confining units and their characteristics can be determined at a particular location only by construction of a well. However, installation and testing of a well characterizes the subsurface at the site only in very close proximity to the well. Reflection seismic surveys provide information laterally, on the continuity of some of the subsurface characteristics between point locations where the subsurface has been characterized by construction of a well.

The presence and continuity or absence and/or disruption of aquifer and semi-confining zones over an existing or proposed wellfield area is valuable factor for evaluating the potential for long term, sustainable groundwater withdrawals from the Upper Floridan Aquifer. For this reason, reflection seismic survey investigations provide valuable information on subsurface conditions influencing performance of both existing and proposed water supply wells.

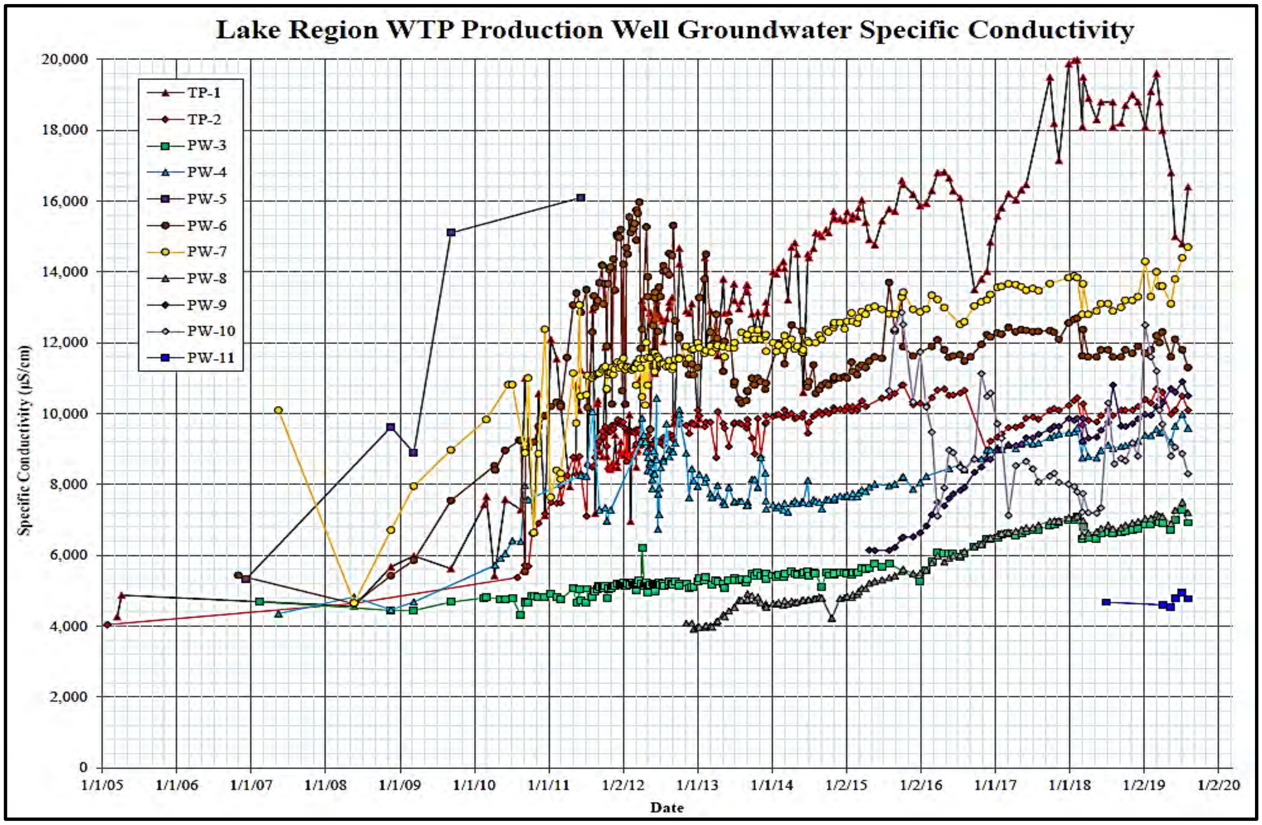


Figure 28: Lake Region Wellfield Historical Electrical Conductivity Data.

5.0 SUMMARY

Seismic reflection data was collected at four sites to demonstrate the ability of the seismic reflection method to map the stratigraphy and structure of the Floridan aquifer system. Data was collected using 2D swath geometry at three sites. Data was collected using 3D acquisition geometry at one site. The data from all four sites produced high resolution images of the stratigraphy, faulting, fracture zones and karst features to depths below the FAS on all sites. The surveys produced rich, high resolution data suitable for hydrogeology and stratigraphic analysis. The 3D survey produced data with higher spatial resolution. However, all four surveys produced data suitable for several types of geologic analysis.

Attribute processing was applied to the 3D data set to map large discontinuities in the formation that indicate voids or large karst features. These features may be favorable targets for injection wells, particularly in the Boulder Zone. Conversely, zones where these features are absent may be more favorable locations for supply or ASR wells where minimal mixing and the integrity of confining units is critical. Additional attribute analysis could be applied to both the 3D and 2D data sets to enhance features of interest for a variety of hydrogeologic and geologic studies.

It is important to note that features interpreted on the 2D seismic lines are three-dimensional features transected by 2D seismic lines. It is impossible to be certain how these features trend between lines and how continuous they may be. For these reasons, additional comparison of the 2D swath geometry lines is important to get a sense of the projected trend of the features. It may also be prudent to collect 3D surveys over critical areas before drilling new wells to better define the trend and extent of features of interest, either; faults, fractures or collapse structures that may hasten migration of saline water, or zones of continuous parallel reflectors that may inhibit migration and reduce the increase in TDS over time. With careful review, including attribute processing, high resolution seismic reflection data can be used to screen sites as to having a higher density of voids and karst features in the Boulder Zone and being more favorable for injection wells, or as having lower densities of fractures and faults in the Upper Avon Park and Suwanee intervals and being more suitable for production wells or ASR storage zones. The high resolution reflection data provides the only practical method to screen potential well sites prior to drilling in the FAS. Given the cost of drilling, this method promises to provide significant savings in terms of maximizing the performance of wells depending upon their intended use.

Appendix 1 – Geodetic Survey Data

- OUA Receiver & Source Line Coordinates
- Kissimmee Receiver & Source Line Coordinates
- State Road 80 Segments 1 and 2 Receiver & Source Line Coordinates
- State Road 715 Segments 1 and 2 Receiver and Source Line Coordinates

OUA RCVR Line 5001 X-Y Station Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5001	1001	218094.480	327437.910	35.1010
5001	1002	218106.020	327448.080	35.1010
5001	1003	218117.280	327458.260	35.0882
5001	1004	218128.540	327468.430	35.0639
5001	1005	218139.790	327478.600	35.0292
5001	1006	218151.050	327489.090	34.9852
5001	1007	218162.310	327499.260	34.9329
5001	1008	218173.850	327509.430	34.8729
5001	1009	218185.110	327519.610	34.8062
5001	1010	218196.370	327529.780	34.7333
5001	1011	218207.630	327539.950	34.6550
5001	1012	218218.880	327550.430	34.5717
5001	1013	218230.140	327560.610	34.4839
5001	1014	218241.400	327570.780	34.3921
5001	1015	218252.940	327580.960	34.2967
5001	1016	218264.200	327591.130	34.1980
5001	1017	218275.460	327601.300	34.0965
5001	1018	218286.710	327611.480	33.9923
5001	1019	218297.970	327621.960	33.8857
5001	1020	218309.230	327632.130	33.7770
5001	1021	218320.770	327642.300	33.6663
5001	1022	218332.030	327652.480	33.5540
5001	1023	218343.290	327662.650	33.4400
5001	1024	218354.540	327672.830	33.3247
5001	1025	218365.800	327683.310	33.2081
5001	1026	218377.060	327693.480	33.0904
5001	1027	218388.600	327703.650	32.9835
5001	1028	218399.850	327713.830	32.8864
5001	1029	218411.110	327724.000	32.7980
5001	1030	218422.370	327734.180	32.7175
5001	1031	218433.630	327744.660	32.6442
5001	1032	218444.890	327754.830	32.5772
5001	1033	218456.420	327765.000	32.5160
5001	1034	218467.680	327775.180	32.4599
5001	1035	218478.940	327785.350	32.4085
5001	1037	218501.460	327805.700	32.3613
5001	1038	218512.720	327816.180	32.3179
5001	1039	218523.980	327826.350	32.2779
5001	1040	218535.510	327836.530	32.2409
5001	1041	218546.770	327846.700	32.2067
5001	1042	218558.030	327856.880	32.1750

5001	1043	218569.290	327867.050	32.1455
5001	1044	218580.550	327877.530	32.1180
5001	1045	218591.800	327887.710	32.0923
5001	1046	218603.340	327897.880	32.0682
5001	1047	218614.600	327908.050	32.0456
5001	1048	218625.850	327918.230	32.0243
5001	1049	218637.110	327928.400	32.0042
5001	1050	218648.370	327938.880	31.9852
5001	1051	218659.630	327949.060	31.9671
5001	1052	218671.160	327959.230	31.9499
5001	1053	218682.420	327969.400	31.9316
5001	1054	218693.680	327979.580	31.9123
5001	1055	218704.940	327989.750	31.8921
5001	1056	218716.200	327999.930	31.8710
5001	1057	218727.460	328010.410	31.8493
5001	1058	218738.990	328020.580	31.8269
5001	1059	218750.250	328030.760	31.8039
5001	1060	218761.510	328040.930	31.7803
5001	1061	218772.760	328051.100	31.7563
5001	1062	218784.020	328061.280	31.7319
5001	1063	218795.280	328071.760	31.7070
5001	1064	218806.810	328081.930	31.6819
5001	1065	218818.070	328092.110	31.6564
5001	1066	218829.330	328102.280	31.6306
5001	1067	218840.590	328112.460	31.6046
5001	1068	218851.850	328122.630	31.5783
5001	1069	218863.100	328133.110	31.5519
5001	1070	218874.640	328143.290	31.5252
5001	1071	218885.900	328153.460	31.4984
5001	1072	218897.150	328163.630	31.4715
5001	1073	218908.410	328173.810	31.4444
5001	1074	218919.670	328183.980	31.4172
5001	1075	218930.930	328194.160	31.3898
5001	1076	218942.460	328204.640	31.3624
5001	1077	218953.720	328214.810	31.3349
5001	1078	218964.980	328224.990	31.3073
5001	1079	218976.240	328235.160	31.2889
5001	1080	218987.490	328245.340	31.2788
5001	1081	218998.750	328255.510	31.2760
5001	1082	219010.280	328265.990	31.2800
5001	1083	219021.540	328276.170	31.2900

5001	1084	219032.800	328286.340	31.3055
5001	1085	219044.060	328296.510	31.3258
5001	1086	219055.320	328306.690	31.3505
5001	1087	219066.570	328316.860	31.3791
5001	1088	219078.110	328327.350	31.4113
5001	1089	219089.360	328337.520	31.4467
5001	1090	219100.620	328347.690	31.4850
5001	1091	219111.880	328357.870	31.5259
5001	1092	219123.140	328368.040	31.5691
5001	1093	219134.400	328378.220	31.6144
5001	1094	219145.650	328388.390	31.6616
5001	1095	219157.190	328398.870	31.7105
5001	1097	219179.700	328419.220	31.7609
5001	1098	219190.960	328429.400	31.8128
5001	1099	219202.220	328439.570	31.8658
5001	1100	219213.750	328449.750	31.9200
5001	1101	219225.010	328460.230	31.9752
5001	1102	219236.260	328470.400	32.0312
5001	1103	219247.520	328480.580	32.0881
5001	1104	219258.780	328490.750	32.1457
5001	1105	219270.040	328500.930	32.2040
5001	1106	219281.290	328511.100	32.2629

Geodetic Coordinate System: NAD 83 State Plane Florida East FIPS0901

OUA RCVR Line 5002 X-Y Station Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5002	1001	218084.290	327449.280	35.1010
5002	1002	218095.550	327459.460	35.1010
5002	1003	218107.080	327469.630	35.0991
5002	1004	218118.340	327479.800	35.0956
5002	1005	218129.600	327489.980	35.0906
5002	1006	218140.860	327500.150	35.0842
5002	1007	218152.120	327510.630	35.0766
5002	1008	218163.380	327520.810	35.0679
5002	1009	218174.920	327530.980	35.0583
5002	1010	218186.180	327541.150	35.0477
5002	1011	218197.430	327551.330	35.0364
5002	1012	218208.690	327561.500	35.0243
5002	1013	218219.950	327571.670	35.0116
5002	1014	218231.210	327582.150	34.9983
5002	1015	218242.750	327592.330	34.9844
5002	1016	218254.010	327602.500	34.9701
5002	1017	218265.260	327612.680	34.9554
5002	1018	218276.520	327622.850	34.9403
5002	1019	218287.780	327633.020	34.9249
5002	1020	218299.040	327643.500	34.9091
5002	1021	218310.300	327653.680	34.8931
5002	1022	218321.830	327663.850	34.8768
5002	1023	218333.090	327674.020	34.8603
5002	1024	218344.350	327684.200	34.8436
5002	1025	218355.610	327694.370	34.8267
5002	1026	218366.870	327704.850	34.8096
5002	1027	218378.130	327715.030	34.7924
5002	1028	218389.660	327725.200	34.7751
5002	1029	218400.920	327735.370	34.7550
5002	1030	218412.180	327745.550	34.7326
5002	1031	218423.440	327755.720	34.7079
5002	1032	218434.700	327765.900	34.6813
5002	1033	218445.960	327776.380	34.6530
5002	1034	218457.490	327786.550	34.6230
5002	1035	218468.750	327796.720	34.5916
5002	1036	218480.010	327806.900	34.5589
5002	1037	218491.270	327817.070	34.5251
5002	1039	218513.790	327837.730	34.4902
5002	1040	218525.320	327847.900	34.4544
5002	1041	218536.580	327858.070	34.4177
5002	1042	218547.840	327868.250	34.3803

5002	1043	218559.100	327878.420	34.3422
5002	1044	218570.350	327888.600	34.3035
5002	1045	218581.610	327899.080	34.2642
5002	1046	218593.150	327909.250	34.2244
5002	1047	218604.400	327919.430	34.1842
5002	1048	218615.660	327929.600	34.1436
5002	1049	218626.920	327939.770	34.1026
5002	1050	218638.180	327949.950	34.0613
5002	1051	218649.440	327960.120	34.0196
5002	1052	218660.700	327970.600	33.9778
5002	1053	218672.230	327980.780	33.9356
5002	1054	218683.490	327990.950	33.8933
5002	1055	218694.750	328001.120	33.8508
5002	1056	218706.010	328011.300	33.8161
5002	1057	218717.260	328021.470	33.7886
5002	1058	218728.520	328031.950	33.7674
5002	1059	218740.060	328042.130	33.7520
5002	1060	218751.310	328052.300	33.7417
5002	1061	218762.570	328062.480	33.7361
5002	1062	218773.830	328072.650	33.7347
5002	1063	218785.090	328082.820	33.7370
5002	1064	218796.350	328093.310	33.7428
5002	1065	218807.880	328103.480	33.7515
5002	1066	218819.140	328113.650	33.7631
5002	1067	218830.400	328123.830	33.7771
5002	1068	218841.660	328134.000	33.7933
5002	1069	218852.910	328144.180	33.8116
5002	1070	218864.170	328154.350	33.8316
5002	1071	218875.710	328164.830	33.8533
5002	1072	218886.960	328175.010	33.8764
5002	1073	218898.220	328185.180	33.9009
5002	1074	218909.480	328195.360	33.9265
5002	1075	218920.740	328205.530	33.9532
5002	1076	218932.000	328215.700	33.9808
5002	1077	218943.530	328226.190	34.0093
5002	1078	218954.790	328236.360	34.0386
5002	1079	218966.040	328246.530	34.0686
5002	1080	218977.300	328256.710	34.0992
5002	1081	218988.560	328266.880	34.1304
5002	1082	218999.820	328277.060	34.1598
5002	1083	219011.350	328287.540	34.1876

5002	1084	219022.610	328297.710	34.2140
5002	1085	219033.870	328307.890	34.2391
5002	1086	219045.120	328318.060	34.2630
5002	1087	219056.380	328328.240	34.2859
5002	1088	219067.640	328338.410	34.3079
5002	1089	219079.170	328348.580	34.3290
5002	1090	219090.430	328359.070	34.3493
5002	1091	219101.690	328369.240	34.3689
5002	1092	219112.950	328379.410	34.3880
5002	1093	219124.200	328389.590	34.4065
5002	1094	219135.460	328399.760	34.4244
5002	1095	219146.990	328409.940	34.4420
5002	1096	219158.250	328420.420	34.4591
5002	1097	219169.510	328430.590	34.4758
5002	1098	219180.770	328440.770	34.4923
5002	1100	219203.280	328461.120	34.5084
5002	1101	219214.820	328471.290	34.5243
5002	1102	219226.070	328481.470	34.5399
5002	1103	219237.330	328491.950	34.5553
5002	1104	219248.590	328502.120	34.5706
5002	1105	219259.850	328512.300	34.5856
5002	1106	219271.100	328522.470	34.6005

OUA SRC Line 1001 X-Y Station Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
1001	5001	218089.5000	327443.4000	36.0436
1001	5003	218112.0000	327463.8000	36.0440
1001	5005	218134.6000	327484.4000	36.0446
1001	5007	218157.4000	327504.8000	36.0456
1001	5009	218179.9000	327525.1000	36.0471
1001	5011	218202.4000	327545.8000	36.0491
1001	5013	218225.2000	327566.1000	36.0513
1001	5015	218247.7000	327586.5000	36.0540
1001	5017	218270.2000	327607.1000	36.0569
1001	5019	218293.0000	327627.5000	36.0600
1001	5021	218315.5000	327647.8000	36.0635
1001	5023	218338.1000	327668.5000	36.0671
1001	5025	218360.8000	327688.8000	36.0709
1001	5027	218383.4000	327709.2000	36.0749
1001	5029	218405.9000	327729.8000	36.0739
1001	5031	218428.7000	327750.2000	36.0684
1001	5033	218451.2000	327770.5000	36.0589
1001	5035	218473.7000	327791.2000	36.0456
1001	5037	218496.5000	327811.5000	36.0291
1001	5039	218519.0000	327831.9000	36.0097
1001	5041	218541.5000	327852.5000	35.9876
1001	5043	218564.3000	327872.9000	35.9630
1001	5045	218586.8000	327893.2000	35.9364
1001	5047	218609.4000	327913.6000	35.9078
1001	5049	218632.2000	327934.2000	35.8774
1001	5051	218654.7000	327954.6000	35.8455
1001	5053	218677.2000	327974.9000	35.8121
1001	5055	218700.0000	327995.6000	35.7828
1001	5059	218745.0000	328036.3000	35.7570
1001	5061	218767.8000	328056.9000	35.7345
1001	5063	218790.3000	328077.3000	35.7149
1001	5065	218812.8000	328097.6000	35.6979
1001	5067	218835.4000	328118.3000	35.6833
1001	5069	218858.2000	328138.6000	35.6708
1001	5071	218880.7000	328159.0000	35.6602
1001	5073	218903.2000	328179.6000	35.6513
1001	5075	218926.0000	328200.0000	35.6440
1001	5077	218948.5000	328220.3000	35.6381
1001	5079	218971.0000	328240.7000	35.6334
1001	5081	218993.8000	328261.3000	35.6299
1001	5083	219016.3000	328281.7000	35.6309

1001	5085	219038.8000	328302.0000	35.6360
1001	5087	219061.6000	328322.7000	35.6448
1001	5089	219084.1000	328343.0000	35.6570
1001	5091	219106.7000	328363.4000	35.6721
1001	5093	219129.4000	328384.1000	35.6900
1001	5095	219152.0000	328404.4000	35.7102
1001	5097	219174.5000	328424.8000	35.7327
1001	5099	219197.3000	328445.4000	35.7571
1001	5101	219219.8000	328465.8000	35.7832
1001	5103	219242.3000	328486.1000	35.8110
1001	5105	219265.1000	328506.8000	35.8402

Geodetic Coordinate System: NAD 83 State Plane Florida East FIPS0901

Kissimmee RCVR Line 5003 X-Y Station Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5003	1001	212312.2034	312140.0111	20.0780
5003	1002	212303.8742	312151.0668	20.1788
5003	1003	212294.3417	312163.3660	20.2795
5003	1004	212285.2852	312175.4687	20.3803
5003	1005	212276.8979	312187.4242	20.4810
5003	1006	212267.3863	312199.7443	20.5818
5003	1007	212258.6927	312211.8659	20.6825
5003	1008	212248.9559	312224.2679	20.7833
5003	1009	212239.3310	312236.5666	20.8840
5003	1010	212229.6568	312249.0011	20.9848
5003	1011	212221.2484	312260.4316	21.0855
5003	1012	212210.8453	312272.8568	21.1863
5003	1013	212199.9936	312284.9992	21.2870
5003	1014	212189.6106	312296.0770	21.3878
5003	1015	212178.3830	312306.0980	21.4885
5003	1016	212167.0232	312315.7945	21.5893
5003	1017	212155.5145	312325.8479	21.6900
5003	1018	212144.7696	312335.5785	21.7908
5003	1019	212132.7682	312346.0025	21.8915
5003	1020	212120.5317	312356.1385	21.9923
5003	1021	212109.5908	312366.1854	22.0930
5003	1022	212097.7426	312376.3340	22.1938
5003	1023	212086.1991	312386.0478	22.2945
5003	1024	212075.2157	312396.3021	22.3953
5003	1025	212063.3831	312406.1549	22.4960
5003	1026	212052.1128	312416.1804	22.5968
5003	1027	212041.7974	312425.4687	22.6975
5003	1028	212029.2570	312436.0254	22.7983
5003	1029	212018.5303	312446.3655	22.8990
5003	1030	212007.0215	312455.8552	22.9998
5003	1031	211995.4559	312466.1371	23.1005
5003	1032	211984.1019	312476.1289	23.2013
5003	1033	211972.2808	312486.1394	23.3020
5003	1034	211961.1773	312495.7045	23.4028
5003	1035	211949.7483	312506.8014	23.5035
5003	1036	211938.4643	312517.2362	23.6043
5003	1037	211927.4501	312527.5720	23.7050
5003	1038	211916.8357	312538.7955	23.8058
5003	1039	211905.6568	312549.9622	23.9065

5003	1040	211895.6404	312560.6853	24.0073
5003	1041	211886.2701	312571.1975	24.2062
5003	1042	211875.8506	312583.4611	24.1704
5003	1043	211866.0387	312594.0504	24.1346
5003	1044	211856.2425	312605.3272	24.0988
5003	1045	211846.4024	312617.3410	24.0630
5003	1046	211837.0931	312628.8563	24.0272
5003	1047	211827.4921	312640.3599	23.9914
5003	1048	211818.6085	312653.0579	23.9556
5003	1049	211809.9918	312665.0400	23.9199
5003	1050	211800.9574	312677.6737	23.8841
5003	1051	211792.4683	312690.1416	23.8483
5003	1052	211784.1930	312702.9334	23.8125
5003	1053	211776.4247	312716.7000	23.7767
5003	1054	211768.9674	312728.8270	23.7409
5003	1055	211760.5601	312741.8155	23.7051
5003	1056	211753.2753	312754.6673	23.6693
5003	1057	211745.4497	312768.2358	23.6335
5003	1058	211737.6428	312780.7248	23.5977
5003	1059	211729.9250	312793.9534	23.5620
5003	1060	211722.3452	312806.9656	23.5262
5003	1061	211714.7972	312819.7101	23.4904
5003	1062	211707.2916	312833.5680	23.4546
5003	1063	211698.9499	312846.4890	23.4188
5003	1064	211691.5124	312860.0936	23.3830
5003	1065	211683.6201	312872.7357	23.3472
5003	1066	211675.2339	312885.4213	23.3114
5003	1067	211668.1258	312898.4294	23.2756
5003	1068	211660.3274	312912.1527	23.2399
5003	1069	211652.4128	312924.7947	23.2041
5003	1070	211644.2543	312938.0824	23.1683
5003	1071	211637.2185	312952.1778	23.1325
5003	1072	211630.1281	312963.6812	23.0967
5003	1073	211621.2938	312976.9394	23.0609
5003	1074	211614.5864	312989.9651	23.0251
5003	1075	211606.8654	313003.4979	22.9893
5003	1076	211598.9194	313016.7369	22.9535
5003	1077	211591.5379	313030.0377	22.9178
5003	1078	211584.0190	313043.0034	22.8820
5003	1079	211575.8731	313055.5616	22.8462
5003	1080	211568.4627	313069.3229	22.8104

5003	1081	211560.9342	313082.3943	22.7746
5003	1082	211552.6598	313094.9079	22.7388
5003	1083	211544.6842	313108.6483	22.7030
5003	1084	211537.2669	313121.8492	22.6672
5003	1085	211529.7898	313134.5791	22.6314
5003	1086	211522.1177	313147.6379	22.5956
5003	1087	211514.3425	313160.7818	22.5599
5003	1088	211506.9441	313173.6547	22.5241
5003	1089	211498.9431	313187.2655	22.4883
5003	1090	211491.1949	313199.5893	22.4525
5003	1091	211483.1334	313213.2330	22.4167
5003	1092	211475.9521	313226.3327	22.3809
5003	1093	211468.2817	313239.4205	22.3451
5003	1094	211460.4916	313252.5841	22.3093
5003	1095	211452.8369	313265.6774	22.2735
5003	1096	211445.2044	313278.3412	22.2378
5003	1097	211437.3946	313292.7541	22.2020
5003	1098	211429.8740	313305.1854	22.1662
5003	1099	211421.9887	313318.1739	22.1304
5003	1100	211414.4988	313331.5130	22.0946
5003	1101	211406.4082	313344.3094	22.0588
5003	1102	211399.0459	313357.1550	22.0230
5003	1103	211391.2187	313370.0425	21.9872
5003	1104	211383.6303	313383.7640	21.9514
5003	1105	211375.7457	313396.7008	21.9156
5003	1106	211367.4710	313410.3047	21.8799

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Kissimmee RCVR Line 5004 X-Y Station Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5004	1001	212300.9763	312130.1952	24.5367
5004	1002	212291.5144	312143.3838	24.5367
5004	1003	212282.0751	312154.6243	24.5380
5004	1004	212273.0636	312167.2907	24.5404
5004	1005	212264.3444	312179.6164	24.5436
5004	1006	212255.1635	312191.1012	24.5476
5004	1007	212245.9295	312203.5278	24.5520
5004	1008	212237.1343	312215.5679	24.5569
5004	1009	212227.6249	312227.2725	24.5622
5004	1010	212218.5831	312239.3857	24.5677
5004	1011	212209.2603	312251.1005	24.5735
5004	1012	212199.4951	312263.2229	24.5794
5004	1013	212189.5205	312274.1400	24.5855
5004	1014	212179.4932	312284.7942	24.5917
5004	1015	212168.3210	312295.0943	24.5980
5004	1016	212156.8769	312304.7896	24.6043
5004	1017	212146.0013	312314.8337	24.6675
5004	1018	212134.4064	312325.0671	24.7761
5004	1019	212122.6014	312335.1195	24.9211
5004	1020	212111.0689	312345.1304	25.0952
5004	1021	212099.0863	312355.3672	25.2926
5004	1022	212088.5166	312364.7853	25.5085
5004	1023	212076.3638	312374.9848	25.7394
5004	1024	212064.8331	312384.8976	25.9822
5004	1025	212053.4214	312395.0959	26.2345
5004	1026	212042.1773	312405.1165	26.4944
5004	1027	212030.2363	312415.3878	26.7605
5004	1028	212019.5004	312425.2560	27.0314
5004	1029	212007.3113	312435.7113	27.3062
5004	1030	211995.6296	312445.9645	27.6012
5004	1031	211984.1349	312456.5899	27.8347
5004	1032	211972.9319	312465.7893	28.0193
5004	1033	211961.3947	312475.5489	28.1645
5004	1034	211949.8869	312486.7820	28.2784
5004	1035	211939.7720	312496.2826	28.3671
5004	1036	211927.6807	312506.4250	28.4358
5004	1037	211917.2840	312517.3277	28.4883
5004	1038	211906.1330	312528.3720	28.5280
5004	1039	211895.2587	312538.1041	28.5574

5004	1040	211885.1939	312549.9752	28.5786
5004	1041	211875.0454	312562.0334	28.5932
5004	1042	211864.6722	312572.8409	28.6025
5004	1043	211854.8238	312584.7279	28.6076
5004	1044	211844.5802	312595.9577	28.6094
5004	1045	211834.4843	312607.4861	28.6084
5004	1046	211824.9055	312620.1660	28.6053
5004	1047	211815.6114	312632.4717	28.6005
5004	1048	211806.8470	312643.8044	28.5942
5004	1049	211797.7553	312656.9656	28.5869
5004	1050	211788.7884	312669.6758	28.5787
5004	1051	211780.5546	312681.9095	28.5630
5004	1052	211772.0024	312694.7465	28.5413
5004	1053	211764.0754	312708.1667	28.5149
5004	1054	211755.7244	312721.0235	28.4846
5004	1055	211748.0888	312733.1909	28.4513
5004	1056	211740.3907	312746.6310	28.4155
5004	1057	211732.7604	312760.1046	28.3778
5004	1058	211725.0307	312772.4942	28.3385
5004	1059	211717.1669	312786.0671	28.2979
5004	1060	211709.3924	312798.4269	28.2563
5004	1061	211702.2512	312811.9897	28.2140
5004	1062	211693.6528	312825.2245	28.1710
5004	1063	211685.6615	312838.4335	28.1274
5004	1064	211678.4353	312851.1895	28.0835
5004	1065	211670.1539	312864.9375	28.0392
5004	1066	211662.5496	312877.9089	27.9947
5004	1067	211655.6016	312891.0054	27.9500
5004	1068	211647.5077	312904.2311	27.9051
5004	1069	211638.3471	312916.5687	27.8600
5004	1070	211632.6501	312930.0180	27.8149
5004	1071	211625.0078	312943.5179	27.7697
5004	1072	211617.5414	312956.4802	27.7244
5004	1073	211609.6087	312969.5733	27.6790
5004	1074	211601.7409	312982.9493	27.6336
5004	1075	211594.3165	312995.6504	27.5882
5004	1076	211586.2143	313009.2029	27.5427
5004	1077	211578.7189	313022.0116	27.4972
5004	1078	211571.0978	313035.9098	27.4517
5004	1079	211563.2353	313047.8997	27.4062
5004	1080	211555.2094	313061.9575	27.3607

5004	1081	211548.1064	313074.4089	27.3151
5004	1082	211540.2128	313087.5356	27.2696
5004	1083	211532.8827	313101.3914	27.2240
5004	1084	211524.1888	313114.2225	27.1785
5004	1085	211516.3761	313126.7468	27.1329
5004	1086	211508.5715	313140.3759	27.0874
5004	1087	211501.4843	313153.6763	27.0418
5004	1088	211493.7355	313167.0494	26.9962
5004	1089	211485.8513	313179.7525	26.9506
5004	1090	211477.6789	313193.0947	26.9051
5004	1091	211469.8060	313205.9397	26.8595
5004	1092	211462.1764	313219.1415	26.8139
5004	1093	211454.9396	313232.2681	26.7684
5004	1094	211447.1039	313244.3935	26.7228
5004	1095	211439.5538	313258.0859	26.6772
5004	1096	211431.4636	313270.7512	26.6316
5004	1097	211424.1745	313283.6866	26.5861
5004	1098	211415.9924	313297.1900	26.5405
5004	1099	211408.5179	313309.8298	26.4949
5004	1100	211401.1051	313322.7813	26.4493
5004	1101	211393.0422	313336.0022	26.4038
5004	1102	211385.3633	313349.1220	26.3582
5004	1103	211377.9115	313362.7640	26.3126
5004	1104	211370.2743	313376.2086	26.2670
5004	1105	211362.1814	313389.2016	26.2215
5004	1106	211354.3141	313401.3465	26.1759

Geodetic Coordinate System: NAD 83 State Plane Florida East FIPS0901

Kissimmee SRC Line 3000 X-Y Station Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3000.00	1001.00	212437.0000	311968.1000	22.0170
3000.00	1003.00	212417.4000	311991.8000	22.0170
3000.00	1005.00	212398.3000	312016.8000	22.0190
3000.00	1007.00	212380.2000	312041.3000	22.0227
3000.00	1009.00	212362.2000	312065.2000	22.0277
3000.00	1011.00	212343.7000	312089.4000	22.0337
3000.00	1013.00	212325.4000	312113.3000	22.0406
3000.00	1015.00	212306.4000	312136.3000	22.0481
3000.00	1017.00	212288.0000	312160.7000	22.0562
3000.00	1019.00	212269.4000	312185.7000	22.0646
3000.00	1021.00	212251.6000	312209.6000	22.0735
3000.00	1023.00	212233.0000	312233.9000	21.9409
3000.00	1025.00	212214.0000	312258.3000	21.8713
3000.00	1027.00	212194.0000	312281.5000	21.8523
3000.00	1029.00	212171.9000	312303.3000	21.8737
3000.00	1031.00	212149.1000	312323.1000	21.9273
3000.00	1033.00	212126.5000	312343.1000	22.0068
3000.00	1035.00	212102.8000	312363.1000	22.1070
3000.00	1037.00	212080.0000	312383.6000	22.2237
3000.00	1039.00	212057.6000	312403.7000	22.3536
3000.00	1041.00	212034.2000	312423.2000	22.4942
3000.00	1043.00	212011.1000	312443.1000	22.6432
3000.00	1045.00	211988.4000	312463.7000	22.7989
3000.00	1047.00	211965.8000	312483.7000	22.9601
3000.00	1049.00	211943.4000	312503.7000	23.1257
3000.00	1051.00	211921.4000	312525.2000	23.2947
3000.00	1053.00	211899.8000	312546.0000	23.4664
3000.00	1055.00	211879.2000	312569.3000	23.6404
3000.00	1057.00	211859.1000	312591.7000	23.8162
3000.00	1059.00	211839.4000	312615.2000	23.9934
3000.00	1061.00	211821.0000	312639.3000	24.1717
3000.00	1063.00	211803.2000	312663.6000	24.3510
3000.00	1065.00	211786.3000	312689.0000	24.5309
3000.00	1067.00	211769.6000	312714.5000	24.7115
3000.00	1069.00	211753.7000	312740.3000	24.8590
3000.00	1071.00	211738.1000	312765.9000	24.9802
3000.00	1073.00	211722.7000	312793.0000	25.0803
3000.00	1075.00	211707.3000	312818.2000	25.1634
3000.00	1077.00	211691.8000	312845.3000	25.2331

3000.00	1079.00	211676.7000	312871.3000	25.2920
3000.00	1081.00	211661.1000	312897.9000	25.3422
3000.00	1083.00	211645.4000	312924.7000	25.3854
3000.00	1085.00	211630.8000	312950.5000	25.4232
3000.00	1087.00	211615.6000	312976.4000	25.4565
3000.00	1089.00	211600.1000	313002.5000	25.4863
3000.00	1091.00	211584.7000	313028.7000	25.5132
3000.00	1093.00	211569.5000	313054.8000	25.5144
3000.00	1095.00	211554.3000	313081.0000	25.4950
3000.00	1097.00	211538.2000	313106.5000	25.4592
3000.00	1099.00	211523.5000	313132.8000	25.4101
3000.00	1101.00	211507.7000	313159.8000	25.3505
3000.00	1103.00	211492.9000	313186.5000	25.2825
3000.00	1105.00	211477.1000	313212.4000	25.2077
3000.00	1107.00	211461.7000	313237.6000	25.1275
3000.00	1109.00	211446.4000	313264.0000	25.0430
3000.00	1111.00	211430.8000	313290.1000	24.9551
3000.00	1113.00	211415.5000	313316.5000	24.8644
3000.00	1115.00	211399.8000	313343.6000	24.7714
3000.00	1117.00	211385.4000	313368.6000	24.6767
3000.00	1119.00	211369.5000	313396.1000	24.5806
3000.00	1121.00	211353.5000	313421.9000	24.4834
3000.00	1123.00	211338.3000	313448.4000	24.3852
3000.00	1125.00	211322.2000	313473.7000	24.2864
3000.00	1127.00	211307.0000	313499.6000	24.1869
3000.00	1129.00	211291.4000	313525.9000	24.0870
3000.00	1131.00	211276.6000	313551.5000	23.9867
3000.00	1133.00	211260.4000	313578.8000	23.8861

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State Road 80 RCVR Segment 1 Line 5015 X-Y Station Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5015	1001	229578.5600	265056.4500	12.9880
5015	1002	229593.3600	265055.3300	12.9661
5015	1003	229608.0900	265056.3000	12.9442
5015	1004	229624.1500	265055.0800	12.9223
5015	1005	229638.8100	265056.6400	12.9004
5015	1006	229654.7400	265056.1700	12.8784
5015	1007	229669.2100	265057.1600	12.8565
5015	1008	229685.3500	265056.2800	12.8346
5015	1009	229699.4400	265057.2700	12.8127
5015	1010	229715.9000	265056.2600	12.7908
5015	1011	229730.2500	265057.5600	12.7689
5015	1012	229746.5000	265056.1400	12.7470
5015	1013	229760.6300	265057.0800	12.7251
5015	1014	229776.8700	265056.2200	12.7031
5015	1015	229791.9000	265056.8000	12.6812
5015	1016	229810.5900	265053.3700	12.6593
5015	1017	229820.1200	265057.4300	12.6374
5015	1018	229851.9000	265058.9800	12.6155
5015	1019	229868.8800	265057.7300	12.5936
5015	1020	229882.8700	265058.6200	12.5717
5015	1021	229898.8500	265057.9800	12.5498
5015	1022	229913.1800	265059.0900	12.5279
5015	1023	229929.4800	265057.2200	12.5059
5015	1024	229943.8400	265058.4000	12.4840
5015	1025	229959.8500	265058.5800	12.4621
5015	1026	229974.3000	265058.5000	12.4402
5015	1027	229990.5400	265058.0800	12.4183
5015	1028	230005.0700	265058.3500	12.3964
5015	1029	230020.3900	265058.0000	12.3745
5015	1030	230036.3400	265057.9500	12.3526
5015	1031	230051.7300	265058.0600	12.3306
5015	1032	230066.0800	265058.6700	12.3087
5015	1033	230081.6400	265058.1900	12.2868
5015	1034	230096.3400	265058.7000	12.2649
5015	1035	230111.9800	265058.3200	12.2430
5015	1036	230127.1300	265059.2000	12.2211
5015	1037	230143.1000	265058.6400	12.1992
5015	1038	230157.7700	265058.6800	12.1773
5015	1039	230173.5600	265058.0100	12.1554
5015	1040	230187.7800	265064.7700	12.1334
5015	1041	230205.3700	265064.5400	12.1115

5015	1042	230223.7000	265068.4100	12.0896
5015	1043	230234.4100	265057.5400	12.0677
5015	1044	230249.6000	265058.8000	12.0458
5015	1045	230265.2800	265058.3100	12.0239
5015	1046	230279.5300	265059.4500	12.0020
5015	1047	230295.5800	265058.1300	11.9801
5015	1048	230309.8500	265059.7900	11.9581
5015	1049	230326.6000	265059.0500	11.9362
5015	1050	230341.0100	265059.3100	11.9143
5015	1051	230356.4500	265058.4600	11.8924
5015	1052	230372.0100	265059.7100	11.8705
5015	1053	230387.0600	265059.2800	11.8486
5015	1054	230402.4700	265059.1500	11.8267
5015	1055	230417.3700	265058.8600	11.8048
5015	1056	230432.4600	265060.0200	11.7829
5015	1057	230448.6400	265059.6400	11.7609
5015	1058	230463.7300	265059.4700	11.7390
5015	1059	230479.1500	265059.2500	11.7171
5015	1060	230493.8200	265059.8700	11.6952
5015	1061	230509.5100	265059.7500	11.6733
5015	1062	230524.2400	265060.1100	11.6514
5015	1063	230539.7500	265059.6800	11.6295
5015	1064	230554.7200	265060.0900	11.6076
5015	1065	230571.2500	265059.0100	11.5856
5015	1066	230584.8200	265059.8100	11.5637
5015	1067	230600.9100	265058.2000	11.5418
5015	1068	230617.6000	265060.8800	11.5199
5015	1069	230634.1500	265059.2000	11.4980
5015	1070	230646.8300	265061.1900	11.4854
5015	1071	230662.7900	265060.6200	11.4727
5015	1072	230677.0200	265061.4600	11.4601
5015	1073	230692.9800	265060.3500	11.4474
5015	1074	230708.2400	265061.6600	11.4348
5015	1075	230723.6000	265060.4500	11.4222
5015	1076	230738.4800	265061.1800	11.4095
5015	1077	230753.7700	265060.2200	11.3969
5015	1078	230768.5600	265061.0400	11.3843
5015	1079	230784.6600	265060.4500	11.3716
5015	1080	230799.4800	265061.7500	11.3590
5015	1081	230816.0200	265060.5600	11.3463
5015	1082	230830.1600	265061.5600	11.3337

5015	1083	230845.8200	265060.0300	11.3211
5015	1084	230860.4800	265060.8500	11.3084
5015	1085	230876.4500	265060.4100	11.2958
5015	1086	230891.4100	265061.3600	11.2831
5015	1087	230907.2400	265060.6100	11.2705
5015	1088	230921.4500	265061.9500	11.2579
5015	1089	230936.6000	265061.6500	11.2452
5015	1090	230952.3100	265061.8900	11.2326
5015	1091	230968.0600	265061.1700	11.2200
5015	1092	230982.7200	265061.5500	11.2073
5015	1093	230998.4300	265061.9500	11.1947
5015	1094	231013.2600	265062.5000	11.1820
5015	1095	231029.1400	265061.4300	11.1694
5015	1096	231043.9100	265061.8200	11.1568
5015	1097	231059.2400	265061.7400	11.1441
5015	1098	231074.1200	265062.6000	11.1315
5015	1099	231089.5400	265061.5500	11.1189
5015	1100	231104.8800	265063.1300	11.1062
5015	1101	231120.2500	265062.2000	11.0936
5015	1102	231135.4700	265062.9300	11.0809
5015	1103	231150.4200	265062.8800	11.0683
5015	1104	231165.9500	265063.4900	11.0557
5015	1105	231181.6100	265062.2500	11.0430
5015	1106	231196.0100	265064.0300	11.0304
5015	1107	231211.9500	265062.5200	11.0177
5015	1108	231227.1000	265062.9100	11.0051
5015	1109	231242.3900	265062.9600	10.9925
5015	1110	231256.6900	265063.4700	10.9798
5015	1111	231272.7100	265062.9700	10.9672
5015	1112	231287.9100	265063.5500	10.9546
5015	1113	231303.5200	265063.6500	10.9419
5015	1114	231318.1500	265063.8000	10.9293
5015	1115	231333.9900	265064.2100	10.9166
5015	1116	231347.3400	265064.5400	10.9040

Geodetic Coordinate System: NAD 83 State Plane Florida East FIPS0901

State Road 80 SRC Segment 1 Line 1015 X-Y Station Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
1015	5001	229570.9000	265063.8000	12.9880
1015	5002	229601.0000	265062.9000	12.9442
1015	5003	229632.5000	265063.3000	12.9004
1015	5004	229662.3000	265064.0000	12.8565
1015	5005	229692.7000	265063.1000	12.8127
1015	5006	229723.7000	265064.1000	12.7689
1015	5007	229753.8000	265062.4000	12.7251
1015	5008	229783.6000	265063.4000	12.6812
1015	5009	229814.6000	265064.7000	12.6374
1015	5010	229845.0000	265064.1000	12.5936
1015	5011	229876.2000	265063.0000	12.5498
1015	5012	229906.1000	265063.3000	12.5059
1015	5013	229935.6000	265063.4000	12.4621
1015	5014	229967.2000	265063.8000	12.4183
1015	5015	229997.6000	265063.6000	12.3745
1015	5016	230028.0000	265063.6000	12.3306
1015	5017	230058.1000	265063.4000	12.2868
1015	5018	230088.5000	265063.5000	12.2430
1015	5019	230118.9000	265064.8000	12.1992
1015	5020	230149.6000	265064.2000	12.1554
1015	5021	230180.2000	265064.3000	12.1115
1015	5022	230210.4000	265064.7000	12.0677
1015	5023	230240.5000	265066.6000	12.0239
1015	5024	230271.7000	265066.7000	11.9801
1015	5025	230302.1000	265065.8000	11.9362
1015	5026	230331.7000	265065.0000	11.8924
1015	5027	230362.9000	265065.3000	11.8486
1015	5028	230392.5000	265065.1000	11.8048
1015	5029	230423.4000	265065.2000	11.7609
1015	5030	230453.3000	265065.9000	11.7171
1015	5031	230484.5000	265065.3000	11.6733
1015	5032	230514.6000	265065.1000	11.6295
1015	5033	230544.7000	265065.8000	11.5856
1015	5034	230574.3000	265065.9000	11.5418
1015	5035	230605.5000	265066.2000	11.4980
1015	5036	230635.7000	265070.6000	11.4727
1015	5037	230665.8000	265070.4000	11.4474
1015	5038	230695.9000	265070.1000	11.4222
1015	5039	230726.9000	265069.9000	11.3969
1015	5040	230757.3000	265069.7000	11.3716
1015	5041	230787.1000	265069.8000	11.3463

1015	5042	230817.5000	265070.1000	11.3211
1015	5043	230851.2000	265070.2000	11.2958
1015	5044	230882.7000	265070.0000	11.2705
1015	5045	230912.6000	265070.7000	11.2452
1015	5046	230944.3000	265071.4000	11.2200
1015	5047	230975.3000	265071.1000	11.1947
1015	5048	231005.4000	265070.6000	11.1694
1015	5049	231036.9000	265071.3000	11.1441
1015	5050	231066.2000	265071.7000	11.1189
1015	5051	231097.2000	265072.7000	11.0936
1015	5052	231128.7000	265073.1000	11.0683
1015	5053	231158.0000	265073.4000	11.0430
1015	5054	231188.6000	265073.5000	11.0177
1015	5055	231219.0000	265073.0000	10.9925
1015	5056	231248.9000	265073.3000	10.9672
1015	5057	231279.8000	265073.4000	10.9419
1015	5058	231309.1000	265073.2000	10.9166
1015	5059	231339.0000	265074.8000	10.9166

Geodetic Coordinate System: NAD 83 State Plane Florida East FIPS0901

State Road 80 RCVR Segment 2 Line 5015 X-Y Station Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5015	1127	231467.5000	265072.0400	8.1590
5015	1128	231482.9700	265072.3900	8.1354
5015	1129	231497.8900	265072.7300	8.1118
5015	1130	231513.3700	265072.4600	8.0882
5015	1131	231528.5700	265072.8100	8.0647
5015	1132	231544.0500	265073.1600	8.0411
5015	1133	231560.3500	265072.8900	8.0175
5015	1134	231575.0000	265073.2300	7.9939
5015	1135	231589.3700	265072.6500	7.9703
5015	1136	231605.4000	265072.6900	7.9467
5015	1137	231620.3200	265072.7300	7.9231
5015	1138	231636.6300	265073.0800	7.8996
5015	1139	231647.4100	265072.4900	7.8760
5015	1140	231663.7100	265073.1500	7.8524
5015	1141	231678.0800	265072.8800	7.8288
5015	1142	231693.5600	265073.5300	7.8052
5015	1143	231708.2000	265072.9500	7.7816
5015	1144	231723.6800	265073.6000	7.7580
5015	1145	231739.7100	265073.3400	7.7344
5015	1146	231754.0800	265073.0700	7.7109
5015	1147	231768.4500	265073.1000	7.6873
5015	1148	231784.2000	265073.4500	7.6637
5015	1149	231799.1300	265073.1800	7.6401
5015	1150	231813.7800	265072.2900	7.6165
5015	1151	231829.8000	265073.2600	7.5929
5015	1152	231845.0000	265073.2900	7.5693
5015	1153	231860.4800	265073.0200	7.5458
5015	1154	231875.6800	265072.1400	7.5222
5015	1155	231890.3300	265073.1000	7.4986
5015	1156	231905.8000	265074.3700	7.4750
5015	1157	231921.0000	265073.7900	7.4986
5015	1158	231935.6500	265074.1400	7.5223
5015	1159	231951.4000	265073.5600	7.5459
5015	1160	231966.6000	265074.2200	7.5695
5015	1161	231982.9100	265073.0300	7.5932
5015	1162	231997.0000	265073.9800	7.6168
5015	1163	232012.2000	265073.4100	7.6404
5015	1164	232027.9500	265074.0600	7.6641
5015	1165	232042.6000	265073.4800	7.6877
5015	1166	232058.6300	265073.8300	7.7113
5015	1167	232073.5500	265072.9500	7.7349

5015	1168	232088.7500	265073.2900	7.7586
5015	1169	232104.2300	265074.2600	7.7822
5015	1170	232119.1500	265073.6800	7.8058
5015	1171	232134.9100	265073.1000	7.8295
5015	1172	232150.1000	265074.6800	7.8531
5015	1173	232165.3000	265073.4900	7.8767
5015	1174	232181.0600	265074.1400	7.9004
5015	1175	232195.9800	265072.9500	7.9240
5015	1176	232211.4600	265073.3000	8.0098
5015	1177	232227.2200	265071.1800	8.0956
5015	1178	232242.6900	265073.0700	8.1814
5015	1179	232256.7800	265073.1000	8.2673
5015	1180	232273.3600	265073.7600	8.3531
5015	1181	232287.1800	265073.4900	8.4389
5015	1182	232303.4800	265073.8400	8.5247
5015	1183	232318.1300	265073.2600	8.6105
5015	1184	232334.4400	265074.2200	8.6963
5015	1185	232349.6400	265073.3400	8.7821
5015	1186	232364.8400	265073.0700	8.8679
5015	1187	232380.3200	265072.5000	8.9538
5015	1188	232395.7900	265073.4600	9.0396
5015	1189	232410.7200	265072.5700	9.1254
5015	1190	232426.7500	265072.6100	9.2112
5015	1191	232440.8500	265069.8800	9.2970
5015	1192	232455.4900	265070.8400	9.3073
5015	1193	232471.5200	265071.8100	9.3176
5015	1194	232486.9900	265073.0800	9.3279
5015	1195	232501.9100	265073.1100	9.3382
5015	1196	232517.6700	265072.2300	9.3485
5015	1197	232533.1400	265072.8900	9.3588
5015	1198	232548.6200	265073.2300	9.3692
5015	1199	232563.2600	265073.8900	9.3795
5015	1200	232579.5700	265074.2400	9.3898
5015	1201	232593.6700	265073.3500	9.4001
5015	1202	232610.2500	265073.7000	9.4104
5015	1203	232624.6200	265073.7400	9.4207
5015	1204	232640.0900	265073.4700	9.4310
5015	1205	232655.2900	265074.7400	9.4413
5015	1206	232671.3200	265073.2400	9.4516
5015	1207	232685.6900	265073.2800	9.4619
5015	1208	232701.7200	265073.3200	9.4722

5015	1209	232716.3700	265073.6700	9.4825
5015	1210	232729.9100	265073.3900	9.4928
5015	1211	232745.3900	265073.1300	9.5032
5015	1212	232762.8000	265073.1700	9.5135
5015	1213	232776.6100	265074.4400	9.5238
5015	1214	232791.5400	265072.9400	9.5341
5015	1215	232806.1900	265072.9700	9.5444
5015	1216	232822.4900	265073.0200	9.5547
5015	1217	232837.1400	265073.0600	9.5650

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State Road 80 SRC Segment 2 Line 1015 X-Y Station Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
1015	5069	231465.4500	265069.3500	8.1590
1015	5070	231493.0300	265066.9100	8.1118
1015	5071	231521.9100	265070.0700	8.0647
1015	5072	231555.9200	265068.2100	8.0175
1015	5073	231585.4800	265068.4100	7.9703
1015	5074	231616.0900	265068.6800	7.9231
1015	5075	231638.8900	265068.3400	7.8760
1015	5076	231674.0500	265067.7100	7.8288
1015	5077	231704.3000	265066.7000	7.7816
1015	5078	231734.6900	265067.1800	7.7344
1015	5079	231765.1900	265067.7400	7.6873
1015	5080	231793.7500	265067.3500	7.6401
1015	5081	231825.4100	265067.2000	7.5929
1015	5082	231856.5200	265066.7700	7.5458
1015	5083	231887.7100	265066.4900	7.4986
1015	5084	231916.6400	265068.3800	7.4986
1015	5085	231945.2000	265070.6200	7.5459
1015	5086	231976.7800	265066.9600	7.5932
1015	5087	232006.6600	265067.3500	7.6404
1015	5088	232040.6300	265067.8800	7.6877
1015	5089	232068.3300	265067.3900	7.7349
1015	5090	232100.7400	265068.4200	7.7822
1015	5091	232130.9200	265068.0300	7.8295
1015	5092	232159.9000	265066.6700	7.8767
1015	5093	232190.1400	265067.5200	7.9240
1015	5094	232226.6100	265065.4700	8.0956
1015	5095	232254.5500	265066.0200	8.2673
1015	5096	232285.0400	265067.7800	8.4389
1015	5097	232315.7900	265069.1300	8.6105
1015	5098	232344.4300	265068.4100	8.7821
1015	5099	232375.2000	265069.1700	8.9538
1015	5100	232406.6100	265066.8500	9.1254
1015	5101	232436.6900	265066.8500	9.2970
1015	5102	232469.0000	265067.7500	9.3176
1015	5103	232497.2000	265067.0600	9.3382
1015	5104	232529.6900	265070.2300	9.3588
1015	5105	232559.0600	265070.6600	9.3795
1015	5106	232588.9800	265070.9400	9.4001
1015	5107	232620.3600	265069.3000	9.4207
1015	5108	232646.9700	265071.6900	9.4413

1015	5109	232680.2000	265071.1700	9.4619
1015	5110	232713.4400	265068.8000	9.4825
1015	5111	232741.9400	265068.1400	9.5032
1015	5112	232772.8500	265067.9400	9.5238
1015	5113	232804.5100	265067.2600	9.5444
1015	5114	232832.6800	265067.9800	9.5650

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State Road 715 RCVR Segment 1 Line 5017 X-Y Station Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5017	1001	231403.8900	266648.5500	9.8500
5017	1002	231405.0400	266632.2400	9.8500
5017	1003	231404.5200	266617.1600	9.8487
5017	1004	231404.8400	266602.0800	9.8463
5017	1005	231405.1500	266587.0000	9.8429
5017	1006	231404.9100	266572.2300	9.8385
5017	1007	231405.5000	266557.1500	9.8334
5017	1008	231405.8100	266543.3000	9.8274
5017	1009	231406.6800	266526.3800	9.8208
5017	1010	231407.0000	266511.6100	9.8136
5017	1011	231406.4800	266496.5200	9.8058
5017	1012	231406.7900	266482.0600	9.7976
5017	1013	231406.8300	266466.6700	9.7889
5017	1014	231406.5900	266451.5900	9.7798
5017	1015	231407.4600	266436.2000	9.7704
5017	1016	231408.8800	266420.2000	9.7606
5017	1017	231407.5300	266406.3500	9.7505
5017	1018	231407.8500	266390.9600	9.7402
5017	1019	231407.3300	266375.8800	9.7297
5017	1020	231407.9200	266360.5000	9.7189
5017	1021	231407.6900	266344.1800	9.7079
5017	1022	231408.2800	266330.3400	9.6968
5017	1023	231407.4800	266314.9500	9.6855
5017	1024	231408.3500	266300.4800	9.6741
5017	1025	231407.8300	266285.4000	9.6626
5017	1026	231408.1500	266270.9400	9.6509
5017	1027	231408.1900	266255.2400	9.6464
5017	1028	231408.5000	266239.8500	9.6484
5017	1029	231408.2600	266224.7700	9.6562
5017	1030	231408.0200	266210.6200	9.6692
5017	1031	231408.6100	266194.3100	9.6869
5017	1032	231407.2600	266181.0700	9.7088
5017	1033	231408.4100	266164.7600	9.7345
5017	1034	231408.7200	266149.6800	9.7637
5017	1035	231408.7600	266134.9100	9.7960
5017	1036	231408.5200	266119.8300	9.8310
5017	1037	231408.8400	266103.5200	9.8686
5017	1038	231408.8700	266089.9800	9.9084
5017	1039	231408.6300	266074.5900	9.9502
5017	1040	231408.6700	266059.8100	9.9938

5017	1041	231408.7100	266044.4300	10.0391
5017	1042	231409.0200	266029.3500	10.0858
5017	1043	231409.0600	266013.9600	10.1339
5017	1044	231408.5400	265999.1800	10.1832
5017	1045	231409.1300	265983.8000	10.2335
5017	1046	231409.1700	265968.7200	10.2849
5017	1047	231409.7600	265953.3300	10.3371
5017	1048	231409.5200	265938.2500	10.3900
5017	1049	231409.8400	265923.1700	10.4437
5017	1050	231409.8700	265908.0900	10.4980
5017	1051	231408.2500	265893.6200	10.5529
5017	1052	231410.5400	265864.7000	10.6083
5017	1053	231410.3000	265849.6200	10.6139
5017	1054	231411.4400	265835.4600	10.6159
5017	1055	231410.9200	265819.4600	10.6148
5017	1056	231411.2400	265804.9900	10.6108
5017	1057	231409.8900	265790.5200	10.6042
5017	1058	231411.0300	265775.1400	10.5953
5017	1059	231410.5200	265759.4400	10.5843
5017	1060	231410.5600	265744.9800	10.5715
5017	1061	231410.3200	265729.2800	10.5569
5017	1062	231411.1800	265714.5100	10.5409
5017	1063	231410.6700	265698.8100	10.5234
5017	1064	231411.2600	265683.7300	10.5048
5017	1065	231410.4700	265669.2700	10.4850
5017	1066	231411.3300	265653.8800	10.4642
5017	1067	231411.1000	265638.4900	10.4425
5017	1068	231411.9600	265623.7200	10.4201
5017	1069	231411.4500	265608.3300	10.3969
5017	1070	231411.7600	265593.5600	10.3730
5017	1071	231411.8000	265576.9400	10.3485
5017	1072	231411.5600	265563.0900	10.3236
5017	1073	231412.1500	265547.0900	10.2981
5017	1074	231412.1900	265533.2400	10.2722
5017	1075	231412.2300	265516.9300	10.2460
5017	1076	231412.5400	265503.0800	10.2193
5017	1077	231412.3000	265487.0800	10.1924
5017	1078	231413.4400	265471.6900	10.1659
5017	1079	231411.2700	265456.3000	10.1399
5017	1080	231412.9700	265441.8400	10.1143
5017	1081	231413.5600	265425.5300	10.0890

5017	1082	231413.3200	265411.3700	10.0640
5017	1083	231412.8000	265395.9800	10.0393
5017	1084	231413.3900	265381.2100	10.0148
5017	1085	231412.6000	265366.1300	9.9906
5017	1086	231413.4700	265351.0500	9.9666
5017	1087	231413.5000	265335.9700	9.9427
5017	1088	231413.5400	265320.5800	9.9190
5017	1089	231412.7500	265305.5000	9.8955
5017	1090	231413.6200	265290.7300	9.8721
5017	1091	231412.8200	265275.9500	9.8488
5017	1092	231414.2400	265260.5700	9.8257
5017	1093	231413.4500	265244.8700	9.8026
5017	1094	231413.2100	265230.7100	9.7796
5017	1095	231414.0800	265214.7100	9.7567
5017	1096	231413.8400	265199.9400	9.7339
5017	1097	231413.8800	265183.9400	9.7112
5017	1098	231414.4700	265169.1600	9.6885
5017	1099	231414.7900	265153.1600	9.6658
5017	1100	231414.5400	265139.0000	9.6432
5017	1101	231415.9700	265123.0000	9.6206
5017	1102	231416.0000	265107.9200	9.5981
5017	1103	231414.3800	265093.7600	9.5756

Geodetic Coordinate System: NAD 83 State Plane Florida East FIPS0901

State Road 715 SRC Segment 1 Line 1017 X-Y Station Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
1017	5001	231411.8100	266652.6600	9.8500
1017	5002	231410.5600	266622.4600	9.8487
1017	5003	231410.3800	266593.5700	9.8429
1017	5004	231410.6600	266562.2300	9.8334
1017	5005	231411.4600	266531.6500	9.8208
1017	5006	231412.0100	266502.1800	9.8058
1017	5007	231411.5800	266470.3700	9.7889
1017	5008	231412.7300	266442.7800	9.7704
1017	5009	231412.5000	266412.0200	9.7505
1017	5010	231412.6500	266381.8300	9.7297
1017	5011	231413.3700	266349.9500	9.7079
1017	5012	231413.1800	266320.2600	9.6855
1017	5013	231412.5900	266289.7700	9.6626
1017	5014	231412.4200	266259.9700	9.6464
1017	5015	231412.5000	266228.7600	9.6562
1017	5016	231413.2500	266199.0700	9.6869
1017	5017	231413.5500	266169.5500	9.7345
1017	5018	231413.7600	266138.1700	9.7960
1017	5019	231413.4100	266108.9900	9.8686
1017	5020	231413.4300	266079.1900	9.9502
1017	5021	231413.0200	266048.5800	10.0391
1017	5022	231413.5000	266019.4900	10.1339
1017	5023	231413.6900	265988.2400	10.2335
1017	5024	231414.5100	265957.0100	10.3371
1017	5025	231414.6000	265927.1800	10.4437
1017	5026	231412.0700	265905.3200	10.5529
1017	5027	231412.7400	265860.7200	10.6139
1017	5028	231415.3200	265824.4800	10.6148
1017	5029	231415.1300	265794.0800	10.6042
1017	5030	231415.0600	265763.3000	10.5843
1017	5031	231415.8100	265733.5600	10.5569
1017	5032	231415.6200	265702.6500	10.5234
1017	5033	231415.8700	265672.9700	10.4850
1017	5034	231415.5200	265643.2600	10.4425
1017	5035	231415.9000	265612.8500	10.3969
1017	5036	231415.8700	265582.7100	10.3485
1017	5037	231416.5800	265552.7400	10.2981
1017	5038	231416.5700	265521.8100	10.2460
1017	5039	231416.2600	265493.0400	10.1924
1017	5040	231416.5700	265461.5600	10.1399

1017	5041	231416.8300	265431.4800	10.0890
1017	5042	231417.5900	265400.3400	10.0393
1017	5043	231416.9900	265371.0700	9.9906
1017	5044	231417.3200	265340.8600	9.9427
1017	5045	231417.6300	265309.8100	9.8955
1017	5046	231417.8200	265279.4000	9.8488
1017	5047	231418.7700	265250.0900	9.8026
1017	5048	231418.0700	265217.3700	9.7567
1017	5049	231418.4600	265188.7700	9.7112
1017	5050	231418.6500	265159.1300	9.6658
1017	5051	231420.5900	265128.6100	9.6206
1017	5052	231415.3300	265097.3000	9.5756

Geodetic Coordinate System: NAD 83 State Plane Florida East FIPS0901

State Road 715 RCVR Segment 2 Line 5017 X-Y Station Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5017	1113	231421.7600	265014.9900	9.8760
5017	1114	231421.5200	264999.3000	9.8760
5017	1115	231421.5600	264984.8300	9.8744
5017	1116	231421.3200	264969.4400	9.8714
5017	1118	231421.9500	264938.9800	9.8671
5017	1119	231421.1600	264924.8200	9.8617
5017	1117	231421.6300	264955.2900	9.8552
5017	1120	231421.4700	264909.1200	9.8478
5017	1121	231420.6800	264893.7300	9.8395
5017	1122	231421.0000	264878.0400	9.8305
5017	1123	231421.3100	264863.5700	9.8208
5017	1124	231421.0700	264848.1800	9.8105
5017	1125	231420.8300	264833.4100	9.7997
5017	1126	231420.8700	264818.0200	9.7883
5017	1127	231420.3500	264802.6300	9.7765
5017	1128	231420.9400	264787.2500	9.7643
5017	1129	231421.2600	264772.1700	9.7518
5017	1130	231421.3000	264756.7800	9.7389
5017	1131	231421.3300	264742.0100	9.7257
5017	1132	231421.6500	264726.9300	9.7123
5017	1133	231421.6800	264712.1600	9.6986
5017	1134	231422.5500	264695.5400	9.6847
5017	1135	231422.0300	264682.0000	9.6706
5017	1136	231422.0700	264665.6800	9.6563
5017	1137	231421.5600	264650.6000	9.6430
5017	1138	231421.8700	264636.1400	9.6303
5017	1139	231421.6300	264620.4400	9.6184
5017	1140	231421.9500	264605.3600	9.6072
5017	1141	231421.4300	264591.2000	9.5965
5017	1142	231420.9200	264574.8900	9.5863
5017	1143	231421.7800	264559.5100	9.5766
5017	1144	231421.5400	264545.0400	9.5673
5017	1145	231420.7500	264529.9600	9.5584
5017	1146	231420.7900	264514.8800	9.5498
5017	1147	231421.3800	264499.8000	9.5415
5017	1148	231421.1400	264484.1000	9.5335
5017	1149	231421.4600	264469.0200	9.5257
5017	1150	231421.2200	264454.2500	9.5181
5017	1151	231420.9800	264438.8600	9.5108
5017	1152	231421.5700	264423.7800	9.5036

5017	1154	231421.6400	264393.9300	9.4966
5017	1153	231421.8800	264409.0100	9.4898
5017	1155	231422.7900	264378.8500	9.4830
5017	1156	231421.7200	264364.0800	9.4764
5017	1157	231422.3100	264348.3800	9.4699
5017	1158	231421.7900	264333.9200	9.4635
5017	1159	231421.8300	264318.2200	9.4572
5017	1160	231422.4200	264303.4500	9.4509
5017	1161	231422.7300	264287.7500	9.4447
5017	1162	231422.7700	264273.2900	9.4386
5017	1163	231422.8100	264258.2100	9.4326
5017	1164	231423.1200	264242.8200	9.4265
5017	1165	231423.1600	264227.4300	9.4206
5017	1166	231422.3700	264212.3500	9.4147
5017	1167	231423.7900	264196.9700	9.4088
5017	1168	231423.5500	264181.8900	9.4029
5017	1169	231423.8600	264166.8100	9.3971
5017	1171	231424.7700	264135.7200	9.3913
5017	1170	231424.4600	264151.1100	9.3855
5017	1172	231425.0800	264121.2600	9.3798
5017	1173	231425.1200	264106.1800	9.3874
5017	1174	231425.7100	264090.7900	9.4072
5017	1175	231426.0200	264075.4100	9.4379
5017	1176	231425.7900	264060.6300	9.4783
5017	1177	231425.5500	264044.9400	9.5276
5017	1178	231426.1400	264030.1700	9.5847
5017	1179	231426.1800	264014.7800	9.6491
5017	1180	231426.4900	264000.6200	9.7198
5017	1181	231426.5200	263985.2300	9.7964
5017	1182	231427.1100	263970.1500	9.8781
5017	1183	231426.8800	263955.3800	9.9645
5017	1184	231427.4700	263940.0000	10.0551
5017	1185	231427.7800	263925.5300	10.1496
5017	1186	231426.9900	263910.1400	10.2474
5017	1187	231427.8500	263895.0600	10.3483
5017	1189	231427.0900	263869.2100	10.4520
5017	1188	231427.3400	263879.6700	10.5582
5017	1190	231426.8600	263849.2000	10.6666
5017	1191	231427.7300	263834.1300	10.7770
5017	1192	231427.7700	263819.0500	10.8893
5017	1193	231427.8000	263803.6600	11.0031

5017	1194	231427.2900	263788.8800	11.1185
5017	1195	231427.6000	263773.1900	11.2351
5017	1196	231427.6400	263757.8000	11.3530
5017	1197	231428.2300	263742.7200	11.4719
5017	1198	231427.9900	263727.0300	11.5918
5017	1200	231427.7900	263696.5600	11.7126
5017	1199	231428.0300	263712.2500	11.8141
5017	1201	231428.1100	263681.7800	11.9072
5017	1202	231428.1400	263666.4000	11.9925
5017	1203	231427.0800	263651.0100	12.0710
5017	1204	231428.5000	263635.9300	12.1432
5017	1205	231427.9800	263620.8500	12.2099
5017	1206	231427.7400	263606.0700	12.2716
5017	1207	231428.0600	263589.7600	12.3287
5017	1208	231428.0900	263575.3000	12.3817
5017	1209	231427.8600	263558.0600	12.4311

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State Road 715 SRC Segment 2 Line 1017 X-Y Station Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
1017	5062	231414.2500	265017.2100	9.8760
1017	5063	231415.8900	264989.0300	9.8744
1017	5064	231415.3600	264958.4200	9.8671
1017	5065	231415.2700	264927.6900	9.8552
1017	5066	231414.9200	264898.1400	9.8395
1017	5067	231415.1200	264869.2800	9.8208
1017	5068	231415.5200	264838.6700	9.7997
1017	5069	231416.1500	264806.5400	9.7765
1017	5070	231415.6700	264779.2100	9.7518
1017	5071	231415.4700	264747.3700	9.7257
1017	5072	231417.1200	264716.7000	9.6986
1017	5073	231416.4300	264686.8400	9.6706
1017	5074	231416.2300	264655.8200	9.6430
1017	5075	231417.5600	264625.9500	9.6184
1017	5076	231417.3400	264594.9100	9.5965
1017	5077	231417.2000	264564.6400	9.5766
1017	5078	231416.4800	264533.5800	9.5584
1017	5079	231417.1800	264504.9800	9.5415
1017	5080	231417.7200	264474.1200	9.5257
1017	5081	231417.3200	264443.4500	9.5108
1017	5082	231416.9100	264414.5500	9.4966
1017	5083	231417.3300	264383.7900	9.4830
1017	5084	231417.8700	264354.1100	9.4699
1017	5085	231418.4300	264322.5800	9.4572
1017	5086	231418.1400	264292.7900	9.4447
1017	5087	231419.0300	264260.9400	9.4326
1017	5088	231418.8100	264231.6700	9.4206
1017	5089	231419.4200	264201.7800	9.4088
1017	5090	231419.9700	264171.8300	9.3971
1017	5091	231419.5900	264140.7500	9.3855
1017	5092	231419.5200	264110.2200	9.3874
1017	5093	231419.5400	264081.9300	9.4379
1017	5094	231420.4300	264049.1400	9.5276
1017	5095	231420.9100	264020.1100	9.6491
1017	5096	231420.3700	263989.5500	9.7964
1017	5097	231420.9500	263959.3600	9.9645
1017	5098	231420.9100	263930.3000	10.1496
1017	5099	231421.3200	263899.9600	10.3483
1017	5100	231421.3900	263871.1900	10.5582
1017	5101	231417.4900	263839.4700	10.7770

1017	5102	231417.7500	263809.5800	11.0031
1017	5103	231418.1500	263777.8900	11.2351
1017	5104	231418.5700	263748.6800	11.4719
1017	5105	231418.8000	263717.3800	11.7126
1017	5106	231418.8000	263686.6900	11.9072
1017	5107	231419.1200	263656.4700	12.0710
1017	5108	231419.3400	263627.0900	12.2099
1017	5109	231419.0400	263596.7500	12.3287
1017	5110	231418.6800	263565.1500	12.4311

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Spoil Management 3D Receiver Line 5005 Coordinates

RCVR Line	RCVR Station	X (feet)	Y (ft)	Elevation (ft)
5005	1001	189411.49	275400.92	11.3490
5005	1002	189426.12	275400.90	11.9630
5005	1003	189442.69	275401.50	12.5770
5005	1004	189457.60	275401.18	12.8218
5005	1005	189472.51	275401.17	13.0666
5005	1006	189487.97	275400.85	13.3114
5005	1007	189503.16	275401.76	13.5562
5005	1008	189518.63	275402.06	13.8010
5005	1009	189533.81	275401.74	14.0458
5005	1010	189548.17	275402.34	14.2906
5005	1011	189563.91	275402.02	14.5354
5005	1012	189579.38	275402.62	14.7802
5005	1013	189594.01	275402.61	15.0250
5005	1014	189609.47	275403.21	15.2698
5005	1015	189624.94	275403.20	15.5146
5005	1016	189639.85	275403.19	15.7594
5005	1017	189655.31	275402.87	16.0042
5005	1018	189670.50	275403.16	16.2490
5005	1019	189685.41	275403.77	16.2005
5005	1020	189701.15	275403.75	16.1520
5005	1021	189715.79	275404.05	16.1035
5005	1022	189731.80	275404.34	16.0550
5005	1023	189746.99	275403.72	16.0065
5005	1024	189762.18	275404.32	15.9580
5005	1025	189777.09	275403.69	15.9095
5005	1026	189791.44	275403.68	15.8610

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Spoil Management 3D Receiver Line 5006 Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5006	1001	189413.75	275462.16	15.0120
5006	1002	189428.93	275461.53	15.0120
5006	1003	189444.40	275461.21	15.0120
5006	1004	189459.03	275462.12	14.8642
5006	1005	189473.67	275461.80	14.8098
5006	1006	189489.68	275462.09	14.8300
5006	1007	189504.32	275461.77	14.9100
5006	1008	189520.06	275461.45	14.0730
5006	1009	189535.24	275462.06	13.4209
5006	1010	189550.43	275461.43	12.9167
5006	1011	189565.89	275462.03	12.5308
5006	1012	189581.63	275461.71	12.2396
5006	1013	189597.65	275461.39	12.0241
5006	1014	189611.46	275461.99	11.8692
5006	1015	189626.64	275461.67	11.7628
5006	1016	189641.83	275461.66	12.8182
5006	1017	189656.74	275462.26	13.1858
5006	1018	189672.20	275462.56	13.4491
5006	1019	189687.11	275461.93	13.6289
5006	1020	189702.58	275461.92	13.7421
5006	1021	189718.87	275461.91	13.8019
5006	1022	189733.78	275461.59	13.8189
5006	1023	189748.42	275462.19	13.8018
5006	1024	189764.43	275461.25	13.7574
5006	1025	189779.89	275461.55	13.6911
5006	1026	189794.53	275460.92	13.6073
5006	1027	189809.99	275460.60	13.5095
5006	1028	189826.28	275459.97	13.4005
5006	1029	189841.19	275459.96	13.2825
5006	1030	189856.38	275459.33	13.1574

NAD 83 State Plane Florida East FIPS0901

Spoil Management 3D Receiver Line 5007 Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5007	1001	189413.52	275523.71	14.5424
5007	1002	189428.43	275522.47	14.5090
5007	1003	189444.17	275522.45	14.8466
5007	1004	189459.36	275523.36	14.8720
5007	1005	189474.82	275523.35	14.9384
5007	1006	189489.73	275523.03	14.8816
5007	1007	189505.20	275522.71	14.4639
5007	1008	189520.66	275522.39	14.1529
5007	1009	189535.85	275521.76	13.9273
5007	1010	189550.76	275522.06	13.7699
5007	1011	189565.94	275521.43	13.6673
5007	1012	189581.41	275520.80	13.6083
5007	1013	189596.32	275520.79	13.5843
5007	1014	189611.50	275521.08	13.5883
5007	1015	189627.24	275520.46	13.6147
5007	1016	189642.43	275520.44	13.6589
5007	1017	189657.62	275520.74	13.7175
5007	1018	189672.53	275520.73	13.7876
5007	1019	189687.99	275521.33	13.8668
5007	1020	189703.45	275521.32	13.9533
5007	1021	189718.09	275522.23	14.0458
5007	1022	189733.55	275522.22	14.1429
5007	1023	189749.29	275522.51	14.2437
5007	1024	189763.93	275522.50	14.3476
5007	1025	189779.39	275522.79	14.4539
5007	1026	189794.30	275523.09	14.5621
5007	1027	189809.77	275523.69	14.6718
5007	1028	189825.23	275524.30	14.7828
5007	1029	189840.14	275525.21	14.8947
5007	1030	189855.05	275526.12	15.0075
5007	1031	189870.79	275526.72	15.1209
5007	1032	189885.43	275526.71	15.2347
5007	1033	189901.17	275527.31	15.3490

NAD 83 State Plane Florida East FIPS0901

Spoil Management 3D Receiver Line 5008 Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5008	1001	189414.40	275582.80	13.2292
5008	1002	189429.86	275583.71	13.2620
5008	1003	189445.05	275583.70	14.0202
5008	1004	189461.62	275584.61	14.5440
5008	1005	189476.81	275583.36	15.0565
5008	1006	189491.99	275582.12	15.5601
5008	1007	189507.18	275583.95	16.0565
5008	1008	189521.81	275583.02	15.8610
5008	1009	189537.00	275583.01	15.3336
5008	1010	189552.74	275582.07	14.9404
5008	1011	189568.20	275582.06	14.6545
5008	1012	189582.84	275581.43	14.4545
5008	1013	189598.30	275581.72	14.3232
5008	1014	189614.04	275581.10	14.2469
5008	1015	189628.40	275580.78	14.2146
5008	1016	189643.31	275579.84	14.2174
5008	1017	189658.49	275579.83	14.2483
5008	1018	189674.23	275579.82	14.3018
5008	1019	189688.87	275579.19	14.3733
5008	1020	189704.05	275578.56	14.4592
5008	1021	189719.79	275578.55	14.5566
5008	1022	189735.26	275577.92	14.6633
5008	1023	189750.44	275577.29	14.7773
5008	1024	189765.08	275577.28	14.8972
5008	1025	189781.09	275576.04	15.0218
5008	1026	189796.00	275575.41	15.1502
5008	1027	189812.02	275574.47	15.2817
5008	1028	189826.93	275574.15	15.4155
5008	1029	189841.84	275574.45	15.5513
5008	1030	189857.30	275573.82	15.6887
5008	1031	189872.49	275573.50	15.2619
5008	1032	189887.67	275572.56	15.0358
5008	1033	189902.58	275572.24	14.9702
5008	1034	189917.49	275571.31	15.0329
5008	1035	189932.68	275570.68	15.1983

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Spoil Management 3D Receiver Line 5009 Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5009	1001	189415.83	275645.27	16.9471
5009	1002	189430.47	275645.26	17.0127
5009	1003	189445.93	275645.25	17.1280
5009	1004	189460.84	275645.55	17.2102
5009	1005	189476.86	275645.22	17.3015
5009	1006	189491.49	275645.83	17.4002
5009	1007	189506.96	275646.12	17.5047
5009	1008	189521.87	275645.49	17.6138
5009	1009	189537.05	275646.40	17.7268
5009	1010	189552.79	275646.39	17.8427
5009	1011	189567.70	275646.38	17.9610
5009	1012	189583.17	275647.29	18.0812
5009	1013	189598.63	275647.28	18.2030
5009	1014	189614.37	275647.88	18.2833
5009	1015	189629.00	275647.56	18.3304
5009	1016	189643.92	275648.16	18.3510
5009	1017	189659.65	275647.53	18.3504
5009	1018	189674.57	275648.14	18.3328
5009	1019	189689.20	275648.13	18.3016
5009	1020	189704.66	275648.73	18.2595
5009	1021	189719.85	275648.72	18.2087
5009	1022	189734.76	275649.32	18.1510
5009	1023	189750.22	275649.31	18.0877
5009	1024	189765.14	275649.30	18.0200
5009	1025	189780.32	275649.90	17.9487
5009	1026	189796.89	275650.19	17.8746
5009	1027	189811.25	275651.10	17.7975
5009	1028	189827.54	275651.09	17.7181
5009	1029	189841.62	275650.77	17.6369
5009	1030	189856.81	275651.38	17.5542
5009	1031	189873.10	275647.05	17.4702
5009	1032	189888.01	275648.27	17.3854
5009	1033	189902.92	275649.80	17.2997
5009	1034	189917.28	275646.10	17.2135
5009	1035	189930.80	275638.39	17.1267
5009	1036	189945.16	275631.92	17.0396
5009	1037	189958.40	275625.75	16.9522
5009	1038	189971.93	275619.89	16.8645

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Spoil Management 3D Receiver Line 5010 Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5010	1001	189415.61	275705.29	14.0896
5010	1002	189430.79	275706.20	14.0660
5010	1003	189445.98	275706.19	14.0660
5010	1004	189461.72	275706.17	13.9788
5010	1005	189476.08	275706.16	13.9588
5010	1006	189491.27	275705.84	13.9301
5010	1007	189506.45	275706.14	13.8944
5010	1008	189521.64	275705.82	13.8531
5010	1009	189537.38	275706.42	13.8074
5010	1010	189552.29	275706.10	13.7580
5010	1011	189567.48	275706.70	13.7058
5010	1012	189582.39	275707.30	13.6513
5010	1013	189597.57	275706.98	13.5949
5010	1014	189613.31	275706.66	13.5371
5010	1015	189628.22	275707.27	13.4782
5010	1016	189644.24	275706.95	13.4182
5010	1017	189658.87	275706.32	13.3576
5010	1018	189674.34	275706.92	13.2963
5010	1019	189689.52	275707.52	13.2345
5010	1020	189704.43	275707.20	13.1724
5010	1021	189719.35	275706.58	13.1099
5010	1022	189734.53	275705.95	13.0472
5010	1023	189749.99	275705.94	12.9843
5010	1024	189765.46	275705.92	12.9213
5010	1025	189780.09	275706.22	12.8581
5010	1026	189796.38	275705.28	12.7949
5010	1027	189810.74	275706.19	12.7315
5010	1028	189826.48	275704.64	12.6681
5010	1029	189841.94	275705.55	12.6046
5010	1030	189856.58	275704.93	12.5411
5010	1031	189871.49	275705.84	12.4775
5010	1032	189887.23	275704.90	12.4140
5010	1033	189902.97	275703.97	12.3504
5010	1034	189917.32	275699.34	12.7912
5010	1035	189932.78	275697.48	13.6356
5010	1036	189947.69	275697.47	13.9598
5010	1037	189962.33	275696.22	14.2429
5010	1038	189977.23	275691.60	14.4931

5010	1039	189991.31	275686.66	14.7168
5010	1040	190005.11	275680.80	14.9195
5010	1041	190019.74	275675.25	15.1053

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Spoil Management 3D Receiver Line 5011 Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5011	1001	189417.32	275767.76	14.0955
5011	1002	189432.23	275766.83	14.0693
5011	1003	189446.31	275765.28	14.0660
5011	1004	189462.60	275766.19	13.9788
5011	1005	189477.23	275766.48	13.9588
5011	1006	189492.70	275766.47	13.9301
5011	1007	189508.16	275767.07	13.8944
5011	1008	189523.35	275765.83	13.8531
5011	1009	189538.26	275766.43	13.8074
5011	1010	189553.72	275766.42	13.7443
5011	1011	189568.91	275766.71	13.6674
5011	1012	189584.09	275766.39	13.5794
5011	1013	189599.00	275767.00	13.4825
5011	1014	189614.74	275767.60	13.3786
5011	1015	189629.66	275767.89	13.2689
5011	1016	189645.39	275767.88	13.1548
5011	1017	189660.03	275768.18	13.0370
5011	1018	189675.77	275767.86	12.9163
5011	1019	189690.40	275767.84	12.7933
5011	1020	189705.31	275765.99	12.6684
5011	1021	189720.50	275766.59	12.5421
5011	1022	189736.51	275765.65	12.4145
5011	1023	189750.32	275765.33	12.2860
5011	1024	189767.16	275765.32	12.8056
5011	1025	189782.07	275764.69	12.9435
5011	1026	189796.43	275764.99	13.0171
5011	1027	189812.45	275764.05	13.0394
5011	1028	189827.36	275764.04	13.0206
5011	1029	189841.99	275764.03	12.9689
5011	1030	189858.00	275762.78	12.8908
5011	1031	189873.74	275763.08	12.7918
5011	1032	189888.10	275762.76	12.6759
5011	1033	189903.29	275762.44	12.5465
5011	1034	189917.92	275760.58	13.5238
5011	1035	189933.94	275759.95	14.0880

5011	1036	189948.85	275759.63	14.3218
5011	1037	189964.31	275759.31	14.5325
5011	1038	189979.22	275759.30	14.7247
5011	1039	189993.30	275759.29	14.9022
5011	1040	190010.15	275758.35	15.0678
5011	1041	190024.50	275757.73	15.2239
5011	1042	190040.24	275756.79	15.3725
5011	1043	190055.43	275755.86	15.5150
5011	1044	190071.17	275755.23	15.6527
5011	1045	190086.35	275754.91	15.7865

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Spoil Management 3D Receiver Line 5011 Coordinates

RCVR Line	RCVR Station	X (feet)	Y (feet)	Elevation (ft)
5012	1001	189416.81	275827.47	14.1298
5012	1002	189432.00	275828.07	14.1626
5012	1003	189446.91	275828.06	14.1908
5012	1004	189462.37	275828.35	14.2340
5012	1005	189477.84	275827.42	14.2697
5012	1006	189492.47	275828.64	14.3815
5012	1007	189507.93	275828.01	14.4473
5012	1008	189523.40	275828.00	14.4762
5012	1009	189538.86	275827.37	14.4756
5012	1010	189554.05	275827.97	14.4514
5012	1011	189569.79	275827.65	14.4083
5012	1012	189584.42	275828.25	14.3502
5012	1013	189599.88	275827.93	14.2800
5012	1014	189615.62	275828.23	14.2000
5012	1015	189630.81	275827.91	14.1124
5012	1016	189646.00	275827.89	14.0186
5012	1017	189661.46	275827.57	13.9198
5012	1018	189676.37	275828.18	13.8171
5012	1019	189691.00	275827.24	13.7112
5012	1020	189707.29	275827.54	13.6028
5012	1021	189722.48	275827.83	13.4924
5012	1022	189737.39	275827.51	13.3803
5012	1023	189753.13	275827.50	13.3920
5012	1024	189768.04	275827.18	13.5027
5012	1025	189783.23	275827.78	13.6926
5012	1026	189799.24	275827.77	13.9458
5012	1027	189814.43	275827.14	14.2498

5012	1028	189829.34	275827.13	14.5943
5012	1029	189843.97	275827.12	14.9712
5012	1030	189859.44	275827.11	14.7270
5012	1031	189874.90	275826.79	14.5118
5012	1032	189890.09	275826.16	14.3199
5012	1033	189905.27	275826.76	14.1467
5012	1034	189920.74	275827.06	13.9883
5012	1035	189936.20	275826.74	13.8418
5012	1036	189951.66	275826.42	13.7049
5012	1037	189965.74	275827.02	13.5756
5012	1038	189981.76	275826.09	13.4524
5012	1039	189997.77	275826.07	13.3341
5012	1040	190012.41	275825.75	13.2197
5012	1041	190027.59	275825.74	13.1084
5012	1042	190043.33	275825.11	12.9996
5012	1043	190058.24	275825.10	12.8928
5012	1044	190073.98	275825.09	12.7876
5012	1045	190089.17	275825.08	12.6837
5012	1046	190104.91	275825.06	12.9049
5012	1048	190135.00	275824.73	13.3862
5012	1047	190119.54	275823.51	14.0755
5012	1049	190150.47	275824.72	14.3227

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Spoil Management 3D Source Line 3003 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3003	1001	189420.17	275403.61	11.5653
3003	1002	189421.79	275435.10	11.3490
3003	1003	189421.33	275464.32	11.7153
3003	1004	189422.33	275495.66	12.3746
3003	1005	189422.24	275526.35	12.8551
3003	1006	189422.30	275556.12	13.1926
3003	1007	189422.86	275585.61	13.3312
3003	1008	189423.03	275617.66	13.3108
3003	1009	189423.77	275649.20	13.6663
3003	1010	189424.31	275678.82	14.3224
3003	1011	189423.95	275708.83	14.5616
3003	1012	189424.23	275738.39	14.4672
3003	1013	189424.59	275769.25	14.3923
3003	1014	189425.06	275800.62	14.3329
3003	1015	189424.70	275831.32	14.2889
3003	1016	189427.55	275844.38	14.2571

Spoil Management 3D Source Line 3004 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3004	1001	189482.35	275404.02	13.0666
3004	1002	189478.59	275429.97	13.2435
3004	1003	189481.62	275465.40	13.2409
3004	1004	189483.98	275490.61	13.5547
3004	1005	189483.29	275520.50	13.8186
3004	1006	189481.98	275551.08	14.0425
3004	1007	189481.77	275581.42	14.2335
3004	1008	189481.40	275613.18	14.3981
3004	1009	189481.87	275643.14	14.7543
3004	1010	189483.83	275673.66	15.2637
3004	1011	189482.83	275704.03	15.3370
3004	1012	189484.17	275734.67	15.0614
3004	1013	189482.85	275765.30	14.8409
3004	1014	189483.89	275795.55	14.6645
3004	1015	189483.73	275825.89	14.5544
3004	1016	189487.42	275843.85	14.4975

Spoil Management 3D Source Line 3005 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3005	1001	189539.38	275405.17	14.2344
3005	1002	189541.29	275435.58	14.0458
3005	1003	189541.81	275465.05	13.9833
3005	1004	189542.61	275493.93	13.8708
3005	1005	189543.10	275525.00	13.8315
3005	1006	189542.99	275552.16	13.8506
3005	1007	189543.27	275586.02	14.0066
3005	1008	189543.87	275604.41	14.2720
3005	1009	189544.67	275650.13	14.7236
3005	1010	189542.80	275673.04	15.3243
3005	1011	189543.52	275711.26	15.4128
3005	1012	189544.71	275742.30	15.0917
3005	1013	189545.49	275769.29	14.8349
3005	1014	189544.77	275799.39	14.6294
3005	1015	189546.50	275826.17	14.5318
3005	1016	189550.44	275840.88	14.5205

Spoil Management 3D Source Line 3006 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3006	1001	189603.71	275405.25	15.2345
3006	1002	189602.54	275434.57	15.0250
3006	1003	189601.85	275459.58	14.7249
3006	1004	189602.35	275488.29	14.1847
3006	1005	189603.80	275517.41	13.9086
3006	1006	189604.36	275547.73	13.8438
3006	1007	189605.99	275578.51	13.8658
3006	1008	189608.66	275607.17	13.9573
3006	1009	189606.46	275644.64	14.4184
3006	1010	189609.29	275681.70	15.1753
3006	1011	189607.58	275703.23	15.3201
3006	1012	189606.53	275729.87	14.9750
3006	1013	189606.74	275765.70	14.6878
3006	1014	189605.50	275791.00	14.4467
3006	1015	189608.66	275825.30	14.3336
3006	1016	189611.06	275842.40	14.3229

Spoil Management 3D Source Line 3007 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3007	1001	189664.68	275404.96	16.2340
3007	1002	189663.61	275434.23	16.0042
3007	1003	189665.61	275463.70	15.7224
3007	1004	189664.87	275495.28	15.2150
3007	1005	189665.27	275523.23	14.8624
3007	1006	189665.35	275552.76	14.6334
3007	1007	189663.40	275581.03	14.5033
3007	1008	189662.73	275613.96	14.4523
3007	1009	189665.42	275647.52	14.8217
3007	1010	189666.57	275674.98	15.5274
3007	1011	189667.50	275709.29	15.5927
3007	1012	189666.94	275736.54	15.1457
3007	1013	189668.37	275770.74	14.7560
3007	1014	189668.00	275796.02	14.4122
3007	1015	189667.99	275820.44	14.2255
3007	1016	189668.04	275843.27	14.1643

Spoil Management 3D Source Line 3008 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3008	1001	189726.33	275405.39	16.2343
3008	1002	189724.56	275430.32	16.1035
3008	1003	189725.33	275459.25	15.8733
3008	1004	189725.29	275487.39	15.4590
3008	1005	189724.93	275520.65	15.1520
3008	1006	189724.76	275549.38	14.9307
3008	1007	189727.92	275574.92	14.8048
3008	1008	189725.81	275607.24	14.7552
3008	1009	189727.05	275645.65	15.0807
3008	1010	189725.83	275669.58	15.7063
3008	1011	189726.36	275704.04	15.6685
3008	1012	189728.07	275728.98	15.1568
3008	1013	189728.18	275762.90	14.6906
3008	1014	189730.60	275790.62	14.2609
3008	1015	189727.52	275832.59	14.0122
3008	1016	189729.67	275842.77	13.9082

Spoil Management 3D Source Line 3009 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3009	1001	189787.09	275407.50	16.2432
3009	1002	189785.78	275434.75	15.9095
3009	1003	189786.38	275463.69	15.6877
3009	1004	189787.23	275489.34	15.2883
3009	1005	189787.05	275525.62	15.0452
3009	1006	189785.91	275552.47	14.9269
3009	1007	189787.09	275578.03	14.8891
3009	1008	189785.01	275607.78	14.9156
3009	1009	189790.66	275650.00	15.2296
3009	1010	189787.82	275679.32	15.7734
3009	1011	189787.84	275708.86	15.6994
3009	1012	189788.33	275736.10	15.1311
3009	1013	189788.95	275767.54	14.6851
3009	1014	189788.99	275794.50	14.3368
3009	1015	189788.90	275830.03	14.1330
3009	1016	189793.92	275843.91	14.0449

Spoil Management 3D Source Line 3010 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3010	1001	189844.49	275464.88	13.5756
3010	1002	189845.79	275479.15	13.2825
3010	1003	189848.48	275523.16	13.4438
3010	1004	189848.94	275545.53	13.7340
3010	1005	189847.16	275571.08	14.0318
3010	1006	189848.53	275604.31	14.3357
3010	1007	189849.74	275649.24	14.7874
3010	1008	189850.40	275670.93	15.3573
3010	1009	189850.05	275703.55	15.3100
3010	1010	189849.24	275731.01	14.7689
3010	1011	189848.01	275760.98	14.3725
3010	1012	189843.23	275789.25	14.0917
3010	1013	189849.62	275824.59	14.0674
3010	1014	189854.45	275843.86	14.2482

Spoil Management 3D Source Line 3011 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3011	1001	189924.64	275557.59	15.2346
3011	1002	189913.13	275573.37	15.0329
3011	1003	189927.65	275616.82	15.2510
3011	1004	189920.63	275647.46	15.6435
3011	1005	189914.95	275675.65	15.5152
3011	1006	189908.86	275705.03	14.9704
3011	1007	189910.88	275737.62	14.6078
3011	1008	189913.48	275754.74	14.3910
3011	1009	189913.46	275793.66	14.2640
3011	1010	189913.38	275823.32	14.2089
3011	1011	189914.72	275842.86	14.2536

Spoil Management 3D Source Line 3012 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3012	1001	189992.88	275641.74	17.2343
3012	1002	189989.72	275664.86	16.8645
3012	1003	189986.52	275685.58	16.6273
3012	1004	189985.24	275723.49	16.2005
3012	1005	189986.77	275756.36	15.8822
3012	1006	189982.26	275788.49	15.6507
3012	1007	189976.31	275824.34	15.3383
3012	1008	189974.70	275844.69	14.9611

Spoil Management 3D Source Line 3013 Coordinates

SRC Line	SRC Station	X (feet)	Y (feet)	Elevation (ft)
3013	1001	190059.83	275725.39	16.1234
3013	1002	190047.91	275759.32	15.6527
3013	1003	190042.04	275794.34	15.3662
3013	1004	190036.40	275827.95	14.8505
3013	1005	190036.76	275844.64	14.6073

Appendix 2 – Instruments & Equipment

- Geospace GSX Nodal Seismic System
- Trimble R8 GPS Survey Instruments
- Accelerated Impact Source (AIS) Energy Source System

GSX

Land Based Recorder

Cable-free, Radio-free, Autonomous Data Recorder

- Scalability greater than 50,000 channels
- Delivers high-resolution with a 24-bit delta-sigma ADC
- Built-in GPS receiver and disciplined clock
- Greater than 30 days of continuous recording
- Compatible with explosive, vibratory, and impulsive energy sources
- Accepts standard analog sensor inputs
- Has a built-in full-resolution test generator
- Available as 1, 2, 3, or 4 channel versions
- Has an LED Status/Deployment state indicator

GEOSPACE®
Technologies

Cable-free, Radio-free Autonomous Data Recording

The GSX is designed for cable-free/radio-free seismic data recording. The self-contained unit includes 1 to 4 channels of 24-bit digitization, an integrated high sensitivity GPS receiver, built-in test signal generator, up to 32 GB per channel of non-volatile solid-state data storage, and a high-speed data port. The unit is housed in a sealed case, with an input connector and an extended life battery/data port connector.

GSX System Tests

The seismic channel performance and sensor tests can be performed by the GSX System. The user can choose a partial or complete set of tests that can be run in sequence. The user can also choose to display all of the results or only the failures. In the tests described below, the system software automatically controls the Channel Input Switch Positions and Test Oscillator Settings during the tests. All tests can be run at all sample intervals and preamp gains of the GSX.

☐ Harmonic Distortion
☐ Impulse Response
☐ Equivalent Input Noise
☐ Instantaneous System Dynamic Range
☐ Gain Accuracy
☐ Common Mode Rejection
☐ Geophone Impedance and THD
☐ Crossfeed (multi-channel)

FEATURES and SPECIFICATIONS

- 24-bit digital recorder
- Built-in GPS and disciplined clock
- Built-in full resolution test signal generator
- Solid-state flash memory
- Scalability greater than 50,000 channels
- Greater than 30 days of continuous recording
- Compatible with vibratory, explosive, and impulsive energy sources
- LED Status/Deployment State Indicator
- Accepts standard analog sensor input
- Available as 1, 2, 3, or 4 channel versions
- 24-bit delta-sigma ADC
- 1 Hz to 1600 Hz freq. response
- <20 µsec of UTC (GPS clock)
- Up to 32 GBytes per channel flash memory storage
- External extended life battery
- Operating Temperature: –40° C to +85° C
- Humidity: 0 to 100%
- Selectable Gains:
  - — X1, X2, X4, X8, X16, X32, X64
  - — 0, 6, 12, 18, 24, 30, 36 dB
- Sample Intervals:
  - — .25, .5, 1, 2, 4 milliseconds

Max Input Signal:	1.80 Vrms @ 0 Gain
Total Dynamic Range:	140 dB
System Dynamic Range @ 0dB Gain:	126 dB @ 4 msec SI 124 dB @ 2 msec SI 120 dB @ 1 msec SI 117 dB @ .5 msec SI 106 dB @ .25 msec SI
Equivalent Input Noise @ 2 msec SI:	1.13 µV @ Gain 0 dB 0.58 µV @ Gain 6 dB 0.33 µV @ Gain 12 dB 0.22 µV @ Gain 18 dB 0.19 µV @ Gain 24 dB 0.18 µV @ Gain 30 dB 0.17 µV @ Gain 36 dB
Input Impedance:	20 kΩ/0.06 µf Difference Mode 205 kΩ Common Mode

System Dynamic Range @ 2 msec SI:	124 dB @ Gain 0 dB 123 dB @ Gain 6 dB 122 dB @ Gain 12 dB 120 dB @ Gain 18 dB 115 dB @ Gain 24 dB 110 dB @ Gain 30 dB 105 dB @ Gain 36 dB
Total Harmonic Distortion:	0.0005%
Common Mode Rejection:	0.001%
Gain Accuracy:	1%
Anti-Alias Filter:	Rejection @ Nyquist: 130 dB Frequency @ –3 dB: 0.83 Nyquist Linear or Minimum Phase
GPS Time Standard:	<1 ppm
Weight:	2 lbs.
Max Dimensions:	3.5"W x 3.0"H x 6.67"L

Big Advances in Small Packages

GSX1 with a BN6 battery and a GS-ONE geophone in a Land Case.

DATASHEET

Trimble R8s

GNSS SYSTEM

One Receiver Configured for Today Scalable for Tomorrow

Rather than a pre-configured system, the Trimble® R8s GNSS system gives you just the features and benefits you need, in one flexible, scalable system. It's never been easier to build a system tailored to your job.

The Trimble R8s easily integrates with Trimble S-Series total stations and the innovative Trimble V10 imaging rover. Create a complete solution by combining the Trimble R8s receiver with a Trimble controller running Trimble Access™ field software, and Trimble Business Center office software.

Configure and Scale With Ease

With the Trimble R8s, it's easy and simple to build a receiver that is right for the job. Choose the configuration level that suits your needs best, whether it's post-processing, base, rover, or a combination of base and rover functionality. After you've selected a configuration level, additional individual options can be added to further extend the receiver functionality.

The Trimble R8s offers the ultimate in scalability. As your requirements change, the Trimble R8s can adapt. Simply add functionality whenever you need it.

Trimble 360 Technology

Each Trimble R8s comes integrated with powerful Trimble 360 tracking technology that supports signals from all existing and planned constellations, and augmentation systems. Trimble 360 technology can expand the reach of your GNSS rover to sites that were previously inaccessible due to moderate vegetation or other obstructions by taking advantage of the availability of additional satellite signals.

The Trimble R8s includes two integrated Maxwell™ 6 chips and 440 GNSS channels. Capable of tracking a full range of satellite systems, including GPS, GLONASS, Galileo, BeiDou and QZSS.

Communication Options and Remote Access Via Web UI

The Trimble R8s GNSS receiver provides data communication options including an integrated wide-band UHF radio or 3G cellular modem.

Trimble's exclusive Web UI eliminates the need to travel for routine monitoring of base station receivers.

The Complete Solution

Create an industry-leading field solution by pairing the Trimble R8s GNSS receiver with a powerful Trimble controller loaded with our easy-to-use Trimble Access field software.

Trimble Access field software offers the features and capabilities to simplify everyday work. Our streamlined workflow modules such as Roads, Monitoring, Mines, and Tunnels guide crews through common project types, enabling them to get the job done faster. Survey companies can also implement their unique workflows by taking advantage of the customization capabilities available in the Trimble Access Software Development Kit (SDK).

Once you're back in the office, Trimble Business Center enables you to check, process and adjust your data with confidence. No matter what Trimble solution you use in the field, you can trust that Trimble Business Center office software will help you generate industry leading deliverables.

Trimble Mobile App—A New Way to Quickly Collect GNSS Raw Data

The Trimble DL Android app provides a simple and easy to use mobile interface for collecting static GNSS raw data for post-processing purposes without the need of using a Trimble controller or Trimble Access field software. This free of charge app is available through the Google Play Store and operates on Android smart phones and tablets.

Key Features

- One configurable receiver that is scalable for future needs
- Available in post-processing, base only, rover only, or base & rover configurations
- Advanced satellite tracking with Trimble 360 receiver technology
- Includes Trimble Maxwell 6 chips with 440 channels
- Simple integration with Trimble S-Series Total Stations and the V10 Imaging Rover
- Intuitive Trimble Access Field Software and Trimble Business Center Office Software

Trimble R8s GNSS SYSTEM

PERFORMANCE SPECIFICATIONS[1]

Measurements

- Advanced Trimble Maxwell 6 Custom Survey GNSS chips with 440 channels
- Future-proof your investment with Trimble 360 tracking
- High precision multiple correlator for GNSS pseudorange measurements
- Unfiltered, un-smoothed pseudorange measurements data for low noise, low multipath error, low time domain correlation and high dynamic response
- Very low noise GNSS carrier phase measurements with <1 mm precision in a 1 Hz bandwidth
- Signal-to-Noise ratios reported in dB-Hz
- Proven Trimble low elevation tracking technology
- Satellite signals tracked simultaneously:
  - GPS: L1C/A, L1C, L2C, L2E, L5
  - GLONASS: L1C/A, L1P, L2C/A, L2P, L3
  - SBAS: L1C/A, L5 (for SBAS satellites that support L5)
  - Galileo: E1, E5A, E5B
  - BeiDou (COMPASS): B1, B2
- SBAS: QZSS, WAAS, EGNOS, GAGAN
- Positioning rates: 1 Hz, 2 Hz, 5 Hz, 10 Hz, and 20 Hz

POSITIONING PERFORMANCE[2]

Code differential GNSS positioning

Horizontal	0.25 m + 1 ppm RMS
Vertical	0.50 m + 1 ppm RMS
SBAS differential positioning accuracy[3]	typically <5 m 3DRMS

Static GNSS surveying

High-Precision Static	
Horizontal	3 mm + 0.1 ppm RMS
Vertical	3.5 mm + 0.4 ppm RMS
Static and Fast Static	
Horizontal	3 mm + 0.5 ppm RMS
Vertical	5 mm + 0.5 ppm RMS

Postprocessed Kinematic (PPK) GNSS surveying

Horizontal	8 mm + 1 ppm RMS
Vertical	15 mm + 1 ppm RMS

Real Time Kinematic surveying

Single Baseline <30 km	
Horizontal	8 mm + 1 ppm RMS
Vertical	15 mm + 1 ppm RMS
Network RTK[4]	
Horizontal	8 mm + 0.5 ppm RMS
Vertical	15 mm + 0.5 ppm RMS
Initialization time[5]	typically <8 seconds
Initialization reliability[5]	typically >99.9%

HARDWARE

Physical

Dimensions	19 cm x 10.4 cm (7.5 in x 4.1 in), including connectors
Weight	1.52 kg (3.35 lb) with internal battery, internal radio and antenna 3.81 kg (8.40 lb) items above plus range pole, controller & internal radio
Operating Temperature[6]	–40 °C to +65 °C (–40 °F to +149 °F)
Storage Temperature	–40 °C to +75 °C (–40 °F to +167 °F)
Humidity	100%, condensing
Ingress Protection	IP67 dustproof, protected from temporary immersion to depth of 1 m (3.28 ft)
Shock and vibration	Tested and meets the following environmental standards:
Shock	Non-operating: Designed to survive a 2 m (6.6 ft) pole drop onto concrete. Operating: to 40 G, 10 msec, sawtooth
Vibration	MIL-STD-810F, FIG.514.5C-1

ELECTRICAL

- Power 10.5 V DC to 28 V DC external power input with over-voltage protection on Port 1 (7-pin Lemo)
- Rechargeable, removable 7.4 V, 2.8 Ah Lithium-ion smart battery
- Power consumption is <3.2 W in RTK rover mode with internal radio and Bluetooth® in use[7]
- Operating times on internal battery[8]:
  - 450 MHz receive only option ..... 5.0 hours
  - 450 MHz receive/transmit option (0.5 W) ..... 2.5 hours
  - Cellular receive option ..... 4.0 hours

COMMUNICATIONS AND DATA STORAGE

- Serial: 3-wire serial (7-pin Lemo) on Port 1; full RS-232 serial (Dsub 9 pin) on Port 2
- Radio Modem[1]: fully integrated, sealed 450 MHz wide band receiver/transmitter with frequency range of 403 MHz to 473 MHz, support of Trimble, Pacific Crest, and SATEL radio protocols:
  - Transmit power: 0.5 W
  - Range: 3–5 km typical / 10 km optimal[9]
- Cellular[1]: fully integrated, sealed internal GSM/GPRS/EDGE/UMTS/HSPA+ modem option. CSD (Circuit-Switched Data) and PSD (Packet-Switched Data) supported. Global Operation:
  - Penta-Band UMTS/HSPA+ (850/800, 900, 1900, and 2100 MHz)
  - Quad-Band GSM/CSD & GPRS/EDGE (850, 900, 1800, and 1900 MHz)
- Bluetooth: fully integrated, fully sealed 2.4 GHz communications port (Bluetooth)[10]
- External communication devices for corrections supported on Serial and Bluetooth ports
- Data storage: 56 MB internal memory; 960 hours of raw observables (approx. 1.4 MB/day), based on recording every 15 sec from an average of 14 satellites

Data Formats

- CMR, CMR+, CMRx, RTCM 2.1, RTCM 2.3, RTCM 3.0, RTCM 3.1, RTCM 3.2 inputs and outputs
- 23 NMEA outputs, GSOF, RT17 and RT27 outputs, supports BINEX and smoothed carrier

WebUI

- Offers simple configuration, operation, status, and data transfer
- Accessible via Serial and Bluetooth

Supported Trimble Controllers[1]

- Trimble TSC3, Trimble Slate, Trimble CU, Trimble Tablet Rugged PC

CERTIFICATIONS

IEC 60950-1 (Electrical Safety); FCC OET Bulletin 65 (RF Exposure Safety); FCC Part 15.105 (Class B), Part 15.247, Part 90; PTCRB (AT&T); Bluetooth SIG; IC ES-003 (Class B); Radio Equipment Directive 2014/53/EU. RoHS, WEEE; Australia & New Zealand RCM; Japan Radio and Telecom MIC

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1. Based on Trimble R8s GNSS receiver configuration. Radio frequency settings are country specific.
2. Precision and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. The specifications stated recommend the use of stable mounts in an open sky view, EMI and multipath clean environment, optimal GNSS constellation configurations, along with the use of survey practices that are generally accepted for performing the highest-order surveys for the applicable application including occupation times appropriate for baseline length. Baselines longer than 30 km require precise ephemeris and occupations up to 24 hours may be required to achieve the high precision static specification.
3. Depends on SBAS system performance.
4. Network RTK PPM values are referenced to the closest physical reference station.
5. May be affected by atmospheric conditions, signal multipath, obstructions and satellite geometry. Initialization reliability is continuously monitored to ensure highest quality.
6. Receiver will operate normally to –40 °C, internal batteries are rated to –20 °C, optional internal cellular modem operates to –40 °C.
7. Tracking GPS, GLONASS and SBAS satellites.
8. Varies with temperature and wireless data rate. When using a receiver and internal radio in the transmit mode, it is recommended that an external 6 Ah or higher battery is used. The specified operating times on an internal battery for the cellular receive option are in GSM CSD (Circuit-Switched Data) or GPRS PSD (Packet-Switched Data) mode.
9. Varies with terrain and operating conditions.
10. Bluetooth type approvals are country specific.

COLLIER
CONSULTING

Application of the Accelerated Impact Source (AIS) to High Resolution 2D/3D Seismic Imaging

I. Introduction and Review

Two of most common seismic energy sources used by the seismic industry for 2D and 3D seismic exploration surveys have been Vibroseis and explosives. A less common, but much improved alternative seismic energy source is the Accelerated Impact Source (AIS). All three seismic source types have been in use for more than fifty years worldwide, and GSS utilizes all three energy source types. However, in the past 10 years, significant improvements with the Accelerated Impact Source performance and durability make this source an excellent lower cost, more efficient, and practical alternative to Vibroseis and explosives. With the exception of special seismic surveys where the application of Vibroseis and dynamite are necessary, performance evaluations of AIS has shown it can produce data that is equivalent or superior to Vibroseis and dynamite.

Land seismic surveys that are located over challenging terrain and environmentally sensitive areas can make it difficult or impossible to consider using Vibroseis or explosives. In recent years we have experienced an increase with regard to environmental obstacles and property regulations that often prohibit the use of Vibroseis and explosives. Moreover, the cost associated with using these seismic energy sources is often becoming too expensive and/or risk burdened in many regions. For these reasons, there has been a resurgent interest during the last 5-10 years in the development of more powerful and durable alternative AIS systems that are comparatively equivalent or better than the performance of Vibroseis and explosive seismic energy sources.

Where applicable and economical, Collier Consulting uses both Vibroseis and explosive seismic sources. However, wherever environmental conditions, terrain constraints, infrastructure, and other hazardous risk factors limit the practical and economical use of Vibroseis and explosives CCI will often recommend using the AIS systems, especially where geologic target objectives are 10,000 feet or less. Since 2008, the AIS have been used successfully on numerous high resolution seismic surveys worldwide.

II. Accelerated Impact Source Development

Some of the more fundamental criteria for acquisition of good quality 2D or 3D data on any land seismic project depend largely on energy source performance. Vertical and horizontal seismic resolution, maximum depth of exploration, and to some extent seismic signal-to-noise; all have some dependency on performance of the seismic energy source. Regardless of whether we use Vibroseis, explosives, or the Accelerated Impact Source, there must be sufficient source signal frequency bandwidth and total energy output. Apart from the earth frequency filtering properties, which can vary significantly, source signal bandwidth governs the affective vertical resolution of the data. Horizontal resolution is also governed by source seismic bandwidth, but also the CDP spatial sampling. For many 2D and 3D seismic surveys the typical effective source bandwidth ranges from 10 Hz to 80 Hz. The higher frequency bandwidth component can reach or exceed 100 Hz on some shallow target seismic surveys (≤ 10,000 feet). With the exception of differences caused by near surface signal attenuation and ground decoupling effects, the Vibroseis source, explosives, and Accelerated Impact Source systems can all produce nearly the same source signal bandwidth attributes.

III. The Geophone Coupling Factor

Experiments have been conducted to examine the effects of geophone ground coupling on amplitude frequency bandwidth detection. These tests confirm that poor geophone ground coupling sensitivity and amplitude-frequency response can be severely degraded. With poor geophone coupling the detected seismic signal bandwidth is often significantly reduced, and is dominated by the lower frequency components. This is especially evident where geophones are deployed in poorly consolidated soils, sandy soils, and other loose organic soil materials. For 2D and 3D seismic surveys where geophones are even partially de- coupled, the attenuation of nearly all amplitude-frequency signals above 55 - 62 Hz can be severe. With good geophone coupling, seismic frequency bandwidth and amplitude response is significantly improved.

For several years, significant improvements have been achieved using high performance marsh type geophones (single element) on seismic surveys where soil consolidation conditions are poor. To avoid geophone de-coupling marsh geophones are planted in shallow auger pilot holes, in soil material that is at least semi consolidated and geophone coupling is assured. Often, the depth of the geophone pilot hole is only 4 to 6 inches below ground. The result of using this technique is detection and recording of the best possible broadband seismic data, which is especially critical for shallow exploration targets requiring high resolution seismic data.

IV. Accelerated Impact Source (AIS) Seismic Projects

The AIS systems, in various configurations, have been used with success on several non-test commercial production seismic surveys, and on some of these projects, demonstrated that the AIS seismic data was actually superior to previously surveys acquired using Vibroseis and explosives.

AIS Mexico Seismic Project

In 2008 and 2010, 2D reconnaissance seismic data was acquired to delineate a Jurassic Sand reservoir target in the Tampico, Mexico area. The Jurassic Sand overlies a fractured and faulted basement marine carbonate structure. Because the survey area was located in urban and commercial zones, Vibroseis and explosives were strictly prohibited. Moreover, environmental sensitivities also made it impossible to use Vibroseis and explosives. For the 2008 seismic program, a truck mounted AIS equipped with a 2700 lb source hammer was used. On the 2010 2D seismic program, the newer AF750 AIS mounted on a track vehicle was used. Figure 1 presents an end-to-end composite section for some of the interpreted 2008 2D seismic data. The top of section starts at 1.2 seconds TWT.

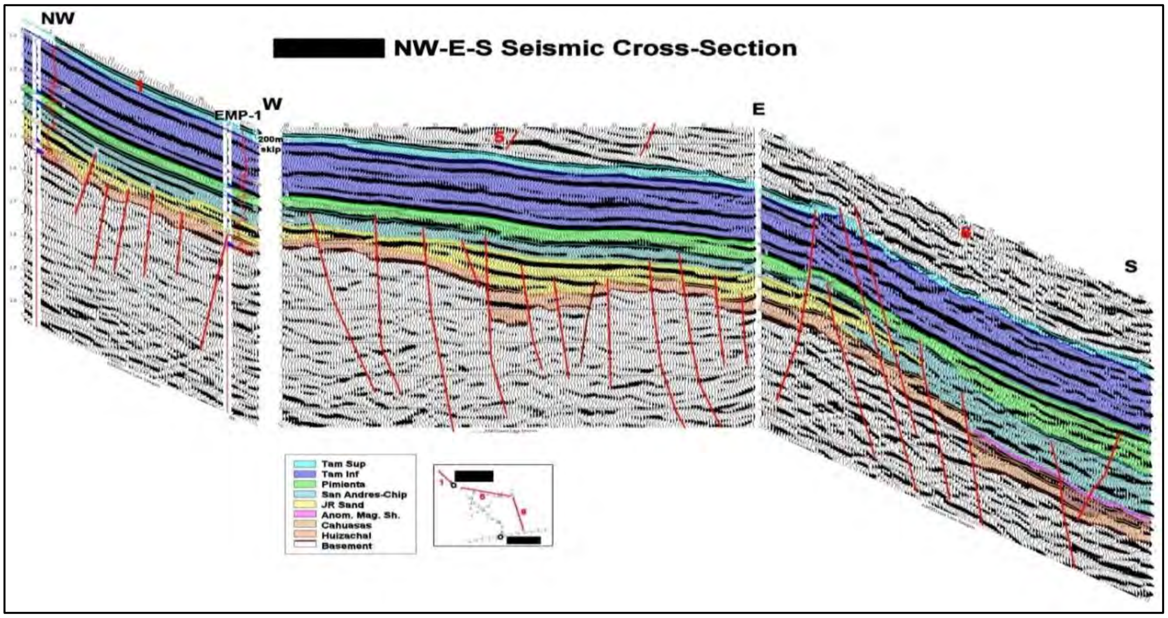

Figure 1. 2D seismic section from 2008 Mexico project. Data was acquired to depth of 3,000 meters using AIS system and cable-free GSX seismic system.

AF750 AIS for Mexico Projects

Advancements in source and cable-free seismic instruments technology were used on the Mexico project to improve the efficiency of the acquisition program and transmit field data to processors for quick turnaround processing. The newer AF750 AIS track mounted "impulsive source" was used to enable efficient, non-intrusive movement around areas congested with urban and commercial infrastructure, and over rough and wet terrain.

In some oil & gas exploration areas, we often discover that little or no seismic information is available for assessment and evaluation of target prospects. In addition, while it may be considered desirable to conduct a 3D seismic program over such areas, 3D surveys are not necessarily the most practical or cost effective approach since the exploration target zone characteristics and attributes may also be unknown. It is often possible that a high quality and less costly 2D / 2.5D seismic program will produce sufficient information for prospect evaluation and initial exploration drilling. For a 2.5D seismic imaging program, a 3D grid for the area of seismic coverage is created in processing, and all X, Y ,Z CDP points from each of the 2D lines is binned accordingly. With 2.5D binning of all 2D seismic grid data, it is possible to generate volume based horizontal and vertical composite depth sections and horizon contour maps to interpret potential exploration target attributes. As a reconnaissance tool, the 2.5D data volume can also be used to identify geo-target zones within the survey area that may require full 3D seismic imaging. Once a 3D zone is identified, in-fill data can be acquired according to a 3D patch source-receiver and azimuthal distribution parameters. For any full 3D zone of coverage, both the original 2.5D binned data and the in-fill data can be merged and re-cubed to generate zone specific 3D grids.

In 2015 a 2D / 2.5D seismic reconnaissance survey was conducted to help identify and isolate target prospects within a 70 square kilometer area. Figure 2a – Peru 2D Seismic Survey Grid & AIS). Because the survey area is located in the northern Peru, Sechura desert region, the Accelerated Impact Source (AIS) as the energy source, along with the Geospace GSX cable-free seismic system. Dynamite and Vibroseis could not be used because of regulatory concerns, and because Vibroseis suffers from severe base plate de-coupling over desert sands. Single element marsh geophones were planted in pilot holes and buried to improve ground coupling, and to eliminate "wind" noise.

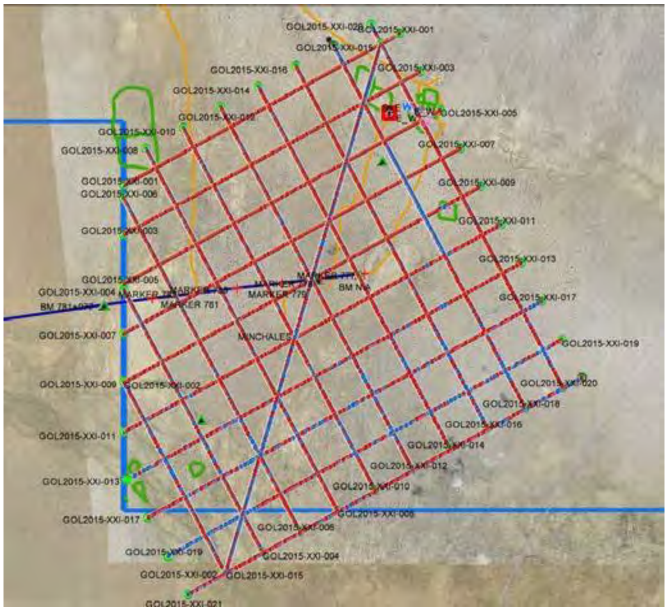

Figure 2a. Sechura Basin Peru 2D / 2.5D 210 km Seismic Program Grid

Geospace GSX Cable-Free Seismic System

CCI XLR8 2000 AIS System

The combined use of cable-free seismic system and Accelerated Impact Source technologies significantly increased field operations efficiency, and reduced project costs by

40% when compared to alternative seismic source and data acquisition instruments. In addition, the 2D / 2.5D method of seismic acquisition and processing produced exceptionally good results in terms of building a pseudo-3D seismic data volume that could be used to identify and characterize significant target prospect attributes to a depth of 2,000 meters (Figure 2b – Peru High Resolution 2D Seismic Section).

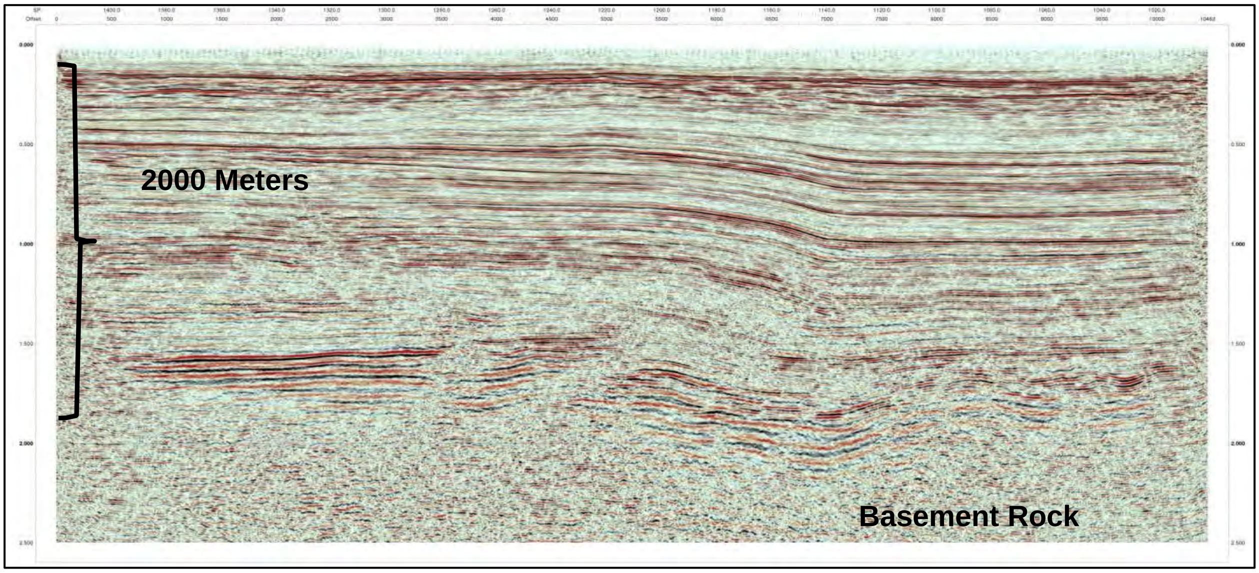

Figure 2b. Sechura Basin 6 km high-resolution 2D seismic section from data acquired using the XLR8 2000 and GSX seismic system. Bandwidth is 12 Hz to 104 Hz

V. Conclusions and Comments

Given any exploration project, the selection of any of the three seismic energy sources should be based on a thorough understanding of the geologic target objectives, the desired resolution, environmental and near surface soil conditions, terrain and climate conditions, and other factors that will affect source operation and data quality. In the last five years we have experienced a renewed interest with the use of Accelerated Impact Source technology as an alternative to Vibroseis and explosives. The latest AIS designs have been successfully field proven in terms of reliability, durability, and overall performance when compared to Vibroseis and explosives.

In some of the more difficult and environmentally sensitive areas, and where exploration target objectives are fairly shallow (≤ 10,000 ft), the AIS can often be the best selection of energy sources. It is becoming increasingly costly, impractical, and too difficult in many parts of the world to use Vibroseis or explosives. Sometimes we can combine energy source types, such as dynamite and AIS on seismic projects that are located in survey areas that have limited access zones for using explosives. At CCI we do employ the use of AIS, Vibroseis, and explosives. However, we will recommend an energy source type based on a number of criteria, all of which must benefit field seismic operations costs, environmental friendliness, local regulations, and overall data quality expected. The combination of cable-free seismic recording instruments and the AIS can provide added flexibility with survey designs and increased density of CDP coverage for 2D and 3D surveys. For even greater flexibility and economy, the 2D / 2.5D reconnaissance data acquisition and processing technique can be a more suitable seismic exploration alternative, especially over areas where we may only need to improve the continuity of seismic horizon and attributes definition, geo-structures characterization, obtain a better focus on prospect zones that may eventually require full 3D seismic imaging. For exploration projects where guidance for delineation of target drill locations is required, the 2D / 2.5D may be all that is needed.

Appendix 3 – Comment & Questions – Author Response Section

I. General Comments

From: Jon Arthur, Ph.D., P.G.
Director and State Geologist
Florida Geologic Survey
Florida Department of Environmental Protection

Comments

1. "I have completed reading the report and it looks solid. Two of my staff have reviewed it as well. The report is a good first pass at a "proof of concept" for using seismic to delineate subsurface structures and the boulder zone (BZ). The preliminary results (e.g., karst and other deformation) indeed raise concerns regarding potential fluid movement".

2. "With the BZ being a target, we expected the interpreted seismic sections to extend deeper, rather than being truncated just below the BZ. Being able to see another thousand feet deeper would allow better comparison of deeper contrasting(?) seismic facies. Similarly, regarding processing, to what extent might artifacts due to the migration step influence the interpretation? Is it possible that deeper parts of the section may reflect downward propagation of distortion"?

3. "I note that the interpreted fractures/faults are all symbolized the same. I suspect they are not all identified at the same level of confidence. Perhaps symbology reflecting "highly likely" faults/fractures relative to those less likely is possible? Solid lines imply a certain level of confidence that may or may not be intended by report authors".

4. "In cases, wells used for correlation are several miles off the seismic line. I realize this is a challenge in a data-poor region. A discussion of vertical resolution/uncertainty stemming from the distant control would be a good addition. I did see the impressive depth-error value. I am uncertain how this ties into my old-fashioned way of thinking about "observed versus expected" in context of ground-truthing to borehole lithology".

Author Response

Comment #1. The "Proof of Concept" was to confirm that using the Accelerated Impact Source, the GSX nodal seismic system, and the data acquisition techniques, broadband high resolution 2D and 3D seismic data could achieve the test objectives. The seismic data bandwidth was 12 Hz to 128 Hz and produced sufficient resolution to delineate numerous horizons and signal attributes from top of the Hawthorn Group to the "Boulder Zone". The preliminary interpretations of karst and other related deformation structures do indeed give rise for concern regarding fluid movement, but also can serve as a general guide to identifying future drilling locations. Although currently beyond the scope of work for this seismic test, additional seismic attributes processing should be performed to extract more information (Velocity versus Porosity, Curvature Attributes, Instantaneous Phase, Fracture Analysis & Mapping).

Comment #2.

Although all seismic data was recorded with a 3 second record length, the seismic test was limited to the top of Oldsmar formation and the "Boulder Zone" (2700 ft to 3500 ft objective). In the time domain 800 ms is the maximum depth of investigation for the SFWMD test project. However, it may be possible to use the test data for imaging deeper into the Cedar Keys formation using Micro-Focusing and Diffraction Imaging processing techniques. Based on preliminary interpretations of faults/fracture zones and vertical deformation, there is reason to believe that the deeper seismic information may provide some additional insight and understanding about the origins of shallow (upper 3000 feet) fracture systems and apparent subsidence/vertical deformations. We believe that there is need in some areas to obtain seismic data to at least 5000 feet…..or more. The 3D and 2D seismic survey design is limited with respect to maximum source-receiver offsets. To achieve seismic imaging to greater depth may require deployment of active seismic spreads with lengths up to 2.0 miles.

The migration step used seismic tomography analysis to derive velocity fields in the depth domain for migration. Comparison between migrated and un-migrated sections showed little or no distortion or artifacts. Principal Component Analysis was also performed to suppress some of the noise artifacts. However, diffractions do still give rise to artifacts that can affect the migration. Additional processing could include Diffraction Mapping and/or Multi-Focus processing.

Comment #3

With the exception of Spoil Management Site 3D survey and the Lake Regions 2D seismic program, acquisition of all other 2D seismic data used the swath approach; layout of two parallel receiver lines with centered parallel source line. This method generates two CDP seismic lines. Interpretation looks for similarities and dis-similarities to guide interpretation of faults and fracture zones. The level of confidence with respect to delineation of fractures and faults is fairly good. 3D surveys, however, do improve accuracy with respect to identifying stratigraphic and structural features.

Comment #4

The OUA well was about 0.5 miles from seismic lines 5001 and 5002. The LRRO-IW1 was only a few hundred yards from State Road 80 Segment 1. The Labbelle-IW1 well was located closest to Spoil Management 3D seismic survey site, but exceeded 10 miles. On review of all geophysical well log data we discovered that log runs were conducted in separate runs, and at different sample rates for the sonic logs. Extensive work was performed to merge the segments, and to normalize the sonic log sampling rates. To the extent possible, sonic, resistivity and gamma ray data were used to develop synthetic seismic traces, some of which were correlated with video logs and coring logs.

For correlation of synthetic seismograms with the seismic data, final velocity analysis results from all of the test sites seismic data was compared and found to be fairly uniform and consistent with respect to formation. Synthetic seismograph horizon picks we also compared to the velocity derived horizon depths. When plotting synthetic picks with seismic horizons in the time and depth domain, the fit was fairly good regionally and we were able to establish reasonable ties between the seismic data depth scale and the synthetic seismogram time and depth scale. There are small site to site differences and the ties could be further refined in the future. In addition, it might be prudent to incorporate other well data to develop a more accurate geologic formation and seismic reflection-velocity model.

APPENDIX E:
NUTRIENT REMOVAL AND UPTAKE BY NATIVE PLANKTONIC AND BIOFILM BACTERIAL COMMUNITIES IN AN ANAEROBIC AQUIFER

frontiers in Microbiology

ORIGINAL RESEARCH
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Nutrient Removal and Uptake by Native Planktonic and Biofilm Bacterial Communities in an Anaerobic Aquifer

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Managed aquifer recharge (MAR) offers a collection of water storage and storage options that have been used by resource managers to mitigate the reduced availability of fresh water. One of these technologies is aquifer storage and recovery (ASR), where surface water is treated then recharged into a storage zone within an existing aquifer for later recovery and discharge into a body of water. During the storage phase of ASR, nutrient concentrations in the recharge water have been shown to decrease due, presumably via the uptake by the native aquifer microbial community. In this study, the native microbial community in an anaerobic carbonate aquifer zone targeted for ASR storage was segregated into planktonic and biofilm communities then challenged with NO_3-N, PO_4-P, and acetate as dissolved organic carbon (DOC) to determine their respective removal and uptake rates. The planktonic community removed NO_3-N at a rate of 0.059 mg $L^{-1}d^{-1}$, PO_4-P at 5.73×10^{-8}–1.03×10^{-7} mg $L^{-1}d^{-1}$ and DOC at 0.015–0.244 mg $L^{-1}d^{-1}$. The biofilm community was significantly more proficient, removing NO_3-N at 0.116 mg $L^{-1}d^{-1}$ (1.6–9.0 $\mu g\ m^{-2}d^{-1}$), PO_4-P at 4.20–5.91×10^{-5} mg $L^{-1}d^{-1}$ (2.47–9.88 ng $m^{-2}d^{-1}$) and DOC at 0.301–0.696 mg $L^{-1}d^{-1}$ (29.0–71.0 $\mu g\ m^{-2}d^{-1}$). Additionally, the PO_4-P sorption rate onto the carbonate aquifer matrix ranged from 1.64×10^{-7} to 9.25×10^{-7} mg PO_4-P m^{-2} day^{-1}. These rates were applied to field data collected at an ASR facility in central Florida and from the same aquifer storage zone from which the biofilm communities were grown. With only 10% of the available surface area within the storage zone being colonized by biofilms, typical concentrations of NO_3-N, PO4-P, and DOC in the recharged filtered surface waters would be reduced to below detection limits, and by 81.4 and 91.1%, respectively, during a 150 days storage period.

Keywords: nutrient uptake, biofilms, phosphorus, nitrogen, carbon, groundwater, managed aquifer recharge, aquifer storage and recovery

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INTRODUCTION

The availability and quality of freshwater is becoming a global issue as sources are impacted by not only natural variability in precipitation but also the expansion of human habitation into wetlands and increases in agricultural, domestic and industrial demands (Koutroulis et al., 2019). One of the options available to water resource managers to recover and store excess freshwater until it's needed is managed aquifer recharge (MAR) (Bekele et al., 2018). MAR is a collective term for technologies that inject a variety of treated surface and process waters into aquifer zones for later recovery

(Bekele et al., 2018). One of these technologies is aquifer storage and recovery (ASR) (Pyne, 2005; Bekele et al., 2018). As part of the ASR optimization process a series of cycle tests are performed where treated source water is recharged into the aquifer storage zone, allowed to stay in the storage zone for a predetermined length of time and then recovered and discharged at the surface into a body of water. During the storage phase of the cycle tests its common for concentrations of constituents in the recharge water (e.g., bacteria, metals, nutrients, etc.) to be significantly reduced in the recovered water (Mirecki, 2004; Patterson et al., 2010; Mirecki et al., 2013; Vanderzalm et al., 2013, 2018; Page et al., 2017). For example, the concentrations of NO_x-N, PO_4-P and TOC in recharged surface water were reduced during the storage phase in an anaerobic aquifer by up to 100.0, 81.4, and 91.1%, respectively (Mirecki, 2013) and by 100.0, 49.4, and 54.1% in recharged stormwater stored in an anoxic aquifer (Vanderzalm et al., 2018). These reduction rates are derived from net removal data of the respective constituents after storage, regardless of the storage time interval. Additionally, biogeochemical processes are assumed to be the dominant, with geochemical reactions being a minor, contributor to most of the removal rates during the storage phase.

The biogeochemical or microbial processes responsible for the reduction in constituents in the recharge water are initially being performed by bacteria native to the aquifer storage zone with the diversity and possibly physiological function being altered after repeated recharge-storage-recovery cycles (Ginige et al., 2013). There is a consensus the vast majority of these processes are associated with the biofilm communities, in contrast to the planktonic communities, in the storage zones. This physiological dominance is due to biofilms having been shown to always contain relatively greater numbers of bacterial cells than in the planktonic phase of the same system (Whitman et al., 1998). Biofilm associated cells in groundwater ecosystems (1.4×10^{30}) have been estimated to exceed that of the planktonic cells (5.0×10^{27}), on a global basis, by several orders of magnitude (McMahon and Parnell, 2014; Flemming and Wuertz, 2019).

In this study, the native microbial community in an anaerobic and reduced zone of the Upper Floridan Aquifer (UFA) (Miller, 1997; Morrissey et al., 2010), that has been targeted as an ASR storage zone, was segregated into planktonic and biofilm communities. These communities were then separately challenged with concentrations of NO_3-N, PO_4-P and dissolved organic carbon (DOC) commonly found in ASR source surface water in south-central Florida. Removal rates for NO_3-N and uptake rates for PO_4-P and DOC were derived from data collected under native groundwater conditions and represent baseline removal and uptake rates for the native microbial planktonic and biofilm communities living in this zone of the UFA.

MATERIALS AND METHODS

Sample Site Location and Hydrogeology

The artesian groundwater source well (27° 09′ 17.3″; 80° 52′ 27.4″ W) is located within the Kissimmee River ASR (KRASR) facility located near the confluence of the Kissimmee River and Lake Okeechobee (Mirecki, 2013; Mirecki et al., 2013). This well is 0.254 m diameter steel cased to 174.3 mbls with a single screened collection zone between 174.3 and 268.2 mbls. The collection zone is within the artesian Upper Floridan Aquifer (UFA) that is characterized as a thick sequence of interlayered marine calcareous and dolomitic limestones of Eocene and Oligocene age, overlain by a confining unit consisting of approximately 122 m of Hawthorn Group interlayered clays, silts, and fine sands (Scott, 1988). The lower confining layer consists of 122–152 m of dolomitic limestone, dolomite, and dolostone (Golder Associates, 2007; Reese and Richardson, 2007; Waldron and Horvath, 2010). These confining units isolate this zone of the UFA from other groundwater sources positioned above or below (Miller, 1997). Additionally, the collection zone is not impacted by meteoric or surface water as the isotopic age of the groundwater in this region of UFA has been estimated at approximately 2.5×10^4 years since it was first recharged into the subsurface (Plummer and Sprinkle, 2001). The permeability within this zone of the UFA is not uniform as 92% of the total flow occurs in two depth intervals at 166.4–185.6 mbls (80%) and 268.2–283.5 mbls (12%). The storage zone is positioned between these two intervals at 166.0–261.0 mbls. The recharged water within this storage zone is nominally-to-unaffected (i.e., not diluted) during the storage phase based on chloride-based conservative mixing modeling (Mirecki et al., 2013). An aquifer performance test on the collective aquifer zone accessed during this study produced a transmissivity of 3,416 $m^2\ d^{-1}$ (Reese and Richardson, 2007).

Sample Container Preparation

All reactors, glass and plasticware, fittings and closures used in these experiments were first washed with laboratory detergent, rinsed in tap water, rinsed in reagent grade water, soaked overnight in a 10% (v/v) HCl solution, rinsed three times with reagent grade water and allowed to air dry. Once dry, all glassware and closures were sterilized by autoclaving then transferred to an anaerobic chamber with a $N_2/CO_2/H_2$ (85%:10%:5%) atmosphere and allowed to degas for a minimum of 2 days before use. Prior to removal from the anaerobic chamber for transport to the research site, all fittings and closures were secured on the respective pieces of glassware and polypropylene containers then placed in gas tight containers for transport.

Groundwater Chemistry

The general geochemistry and nutrient data (mean ± SD) for the zone of the UFA accessed during this study were taken from four wells located on the KRASR facility property previously reported (Mirecki, 2013) (**Table 1**). Additionally, the NO_3-N and dissolved organic carbon (DOC) concentrations used in the calculations of the removal rates during storage were taken from the KRASR pilot study cycle test data (i.e., an ASR cycle is the recharge, storage and recovery of treated surface water into and from the aquifer zone) (Mirecki, 2013). The PO_4-P concentration data were extracted from a figure in the KRASR pilot study

TABLE 1 | Upper Floridan Aquifer geochemical data.

Parameter	Units	Mean (±SD)
Temperature	°C	25.56 ± 0.27
pH		7.89 ± 0.21
ORP	mV	−258.4 ± 30.75
Specific conductance	μS cm^{-1}	1269.8 ± 156.32
Turbidity	NTU	0.45 ± 0.36
Color	PCU	5.85 ± 1.2
Total dissolved solids	mg L^{-1}	727.8 ± 110
Total alkalinity (as $CaCO_3$)	mg L^{-1}	85.2 ± 4.58
Aluminum	μg L^{-1}	5.65 ± 7.99
Barium	μg L^{-1}	29.02 ± 3.16
Boron	μg L^{-1}	82 ± 18.38
Bromide	mg L^{-1}	660 ± 138.2
Calcium	mg L^{-1}	46.42 ± 4.11
Chloride	mg L^{-1}	232.6 ± 50.96
Copper	mg L^{-1}	1.38 ± 0.66
Fluoride	mg L^{-1}	0.53 ± 0.04
Iron	μg L^{-1}	90.17 ± 77.92
Magnesium	mg L^{-1}	36.52 ± 2.72
Manganese	μg L^{-1}	4.45 ± 1.93
Potassium	mg L^{-1}	7.3 ± 1.52
Silica	mg L^{-1}	8.2 ± 5.11
Sodium	mg L^{-1}	137.14 ± 37.33
Sulfate	mg L^{-1}	184.6 ± 12.66
Sulfide	mg L^{-1}	1.07 ± 0.22
Zinc	μg L^{-1}	9.72 ± 11.42
NO_2-N	mg L^{-1}	<0.01[a]
NO_3-N	mg L^{-1}	<0.03[a]
NH_3-N	mg L^{-1}	0.22
Total PO_4-P	mg L^{-1}	0.03
Ortho PO_4-P	mg L^{-1}	<0.01[a]
Total organic carbon	mg L^{-1}	1.7
Dissolved organic carbon	mg L^{-1}	1.40 ± 0.28

[a] *Denotes the analytical detection limit.*

report showing the trends in phosphorus concentrations during the recharge and recovery phases of a cycle test using WebPlotDigitizer[1].

Groundwater Sample Collection

Prior to sampling, the groundwater well was allowed to flush through a 10.2 cm diameter valve to waste until a minimum of three well casing volumes had been removed. The large volume valve was closed and a 2.0 cm diameter, stainless steel valve with a tubing fitting was opened at a laminar flow rate and allowed to flush to waste for several minutes before attaching a sterilized 10.0 L stainless steel pressure vessel (MilliporeSigma, Burlington, MA, United States), fitted with valves and hose connectors on the inflow and outflow ports. Groundwater was allowed to flow through the pressure vessel's inflow and outflow ports to waste for a minimum of four volumes before sealing the groundwater sample from the atmosphere by turning both outflow and inflow valves off while ensuring there was no head space in the vessel. Collecting sub-samples of the collected groundwater was accomplished by pressurizing the vessel with either Ar or N_2 gas, depending on the experimental design, while having all bench top microcosms under constant gas flow of the respective gases when dispensing sub-samples.

Core Material for Biofilm Growth Substrate

Core material from the same well at the depth of the groundwater collection zone was acquired from the core archives maintained at the Florida Geologic Survey[2]. For the nitrogen species biofilm uptake experiments, the core material was cut into irregular shaped coupons with two smooth surfaces and consistent thickness that would fit into a biofilm microcosm as described below. All core coupons for the phosphorus and carbon biofilm uptake experiments were cut in dimensions of 1.21 cm (width) × 0.64 cm (thickness) × 2.54 cm (length). These coupons were sterilized and processed as described above. All coupons were loaded into the respective biofilm growth reactors, as described below, while still in the anaerobic chamber and prior to removal for transport to the research site. All coupons were sterilized by autoclaving (121°C, 15 psi, 15 min) three times, then placed in an anaerobic chamber with a $N_2/CO_2/H_2$ (85%:10%:5%) atmosphere and allowed to degas for a minimum of 2 days.

Currently, there are no data on surface areas within the pore or channel networks of this or any other zone of the Floridan Aquifer System. However, the surface area within the core coupon upon which the biofilm would grow were estimated based upon a range of surface area-to-mass ratios for carbonate rock very similar to that in the UFA (Lai et al., 2015) and known specific densities for carbonate rock from the UFA in south Florida (Sunderland et al., 2011). The surface area-to-mass ratios ranged from 0.8–4.3 $m^2\ g^{-1}$, and the specific gravity values were bimodal ranging from 2.70–2.79 and 2.81–2.83 g cm^{-3}. Using the lower and upper limit specific gravity values to estimate the range of surface areas for biofilm growth within the core coupons, the core segments used in the NO_3-N microcosm ranged from 12.85–72.37 m^2 and 4.25–23.92 m^2 for the coupons in the PO_4-P and carbon microcosms.

Biofilm Growth Reactors

The biofilm growth reactors for the nitrogen species uptake experiments were sterile borosilicate glass chromatography columns (2.5 cm × 30.0 cm). The core coupons were placed into the reactors in irregular orientations before being sealed on both ends with caps fitted with PTFE values with push-tube fittings. The reactors for the phosphorus and carbon uptake experiments were sterile 2.5 cm × 30.5 cm PTFE pipes. The core coupons were placed into these reactors end-to-end and in the same orientation before being sealed with PTFE values with push-tube fittings.

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[1] https://automeris.io/WebPlotDigitizer

[2] https://floridadep.gov/fgs/geologic-collections/content/core-and-cuttings-repository

Biofilm Growth System

A two chamber system was designed to allow groundwater to flow over the biofilm growth reactors that contain the core coupons, at close to *in situ* rates, while insulating the coupons from surface temperatures and exposure to air by groundwater flowing outside the reactors at high rates (**Figure 1**). High volume and flow rates though an insulated 340 L HDPE container (EW0632288; Cole-Parmer, Vernon Hills, IL, United States) were maintained through a black PTFE (1.27 cm OD) tubing connected to a stainless steel valved fitting on the well head and the other end slipped into a water tight fitting located at the bottom of the outside wall on one end of the container. Groundwater discharged from the container through a 5.1 cm diameter opening located at the top container in the wall opposite the inflow tubing.

Low groundwater volume and flow rates for biofilm growth were established via a 3-way valve that had been inserted into the high flow volume PTFE tube prior to entering the 340 L container. A low flow control valve (MR3000; Brooks Instrument, Hatfield, PA, United States) was connected to the 3-way valve via black PFTE tubing (0.47 cm OD) with the tubing from the out flow side of the flow control valve traversing the wall of the container through a water tight fitting and into one end a biofilm growth reactor via the push-tube fitting. Multiple biofilm growth chambers were connected in series using 5.0 cm pieces of the same tubing. A longer piece of the tubing was connected to the last biofilm growth chamber and though a water tight fitting located next to the groundwater discharge opening for the high volume flow. All valves on the biofilm growth reactors were then opened to initiate groundwater flow across the core coupons. The groundwater flow rate through the larger container was set at approximately 10.0 L min^{-1}, while the flow rate through the biofilm growth reactors was 150.0 mL min^{-1}. All reactors were left in place for approximately 10 months before removing for use in the biofilm microbial community uptake experiments described below.

Biofilm Coupon Collection

The valves on both ends of the biofilm growth reactors recovered for an experiment were closed, disconnected from the tubing

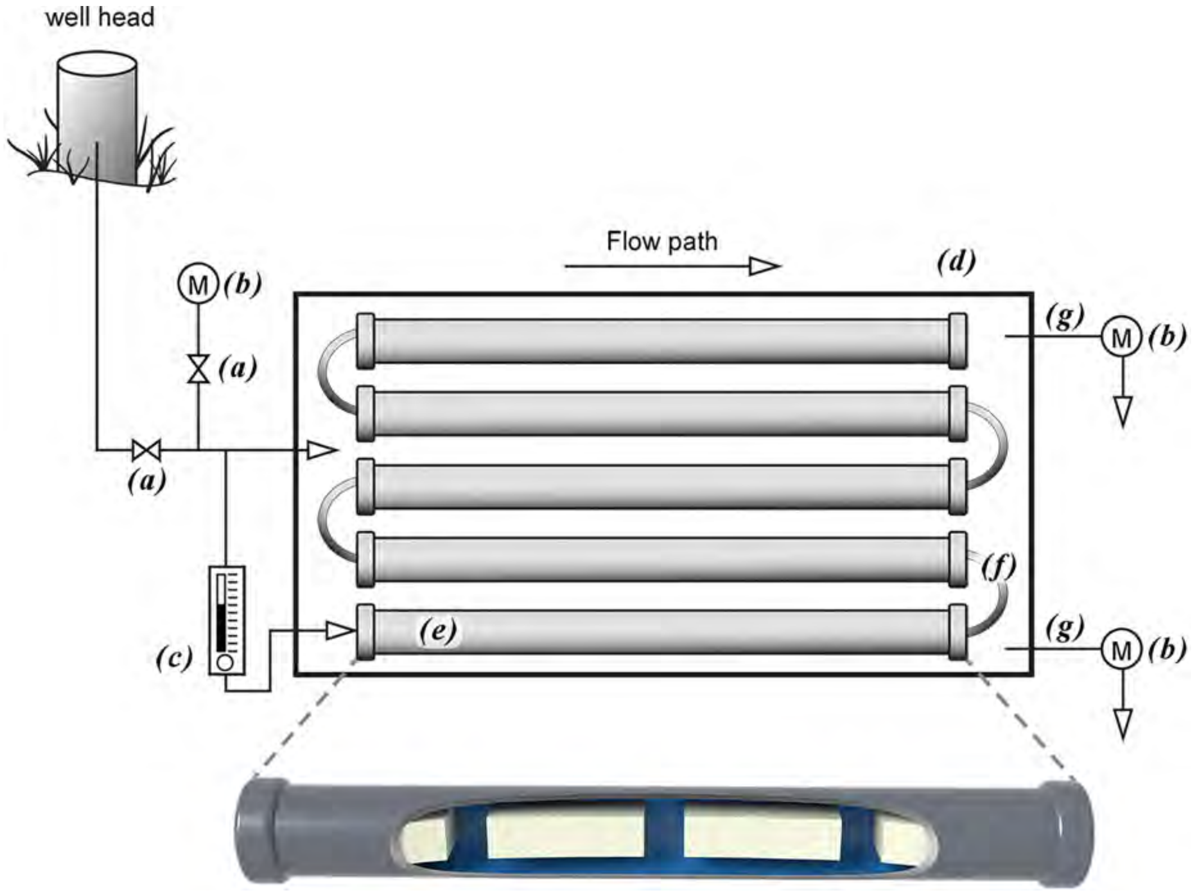

FIGURE 1 | Above ground mesocosm with biofilm growth reactors. Groundwater from the well head is directly transferred to the mesocosm via PTFE tubing into a high flow rate control valve **(a)** that diverts groundwater into a flow cell containing a water quality measurement meter **(b)** and a low flow control valve **(c)**. Groundwater passing through the high flow control valve fills the outside chamber **(d)** while the low flow rate groundwater flows through a series of biofilm growth reactors that contain aquifer core coupons on which the biofilms grow **(e)** and connected by PTFE tubing **(f)**. Both flow systems discharge through PTFE tubing **(g)** into flow cells containing water quality measurement meters **(b)**.

and immediately transferred to and submerged in a container of groundwater collected at the well head. The remaining growth reactors were left in series and maintained groundwater flow by reconnecting the last biofilm growth reactor in the series to the outflow tubing.

Once in the laboratory the biofilm growth reactors were removed from the groundwater container, the valves on either end opened, then connected to a gas source to maintain an anaerobic atmosphere around the biofilms. The groundwater in the reactor was gently drained while under constant Ar-gas flow for the nitrogen species uptake experiments and N_2-gas for the phosphorus and carbon uptake experiments. Biofilm coupons were then aseptically retrieved with sterile forceps, gently dipped in filter sterilized groundwater to remove non-attached cells, then transferred to each of the biofilm benchtop microcosms. All containers and benchtop areas used in these procedures were aggressively flushed with Ar-gas flow for the nitrogen species removal experiments and N_2-gas for the phosphorus and carbon uptake experiments.

Nitrogen Removal by Planktonic and Biofilm Microbial Communities

A benchtop microcosm (500 mL borosilicate glass bottles), with gray bromobutyl rubber septa plugs (Chemglass Life Sciences), was flushed with Ar-gas prior to transferring groundwater from the pressurized sample vessel. Once adequately flushed, 450 mL of groundwater was transferred to the microcosm, then dosed with a standardized stock solution of KNO_3 (12.50 mM; 1.26 g/L) to provide a final concentration of 25.0 μM (0.350 mg/L) NO_3-N. A 50 mL sub-sample was immediately collected for the time zero sample before sealing and gently mixing the microcosm and incubating up-side-down at 25–27°C in the dark.

At each time point, approximately 50.0 mL of Ar-gas was injected into the headspace of the microcosm using a gas tight syringe, then approximately 40.0 mL of groundwater was removed using a 19G needle attached to a 60 mL syringe. Approximately two 20 mL volumes were filtered through a 0.22 μm pore size syringe filter into separate 35 mL HDPE bottles and immediately frozen at −80°C, then stored at −20°C until analysis.

All time point samples were analyzed for NO_2-N, NO_3-N and NH_4-N using a Seal Analytical Auto Analyzer 3 employing the protocols of Gordon et al. (2000). Minor modifications of the ammonium technique were required to extend the dynamic range to 30 μM for anoxic and other high ammonium waters by reducing the respective flow rates for the nitroprusside (50.0 μL min^{-1}), hypochlorite (50.0 μL min^{-1}), phenolate (50.0 μL min^{-1}), citrate (320.0 μL min^{-1}), sample (600.0 μL min^{-1}), air bubble (160.0 μL min^{-1}), and waste draw (1200.0 μL min^{-1}).

The benchtop microcosms for nitrogen species uptake by biofilm microbial communities were set up as described for the planktonic communities, with the exception that the groundwater was filter sterilized (0.22 μm pore size filtration) under Ar-gas flow before adding to each of the microcosms. Once each microcosm had been dosed with the nitrogen species stock solution as described for the planktonic microbial community biofilm coupons were aseptically removed under Ar-gas flow and transferred to the microcosms. Negative controls for the biofilm microbial community uptake microcosms were a set of biofilm coupons that had been immersed in formalin for 15 min before transferring to a 50 mL tube containing filter sterilized and dosed groundwater from the NO_3 or NH_4 benchtop microcosms. These samples were incubated with the benchtop microcosms and processed with the samples collected at the last time point. Sample collection and processing were the same as described for the planktonic microbial community microcosms.

Following the completion of the biofilm uptake experiments, the coupons were air dried before calculating the coupon surface area within each benchtop microcosm. Coupon surface areas were estimated by first tracing the outlines of the flat surfaces and edges of each coupon onto paper and cutting those outlined areas out as individual pieces. The weight of a 2.5 cm^2 piece of the same paper was weighed to provide a surface area-to-weight conversion factor. This conversion factor was then used to convert the total weights of the coupon cutouts into surface areas.

Phosphorus Uptake by Planktonic and Biofilm Microbial Communities

The benchtop microcosms (250 mL polycarbonate screw cap flask) were kept under constant N_2-gas flow and filled with 110 mL of groundwater from the pressure vessel as previously described. To this volume the following were added (final concentration): cold potassium phosphate (1.32 nM; 0.125 μg L^{-1} as PO_4; 0.44 nM; 0.042 μg L^{-1} as P), $^{32}PO_4$ [0.132 nM; 12.50 ng L^{-1} PO_4; 0.044 nM; 4.20 ng L^{-1} as P; 286.6 Ci mg^{-1} (ARC Inc., St. Louis, MO, United States)] for an approximate scintillation count of 2×10^6 CPM 20 mL^{-1} sample and sodium acetate (0.831 mM, 68.17 mg L^{-1}; 0.333 mM, 4.00 mg L^{-1} as C). Acetate was added based on preliminary experiments that had shown no measurable uptake of ^{32}P after up to 6.0 h incubation at 25–27°C, without the addition of acetate. Acetate was chosen as this carbon source is most commonly found in anaerobic and reduced geochemical groundwater conditions similar to those in this zone of the UFA.

The suspension was gently mixed, and 10.0 mL immediately removed and transferred to a 15 mL polypropylene tube containing 500.0 μL of formalin (i.e., killed sample). The remaining volume in the microcosm was under N_2-gas flow for the entirety of the experiment. At each time point 20.0 mL were removed from the microcosm, then 10.0 mL transferred to two 15 mL tubes as replicates. The entire volume of each replicate was filtered through a vacuum filtration system which captured the microbial biomass on a membrane filter (mixed cellulose ester, 25 mm, 0.22 μm pore size) (MilliporeSigma, Burlington, MA, United States) and the filtrate into a separate 15 mL tube.

After removing the filtrate collection tubes from the filtration system, the filters were rinsed three times with filter sterilized source groundwater, transferred to scintillation vials, allowed to air dry, then 5.0 mL of Ultima Gold (PerkinElmer, Waltham, MA, United States) scintillation cocktail added to each. A 1.0 mL sub-sample of each replicate's filtrate was transferred to scintillation vials and 5.0 mL of the same scintillation cocktail was added to each. All samples were allowed to set at room temperature in the dark for 6–8 h to stabilize, then counted on a scintillation counter.

Groundwater (120.0 mL) of groundwater from the pressure vessel was filter sterilized (0.22 μm pore size) into a sterile and degassed flask under constant N_2-gas flow, then dosed with cold potassium phosphate, sodium acetate and $^{32}PO_4$ to final concentrations and activities described for the planktonic microbial community experiments. A set of 12 microcosms (sterile and degassed 50 mL polypropylene tubes) each received 10.0 mL of the filter sterilized and dosed groundwater while under constant N_2-gas flow.

Biofilm growth reactors with the smaller, regularly cut coupons were recovered, transported and processed for delivery biofilm coupons as described for the nitrogen species uptake experiments. Each of 10 microcosms received a single biofilm coupon 2.5 cm in length, with one microcosm being immediately processed as described below for the time zero time point sample. The remaining microcosms were incubated upright at 25–27°C and in the dark.

Two control microcosms were set up for the $^{32}PO_4$ uptake experiments: dosed filtered sterilized groundwater with no biofilm coupon and dosed filter sterilized groundwater into which a biofilm core coupon was transferred that had been inactivated (i.e., killed sample) by immersion in 10.0 mL of filter sterilized groundwater supplemented with 200 μL for 15 min before transfer to the microcosm. The two control experiments were incubated as described for the other tubes and collected and processed with the last time point samples.

For each time point, including time zero, one microcosm was recovered and processed for collection of biofilm biomass which had become suspended into the sterilized groundwater onto a membrane filter with the collection of the filtrate into a separate tube as described for the planktonic microbial community microcosms. The remaining biofilm coupon was transferred to into a scintillation vial. The membrane filters and filtrates were processed as described for the planktonic microbial community samples. Each scintillation vial containing a membrane filter or 1.0 mL filtrate sub-sample received 5.0 mL of Ultima Gold scintillation fluid. The vials containing biofilm coupons received 10.0 mL Ultima Gold. All scintillation vials were set at room temperature in the dark for 6–8 h to stabilize before recording the respective activities on a scintillation counter. The surface area of each biofilm coupon was manually measured after the ^{32}P activity had decreased to a safe level.

Carbon Uptake by Planktonic and Biofilm Microbial Communities

Carbon uptake is the sum of carbon assimilation into biomass and mineralization (i.e., respiration) to CO_2 and/or CH_4. Uptake rates can be determined using a mass balance approach with ^{14}C-labeled carbon substrates (i.e., acetate) and measuring the ^{14}C incorporated into biomass (assimilation), respired CO_2 and/or CH_4 and the unincorporated ^{14}C-labeled substrate remaining in the sample (Wright and Burnison, 1979).

A volume (200.0 mL) of groundwater was transferred from the pressure vessel as previously described into a sterile and degassed 250 mL polycarbonate flask while under N_2-gas flow. Sodium acetate (0.831 mM, 68.17 mg L^{-1}; 0.333 mM, 4.00 mg L^{-1} as C) and [2-^{14}C]-acetate (sodium salt) (23.8 μM, 1.95 mg L^{-1}; 9.54 μM, 0.11 mg L^{-1} as carbon) [58.5 mCi $mmol^{-1}$) (ARC Inc., St. Louis, MO, United States)] for an approximate 2.5×10^6 to 3.0×10^6 CPM 10.0 mL^{-1} and gently mixed. Immediately, 10.0 mL sub-samples were transferred to 25 mL sterile and degassed serum bottles (n = 18) under continuous N_2-gas flow, sealed with butyl rubber plugs and aluminum crimp closures. Two sealed bottles were immediately frozen and stored in crushed dry ice (Boyd et al., 2009, 2012; Urschel et al., 2015). The remaining bottles or microcosms were incubated up-side-down at 25–27°C in the dark. At each subsequent time point, two microcosms were frozen as described for the time zero samples. Upon return to the laboratory all frozen samples were stored at −80°C until processed. For the negative controls a replicate set of 10.0 mL dosed samples were added to sparged microcosms containing 500.0 μL of formalin, sealed and incubated as previously described. The negative control samples were processed with the last time point samples.

Frozen samples were slowly thawed at room temperature, then acidified by the injection of 1.0 mL of 1.0 N HCl through each microcosm's septum. Each acidified sample was connected to a CO_2 scrubbing system designed to collect $^{14}CO_2$ and $^{14}CH_4$ produced by the microbial communities, with the $^{14}CH_4$ being oxidized to $^{14}CO_2$ prior to collection (Nuck and Federle, 1996). Briefly, each acidified microcosm was connected to the gas tight CO_2 scrubbing system by piercing the microcosm's plug with a syringe needle connected to a sequence of scintillation vials which are also connected via syringe needles and PTFE tubing as follows: an empty scintillation vial; two scintillation vials containing 5.0 mL of Carbo-Sorb E (PerkinElmer, Waltham, MA, United States) each; a muffle furnace (Lindburg Blue M; Thomas Scientific, Swedesboro, NJ, United States) containing an oxidation process tube filled with cupric oxide pellets and set to 800°C; two scintillation vials containing 5.0 mL of Carbo-Sorb E each. A gas mixture of O_2/N_2 (21%:79%) at a flow rate of approximately 40.0 mL min^{-1} for 5 min was used to flush the $^{14}CO_2$ and $^{14}CH_4$ from the head space of the acidified microcosm through the CO_2 absorbing solutions.

After flushing each microcosm, the four scintillation vials containing Carbo-Sorb were removed and 6.0 mL of Permafluor E^+ (PerkinElmer, Waltham, MA, United States) added to each vial and gently mixed. A new set of scintillation vials containing 5.0 mL of Carbon-Sorb E each replaced those removed. The acidified microcosms were removed from the scrubbing system and processed to recover the microbial biomass on membrane filters, retain the filtrate and prepare both for scintillation counting as described for the planktonic microbial communities in the phosphorus uptake experiments.

For the biofilm uptake experiments, groundwater (110.0 mL) from the pressure vessel was filter sterilized as described for the phosphorus uptake by the biofilm microbial community experiments, then dosed with sodium acetate and [2-^{14}C]-acetate (sodium salt) to the same final concentration and activity as described planktonic microbial community experiments. Each of nine microcosms (50 mL tubes with septum closures) (Syringa Lab Supplies, Boise, ID, United States) received 10.0 mL of the dosed groundwater. Biofilm growth reactors with the smaller core coupons were recovered, transported, processed and a 2.5 cm long biofilm coupon transferred to each microcosm as described for biofilm microbial community phosphorus uptake experiments. All microcosms were incubated up-side-down at 25–27°C in the dark.

The negative controls were the same as those described for the phosphorus uptake experiments for the biofilm communities, except [2-^{14}C] acetate was dosed in place of $^{32}PO_4$. Both negative controls were incubated as previously described and processed with the last time point samples.

At each time point, including time zero, one microcosm was immediately frozen and transported in crushed dry ice, then stored at −80°C. The frozen samples were thawed and processed for the recovery of $^{14}CO_2$ and oxidized $^{14}CH_4$ to $^{14}CO_2$ using the scrubbing system, retention of biomass on membrane filters and collection and sub-sampling of filtrates as described for the planktonic microbial community samples. Additionally, the biofilm coupons were transferred to separate scintillation vials to which 10.0 mL Ultima Gold was added. The surface area of each biofilm coupon was manually measured after the final scintillation counts had been performed.

Nutrient Removal and Uptake Rate Calculations

The nitrogen species removal and production rates were calculated from the slopes of the regression lines using the linear segments of the plotted data for the planktonic and biofilm communities (**Figure 2**).

Rates of phosphorus and carbon uptake (v) by planktonic and biofilm bacterial communities were calculated using the following equation (Wright, 1974; Wright and Burnison, 1979):

$$v = \frac{f\,(S_n + A)}{t} \tag{1}$$

where f is the decimal fraction of the activity incorporated into biomass (assimilation) and CO_2 (respiration) at each time point relative to total activity added to the solution at time zero using scintillation counts of the biomass (planktonic and biofilm), CO_2 (when applicable) and filtrate samples; S_n is the background or dosed non-radiolabeled nutrient concentration; A is the dosed radiolabeled nutrient concentration; t is incubation time. All scintillation counts used in the calculations were normalized by subtracting the appropriate control sample scintillation counts before conversion to concentrations. The normalized scintillation counts were converted to concentrations and the individual uptake rates (v) were calculated for each time point within the linear segments of the uptake curves for phosphorus and carbon. The individual uptake rates were then used to calculate the respective mean (±standard deviation) uptake rates. The general trends in ^{32}P and ^{14}C uptake by suspended and biofilm associated cells are presented in **Figures 3**, **4**.

Total Cell Counts

Separate 50.0 mL samples were collected directly from the well head in parallel with the larger volumes collected for the respective nutrient uptake experiments. These samples were immediately preserved by adding 0.5 mL of filter sterilized formalin and stored at 4°C until processing. Equal volumes of each preserved sample were filtered through replicate 25 mm diameter, 0.2 μm pore size filters (GTPB, Millipore Corp.) to retain the bacterial biomass. The bacteria were labeled using SYBR Gold (supplied at 10,000×, final concentration 25×) (Invitrogen) as described by Lisle and Priscu (2004). Labeled bacteria were counted on an Olympus BX51 epifluorescent microscope, equipped with a filter cube optimized for SYBR Gold (λ_{Ex} = 480 nm; λ_{Em} = 535 nm; λ_{Bs} = 505 nm), at a final magnification of 1,250×. A minimum of 300 bacterial cells were counted in a minimum of 20 microscope fields per filter. Due to significant amounts of carbonate core material being associated with the biofilm samples during the removal procedure it was not possible to proficiently separate the cells from the carbonate mud to the point where reliable cell counts could be determined.

RESULTS

Native Groundwater Chemistry and Bacterial Abundance

The zone of the UFA accessed is anaerobic and significantly reduced (−289.15 – −227.65 mV), with moderate temperature (25.29–25.83°C) and pH (7.68–8.10). Additionally, this zone can be classified as oligotrophic as NO_2-N, NO_3-N, and PO_4-P are below the methodological detection limits and other terminal electron acceptors (i.e., Mn^{2+} and Fe^{2+}) and dissolved organic carbon (1.12–1.68 mg L^{-1}) are present at relatively low concentrations (**Table 1**). This zone of the UFA is colonized with a planktonic bacterial community at an abundance of $1.40 \times 10^4 \pm 1.15 \times 10^4$ cells mL^{-1} (2.48×10^3–2.54×10^4 cells mL^{-1}). Biofilm cell abundance counts were not performed.

NO_3-N Removal Rates

After an approximate 20 h acclimation period, the planktonic microbial community removed NO_3-N at a rate of 0.059 mg L^{-1} d^{-1} (p-value: 0.036; r^2: 0.893), with a concomitant NO_2-N production rate of 0.103 mg L^{-1} d^{-1} (p-value: 0.026; r^2: 0.997) (**Table 2** and **Figure 2A**). The NH_4-N concentrations during this same time interval did not significantly change (0.430 ± 0.003 mg L^{-1}) (**Figure 2A**).

The biofilm microbial community also initiated NO_3-N removal after approximately 20 h at a rate of 0.116 (mg L^{-1}) d^{-1} (p-value: 0.111; r^2: 0.940) (**Table 2**), which was approximately twofold greater than the planktonic microbial community, to below detection limit concentrations after approximately 120 h (**Figure 2B**). During this same period, NO_2-N was generated at a rate [0.108 (mg L^{-1}) d^{-1}] similar to that for the planktonic microbial community. However, and in contrast to the planktonic

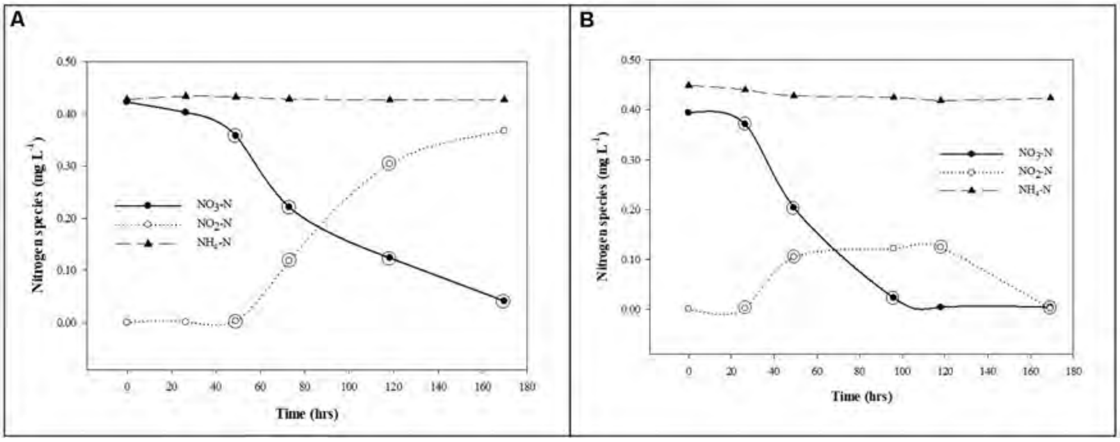

FIGURE 2 | Nitrate removal from groundwater by planktonic and biofilm microbial communities. Trends in NO_3-N (●), NO_2-N (○), and NH_4-N (▲) removal and production rates by planktonic **(A)** and biofilm **(B)** microbial communities in Upper Floridan Aquifer groundwater. The circled data points were used in the linear regressions to derive the respective removal or production rates.

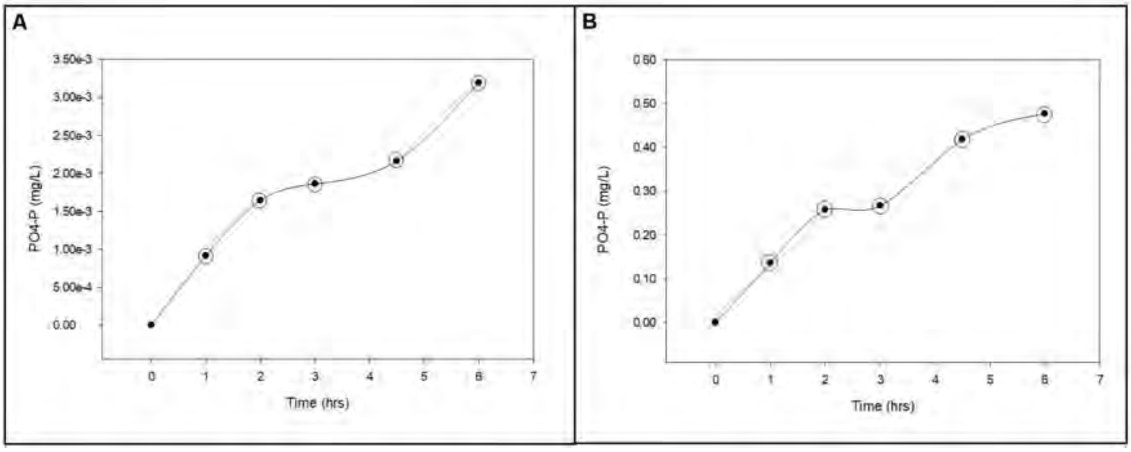

FIGURE 3 | Phosphorus uptake from groundwater by planktonic and biofilm microbial communities. Trends in PO_4-P uptake by planktonic **(A)** and biofilm **(B)** microbial communities in Upper Floridan Aquifer groundwater. The circled data points were used in the linear regressions to derive the respective uptake rates.

microbial community, an approximate 3 days period of no net change in the NO_2-N concentration was followed by a NO_2-N removal phase [0.057 (mg L^{-1}) d^{-1}] to concentrations below detection limits (**Figure 2B**).

Normalizing the removal rates to surface area estimates for the core coupons, the NO_3-N removal rates ranged from 0.0016–0.0090 (mg L^{-1}) m^{-2} d^{-1} (**Table 2**). The initial NO_2-N production rate of 0.0015–0.0084 (mg L^{-1}) m^{-2} d^{-1} was similar to the NO_3-N removal rate over the same time interval (**Figure 2B**). However, and in contrast to the planktonic microbial community data, an approximate 3.0 days period of no net change in NO_2-N concentration was followed by removal at a rate of 0.0008–0.0044 (mg L^{-1}) m^{-2} d^{-1} (**Figure 2B**). As in the planktonic microbial community microcosm, there was no significant change in the NH_4-N concentrations (0.431 ± 0.011 mg L^{-1}) over the duration of the experiments (**Figure 2B**).

PO_4-P Uptake and Sorption Rates

The uptake rates of PO_4-P into the planktonic microbial community biomass was between 5.73×10^{-8} and 1.03×10^{-7} mg L^{-1} d^{-1} (**Table 2** and **Figure 3A**). The biofilm microbial community incorporated PO_4-P into biomass at a rate approximately 2.8-orders of magnitude higher (4.20×10^{-5}–5.91×10^{-5} mg L^{-1} d^{-1}) than the planktonic microbial community (**Table 2** and **Figure 3B**). Normalizing these uptake rates to the estimated surface areas within the core coupons, the uptake rates ranged from 2.47×10^{-6}–9.88×10^{-6} (mg L^{-1}) m^{-2} d^{-1} (**Table 2**).

The PO_4-P sorption rates onto the carbonate coupons can be estimated ^{32}P activity associated with the formalinized negative controls (So et al., 2011). Using the same calculations as used for the uptake rates, where ν would now represent sorption rates, the derived PO_4-P sorption rate ranged from 1.64×10^{-7} to 9.25×10^{-7} mg PO_4-P m^{-2} day^{-1}.

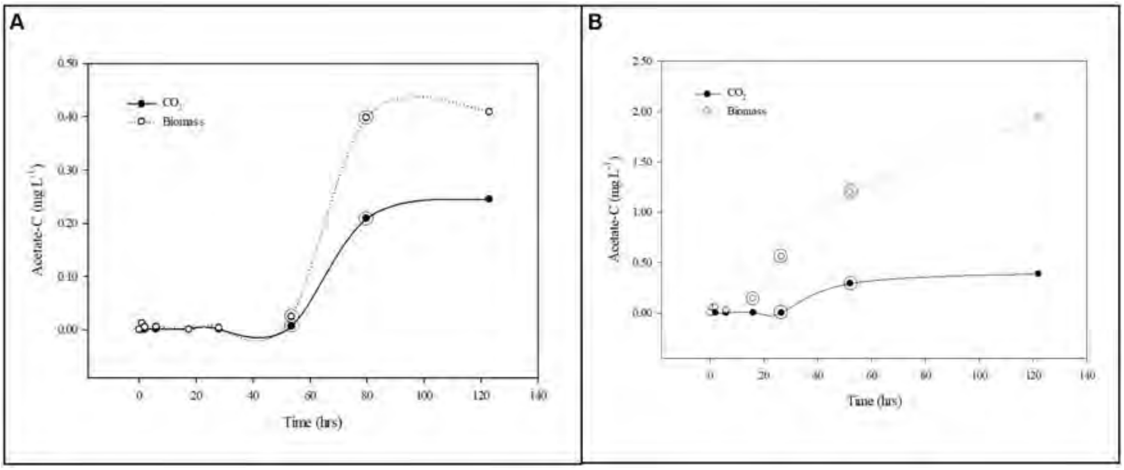

FIGURE 4 | Carbon uptake from groundwater by planktonic and biofilm communities. Trends in acetate-C mineralization to CO_2 (●) and assimilation into biomass (○) by planktonic **(A)** and biofilm **(B)** microbial communities in Upper Floridan Aquifer groundwater. The circled data points were used in the linear regressions to derive the respective uptake rates.

TABLE 2 | Experimental nutrient removal and uptake rates for Upper Floridan Aquifer planktonic and biofilm microbial communities.

Microcosm	Analytical target	Planktonic removal and uptake rates	Biofilm removal and uptake rates		
		$(mg{\cdot}L^{-1})\ d^{-1}$	$(mg{\cdot}L^{-1})\ d^{-1}$	$(m^2)^1$	$(mg{\cdot}L^{-1})\ m^{-2}\ d^{-1}$
NO_3-N	Net removal	0.059	0.116	12.85–72.37	0.0016–0.0090
PO_4-P	Biomass	5.73×10^{-8}–1.03×10^{-7}	4.20×10^{-5}–5.91×10^{-5}	4.25–23.92	2.47×10^{-6}–9.88×10^{-6}
DOC (as acetate)	CO_2	0.003–0.084	0.001–0.014	4.25–23.92	3.29×10^{-4}–5.77×10^{-4}
	Biomass	0.012–0.160	0.299–0.682	4.25–23.92	0.028–0.070
	Total	0.015–0.244	0.301–0.696	4.25–23.92	0.029–0.071

[1] The biofilm coupon surface areas were calculated using specific gravity (2.70–2.83 g cm^{-3}) and surface area:mass ratio (0.8–4.3 m^2 g^{-1}) values.

These sorption rates are 10.7–15.1-fold lower than the biofilm community uptake rates.

Carbon Uptake Rates

After a transition period of 53.5 h, during which there was no detectable uptake of ^{14}C-labeled acetate, the planktonic microbial community respired and assimilated the acetate-C at rates of 0.003–0.084 mg L^{-1} d^{-1} and 0.012–0.160 mg L^{-1} d^{-1}, respectively, for an uptake rate of 0.015–0.244 mg L^{-1} d^{-1} (**Table 2** and **Figure 4A**).

The biofilm microbial community respiration response was detectable after 28.0 h [0.001–0.014 (mg L^{-1}) d^{-1}] and was between two and sixfold lower than that for the planktonic microbial community (**Table 2** and **Figure 4B**). The assimilation response initiated at 16.0 h [0.299–0.682 (mg L^{-1}) d^{-1}] and, in contrast to the respiration rates, was 4- to 25-fold greater than that for the planktonic microbial community (**Table 2**). Collectively, the biofilm microbial community respiration and assimilation rates provide an acetate-C uptake rate of 0.301–0.696 (mg L^{-1}) d^{-1}, which is 3- to 20-fold greater than the uptake rates for the planktonic microbial community (**Table 2**). Normalizing these uptake rates to the estimated surface areas of the core coupons the rates of respiration [3.29×10^{-4}–5.77×10^{-4} (mg L^{-1}) m^{-2} d^{-1}] and assimilation [0.028–0.070 (mg L^{-1}) m^{-2} d^{-1}] the biofilm microbial community uptake rate was 0.029–0.071 (mg L^{-1}) m^{-2} d^{-1} (**Table 2**).

Additionally, both microbial communities incorporated a greater percentage of carbon into bacterial biomass when compared to produced CO_2, indicating a preference for productivity under these conditions. The planktonic community incorporated carbon into biomass at a rate of 1.9–4.0-fold greater than that for CO_2 production, while the biofilm community rate was 85.1–121.3-fold greater (**Table 2**).

There was no ^{14}C-labeled CH_4 detected in any sample, using the CH_4 oxidation to CO_2 method described previously.

Comparison of Experimental and ASR Cycle Test Nutrient Removal and Uptake Rates

Applying the nutrient removal or uptake rates derived from this study (**Table 2**) and the estimated biofilm surface area within the UFA storage zone, the time required for the planktonic and biofilm communities to remove nutrients during the storage phase in the UFA at KRASR can be estimated, assuming no mixing with native groundwater occurs during this period (Mirecki et al., 2013). For example, using averaged data from four cycle tests at the KRASR facility (Mirecki, 2013) and applying the range of porosities (0.25–0.30), carbonate specific gravity (2.70–2.83 g cm^{-3}) and surface area:mass ratio (0.8–4.3 m^2 g^{-1}) values, as previously described, the following variables describe an average ASR cycle: (a) the storage zone is 69.5 m deep × 186.2–204.2 m radial distance from the injection well; (b) giving a storage zone volume of 7.57×10^6–9.10×10^6 m^3 or a mass of 2.04×10^{13}–2.57×10^{13} g; (c) the total surface area within this storage zone volume available for biofilm colonization is 1.64×10^{13}–1.11×10^{14} m^2; (d) only 10% of the total surface area is colonized with biofilms (1.64×10^{12}–1.11×10^{13} m^2); (e) the recharge water volume is 2.27×10^9 L (6.00×10^8 gallons); (f) storage period of 150 days. The average nutrient concentrations in the recharge and recovered water and removal rates, based on 150 days of storage, are listed in **Table 3**.

The planktonic microbial community removal and uptake rates (**Table 2**) are directly comparable to those calculated from the KRASR cycle test data (**Table 3**), when both sets of rates are normalized to a 150 days storage period. The experimental NO_3-N removal rate was approximately 20-fold greater than the rate from the averaged cycle test data, taking 8.0 days within the 150 days storage period to remove the same concentration of NO_3-N (**Table 4**). However, the experimental PO_4-P uptake rates (**Table 2**) were significantly lower than the rates from the cycle tests, taking years to remove the same concentration of PO_4-P as recorded during the cycle tests (**Table 4**). The range of total DOC (i.e., CO_2 + biomass) uptake rates ranged from approximately 7.3-fold lower to 2.2-fold greater than the average cycle test rate, thereby requiring between approximately half of the 150 days storage period (73 days) and 3.0 years to remove the same concentration of DOC (**Table 4**).

The comparison between the average nutrient removal rates from the KRASR cycle tests and the respective biofilm microbial community rates is not direct as with the planktonic microbial community rates. For this example, deriving the percentage of biofilm colonized surface area needed to remove or uptake the same concentrations of nutrients as removed during the cycle test storage period of 150 days is the objective. To facilitate these comparisons, the concentrations of nutrients removed during cycle test storage (**Table 3**) were converted to mass in the storage zone for NO_3-N (1.07×10^9 mg), PO_4-P (8.87×10^7 mg), and total DOC (3.39×10^{10} mg). Thereby, applying the nutrient removal and uptake rates for the biofilm microbial community (**Table 2**), the area of the total biofilm colonized aquifer surfaces required to remove the same mass of nutrients as during the complete 150 days storage period of the cycle test would be <1.0% for NO_3-N, 2.15–3.65% for PO_4-P and <1.0% for total DOC of the 1.64×10^{12}–1.11×10^{13} m^2 of biofilm in the storage zone (**Table 4**).

TABLE 3 | Average nutrient concentrations and removal rates from cycle test data at Kissimmee River ASR facility[1].

Nutrient	Recharge water	Recovered water	Removed during storage	Removal rate during storage
	($mg \cdot L^{-1}$)	($mg \cdot L^{-1}$)	($mg \cdot L^{-1}$)	($mg \cdot L^{-1}$) d^{-1}
NO_3-N	0.47	0.00	0.47	3.13×10^{-3}
PO_4-P	0.059	0.011	0.048	3.19×10^{-4}
DOC	18.0	1.6	16.4	0.11

[1] Assuming a storage period of 150 days.

TABLE 4 | Time or biofilm area required to remove the same concentrations of nutrients in recharged surface water as removed during an average cycle test at the Kissimmee River ASR facility.

Nutrient	Planktonic community	Biofilm community	
	Days[a] or years[b]	m^2	% of biofilm area
NO_3-N	8.0[a]	7.93×10^8–4.46×10^9	0.04–0.05
PO_4-P	1.28×10^3–2.30×10^3 [b]	5.99×10^{10}–2.39×10^{11}	2.15–3.65
DOC (total)	0.2–3. [b]	3.18×10^9–7.80×10^9	0.07–0.19

DISCUSSION

To date, estimates of nutrient reductions during storage have relied on data collected at the surface from the recharge water prior to injection and after a storage period. This "black box" approach necessitates the application of indirect estimates and hypotheses to explain the geochemical and microbial processes responsible for these changes at depth. Where other studies have considered the microbial contribution to these nutrient removal rates as being a single, collective community within the aquifer storage zone, this study partitions this community into two ecological niches: planktonic and biofilm.

In general, the biofilm communities removed all nutrients at significantly greater rates than the planktonic communities (**Table 2**). These greater rates of nutrient removal by the biofilm communities is assumed to be the result of the greater microbial biomass associated with this niche, relative to the planktonic communities. Though not determined during this study, biofilms have also been shown to support microbial groups with physiological capabilities for the metabolism of nutrients that are not associated with the planktonic communities (Nadell et al., 2016; Stubbendieck et al., 2016; Jones and Bennett, 2017).

When comparing the removal rates between these two niches based on a nutrient removal rate per day basis, the biofilm communities removed NO_3-N, PO_4-P and DOC (as acetate) at rates approximately 2-fold, 570 to 733-fold and 3 to 20-fold greater than the planktonic communities, respectively. However, nitrogen, phosphorus and carbon do not cycle independently of other elements as most biogeochemical processes, especially carbon cycling, are intra- and interconnected (Taylor and Townsend, 2010; Anderson, 2018; Hofmann and Griebler, 2018).

Due to this zone of the UFA being anaerobic, NO_3-N removal in the planktonic and biofilm communities is assumed to be the result of denitrification and dissimilatory nitrate/nitrite reduction to ammonium (DNRA), both heterotrophic processes, and to a lesser degree autotrophic denitrification (Lam and Kuypers, 2010; Kuypers et al., 2018). Using the native DOC in the UFA (~1.40 mg/L) (**Table 1**), the planktonic communities removed NO_3-N with a concomitant production of NO_2-N at a stoichiometric ratio of approximately 0.6:1 during the mid-to-late time points of the study (**Figure 2A**). The relatively consistent accumulation of NO_2-N without the production of NH_4-N suggests nitrate reduction, the first step in denitrification, was the dominant process while bacterial groups responsible for nitrite reduction to either NO, N_2 (i.e., complete denitrification), NH_4-N (i.e., dissimilatory nitrate/nitrite reduction to ammonium; DNRA) or oxidation of NH_4-N (i.e., anaerobic ammonium oxidation; anammox) were either not present or at abundances too low to remove NO_2-N and produce NH_4-N at rates reliably measured by the methods used in this study (Lam and Kuypers, 2010; Taylor and Townsend, 2010; Kuypers et al., 2018).

The biofilm community reduced NO_3-N to NO_2-N at a rate approximately twofold greater than the planktonic community during the initial phase of the study (**Figure 2B**). The plateau in the NO_2-N production is accompanied with a slight decrease in NH_4-N, suggesting annamox is present but denitrification is dominant until NO_3-N is completely removed and denitrification removes the remaining NO_2-N. This opposing trend, relative to the planktonic community, suggests the biofilm communities included cells or groups of cells at abundances high enough and spatially positioned within the biofilms to complete the denitrification process and possibly anammox (Elias and Banin, 2012; Liu et al., 2016). The likelihood of denitrification being the dominant and anammox the relatively minor contributors to the nitrogen cycle in the planktonic and biofilm microcosms is increased by the presence of sulfides in the UFA groundwater (**Table 1**) at concentrations that have been shown to suppress rates of anammox while having no effect on denitrification rates (Carvajal-Arroyo et al., 2013).

Preliminary experiments had shown negligible PO_4-P uptake by planktonic communities when using unamended native UFA groundwater, though it contained adequate concentrations of TOC and DOC (**Table 1**). It was only after the addition of acetate that the planktonic and biofilm communities actively incorporated phosphorus into biomass (**Figures 3A,B**), indicating the native TOC and DOC in the UFA (**Table 1**) is recalcitrant and not readily accessible for facilitating the microbial uptake of phosphorus. The coupling of bacterial carbon and phosphorus cycles in aquatic ecosystems has been shown to be an important biogeochemical relationship that imposes partial controls on bacterial productivity (Dorado-Garcia et al., 2014; Anderson, 2018; Hofmann and Griebler, 2018). The cooperative relationship between bacterial access to carbon and phosphorus uptake is the positive relationship between the initiation or increase in free and cell-bound alkaline phosphatase activity and increasing labile carbon concentrations (Anderson, 2018). This increase in alkaline phosphatase activity increases the rate at which phosphate groups are cleaved from complex organic and inorganic compounds outside the bacterial cell or between the cell wall and periplasmic membrane with the subsequent transport of the inorganic phosphate group into the bacterial cell for assimilation (Jansson, 1988). The significantly greater PO_4-P uptake rates by the biofilm communities, relative to the planktonic communities, can be attributed to a greater abundance of bacterial cells actively producing free and cell-bound alkaline phosphatase and the ability of biofilms to retain and concentrate cellular metabolites (Jefferson, 2004; Elias and Banin, 2012). Bacterial biofilms have been shown to not only retain alkaline phosphatase at relatively higher concentrations than the overlying water but also promote higher enzyme activity within the biofilm matrix (Huang et al., 1998).

The rates of PO_4-P sorption onto and desorption from the aquifer core coupon are significant factors when assessing the capacity of an aquifer storage zone to retain this nutrient. A previous study that used carbonate core material, similar to that used in this study, from a surficial aquifer in south Florida derived a sorption rate for PO_4-P in seawater (Price et al., 2010). After normalizing their sorption rates for direct comparison to those in this study by using the density and surface area:mass ratios described previously, their PO_4-P sorption rates of 1.79×10^{-7}–4.54×10^{-6} mg PO_4-P m^{-2} day^{-1} were similar to those derived in this study (1.64×10^{-7}–9.25×10^{-7} mg PO_4-P m^{-2} day^{-1}).

With respect to diversity, it is worthy of note that the nutrient removal and uptake rates described in this study are community-level rate estimates for bacterial populations that have not been impacted by injected treated or untreated surface water. An understanding of changes in the proficiency of nutrient removal during storage of recharged water by planktonic and biofilm communities will require a more detailed characterization of those communities to identify those populations actively cycling those nutrients and the succession of bacterial diversity and function.

In addition to monitoring changes in constituents, including microbial communities, in the recharge and recovered water at an ASR, or any MAR facility, the characterization of biofilms within the aquifer storage zone prior to and during recharge and recovery cycles need to be included if the fate and transport of nutrients and the impact on operational metrics (e.g., well clogging) are to be adequately modeled. However, the application of microbial diversities and rates of biogeochemical processes generated at one ASR location to another location and/or different MAR technology should be attempted with caution if the geochemical (e.g., oxidized, reduced, anoxic, and anaerobic), mineralogical (e.g., presence or absence of iron) and hydrological (e.g., rates of mixing between recharged water and native groundwater within the storage zone) conditions are too dissimilar.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on the USGS Data Release portal (doi: 10.5066/P9EOM5RC).

AUTHOR CONTRIBUTIONS

JL conceived and designed the experiments, performed the samplings, analyzed the data, and wrote the manuscript.

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REFERENCES

Anderson, O. (2018). Evidence for coupling of the carbon and phosphorus biogeochemical cycles in freshwater microbial communities. *Front. Mar. Sci.* 5:20. doi: 10.3389/fmars.2018.00020

Bekele, E., Page, D., Vanderzalm, J., Kaksonen, A., and Gonzalez, D. (2018). Water recycling via aquifers for sustainable urban water quality management: current status, challenges and opportunities. *Water* 10, 1–25.

Boyd, E., Fecteau, K., Havig, J., Shock, E., and Peters, J. (2012). Modeling the habitat range of phototrophs in yellowstone national park: toward the development of a comprehensive fitness landscape. *Front. Microbiol.* 3:221. doi: 10.3389/fmars.2018.000221

Boyd, E., Leavitt, W., and Geesey, G. (2009). CO_2 uptake and fixation by a thermoacidophilic microbial community attached to precipitated sulfur in a geothermal spring. *Appl. Environ. Microbiol.* 75, 4289–4296. doi: 10.1128/aem.02751-08

Carvajal-Arroyo, J., Sun, W., Sierra-Alvarez, R., and Field, J. (2013). Inhibition of anaerobic ammonium oxidizing (anammox) enrichment cultures by substrates, metabolites and common wastewater constituents. *Chemosphere* 91, 22–27. doi: 10.1016/j.chemosphere.2012.11.025

Dorado-Garcia, I., Medina-Sanchez, J., Herrera, G., Cabrerizo, M., and Carrillo, P. (2014). Quantification of carbon and phosphorus co-limitation in bacterioplankton: new insights on an old topic. *PLoS One* 9:e99288. doi: 10.1371/journal.pone.0099288

Elias, S., and Banin, E. (2012). Multi-species biofilms: living with friendly neighbors. *FEMS Microbiol. Rev.* 36, 990–1004. doi: 10.1111/j.1574-6976.2012.00325.x

Flemming, H., and Wuertz, S. (2019). Bacteria and archaea on Earth and their abundance in biofilms. *Nat. Rev. Microbiol.* 17, 247–260. doi: 10.1038/s41579-019-0158-9

Ginige, M., Kaksonen, A., Morris, C., Shackelton, M., and Patterson, B. (2013). Bacterial community and groundwater quality changes in an anaerobic aquifer during groundwater recharge with aerobic recycled water. *FEMS Microbiol. Ecol.* 85, 553–567. doi: 10.1111/1574-6941.12137

Golder Associates (2007). *Lake Okeechobee Aquifer Storage And Recovery (ASR) Regional Project Site Characterization Report: Construction of Single-Zone Monitor Well MW0010 and Groundwater Sampling Site 2 (Kissimmee River Site)*. Jacksonville, FL: Golder Associates.

Gordon, L., Jennings, J., Ross, A., and Krest, J. (2000). *A Suggested Protocol For Continuous Flow Automated Analysis Of Seawater Nutrients (Phosphate, Nitrate, Nitrite and Silicic Acid) in WOCE Hydrogrphic Program And The Joint Global Oceans Fluxes Study in WOCE Hydrographic Program Office Methods Manual WHPO 91-1*. Corvallis, OR: Oregon State University.

Hofmann, R., and Griebler, C. (2018). DOM and bacterial growth efficiency in oligotrophic groundwater: absence of priming and co-limitation by organic carbon and phosphorus. *Aquat. Microb. Ecol.* 81, 55–71. doi: 10.3354/ame01862

Huang, C., Xu, K., McFeters, G., and Stewart, P. (1998). Spatial patterns of alkaline phosphatase expression within bacterial colonies and biofilms in response to phosphate starvation. *Appl. Environ. Microbiol.* 64, 1526–1531. doi: 10.1128/aem.64.4.1526-1531.1998

Jansson, M. (1988). "Phosphate uptake and utilization by bacteria and algae," in *Phosphorus in Freshwater Ecosystems*, eds G. Persson and M. Jansson (Dordrecht: Springer), 177–189. doi: 10.1007/978-94-009-3109-1_11

Jefferson, K. (2004). What drives bacteria to produce a biofilm? *FEMS Microbiol. Lett.* 236, 163–173. doi: 10.1111/j.1574-6968.2004.tb09643.x

Jones, A., and Bennett, P. (2017). Mineral ecology: surface specific colonization and geochemical drivers of biofilm accumulation, composition, and phylogeny. *Front. Microbiol.* 8:491. doi: 10.3389/fmicb.2017.00491

Koutroulis, A., Papadimitriou, L., Grillakis, M., Tsanis, I., Warren, R., and Betts, R. (2019). Global water availability under high-end climate change: a vulnerability based assessment. *Glob. Planet. Chang.* 175, 52–63. doi: 10.1016/j.gloplacha.2019.01.013

Kuypers, M., Marchant, H., and Kartal, B. (2018). The microbial nitrogen-cycling network. *Nat. Rev. Microbiol.* 16, 263–276. doi: 10.1038/nrmicro.2018.9

Lai, P., Moulton, K., and Krevor, S. (2015). Pore-scale heterogeneity in the mineral distribution and reactive surface area of porous rocks. *Chem. Geol.* 411, 260–273. doi: 10.1016/j.chemgeo.2015.07.010

Lam, P., and Kuypers, M. (2010). Microbial nitrogen cycling processes in oxygen minimum zones. *Annu. Rev. Mar. Sci.* 3, 317–345. doi: 10.1146/annurev-marine-120709-142814

Lisle, J., and Priscu, J. (2004). The occurrence of lysogenic bacteria and microbial aggregates in the lakes of the McMurdo Dry Valleys, Antarctica. *Microb. Ecol.* 47, 427–439.

Liu, W., Roder, H., Madsen, J., Bjarnsholt, T., Sorensen, S., and Burmolle, M. (2016). Interspecific bacterial interactions are reflected in multispecies biofilm spatial organization. *Front. Microbiol.* 7:13668. doi: 10.3389/fmicb.2017.013668

McMahon, S., and Parnell, J. (2014). Weighing the deep continental biosphere. *FEMS Microbiol. Ecol.* 87, 113–120. doi: 10.1111/1574-6941.12196

Miller, J. (1997). "Hydrogeology of Florida," in *The Geology of Florida*, eds A. Randazzo and D. Jones (Gainesville, FL: University Press of Florida), 69–88.

Mirecki, J. (2004). *Water-Quality Changes During Cycle Tests At Aquifer Storage Recovery (ASR) Systems Of South Florida. ERCD/EL TR-04-8*. Washington, DC: U.S. Army Corps of Engineers.

Mirecki, J. (2013). *Comprehensive Everglades Restoration Plan Aquifer Storage And Recovery Pilot Project: Final Technical Data Report For The Kissimmee River and Hillsboro ASR Systems. South Florida Water Management District and U.S.Army Corps of Engineers*. Jacksonville, FL: U.S. Army Corps of Engineers.

Mirecki, J., Bennett, M., and López-Baláez, M. (2013). Arsenic control during aquifer storage recovery cycle tests in the Floridan aquifer. *Groundwater* 51, 539–549.

Morrissey, S., Clark, J., Bennett, M., Richardson, E., and Stute, M. (2010). Groundwater reorganization in the Floridan aquifer following Holocene sea-level rise. *Nat. Geosci.* 3, 683–687. doi: 10.1038/ngeo956

Nadell, C., Drescher, K., and Foster, K. (2016). Spatial structure, cooperation and competition in biofilms. *Nat. Rev. Microbiol.* 14, 589–600. doi: 10.1038/nrmicro.2016.84

Nuck, B., and Federle, T. (1996). Batch test for assessing the mineralization of 14C-radiolabeled compounds under realistic anaerobic conditions. *Environ. Sci. Technol.* 30, 3597–3603. doi: 10.1021/es960302u

Page, D., Peeters, L., Vanderzalm, J., Barry, K., and Gonzalez, D. (2017). Effect of aquifer storage and recovery (ASR) on recovered stormwater quality variability. *Water Res.* 117, 1–8. doi: 10.1016/j.watres.2017.03.049

Patterson, B., Shackleton, M., Furness, A., Pearce, J., Descourvieres, C., Linge, K., et al. (2010). Fate of nine recycled water trace organic contaminants and metal(loid)s during managed aquifer recharge into a anaerobic aquifer: column studies. *Water Res.* 44, 1471–1481. doi: 10.1016/j.watres.2009.10.044

Plummer, N., and Sprinkle, C. (2001). Radiocarbon dating of dissolved inorganic carbon in groundwater from confined parts of the Upper Floridan aquifer, Florida, USA. *Hydrogeol. J.* 9, 127–150. doi: 10.1007/s100400000121

Price, R., Savabi, M., Jolicoeur, J., and Roy, S. (2010). Adsorption and desorption of phosphate on limestone in experiments simulating seawater intrusion. *Appl. Geochem.* 25, 1085–1091. doi: 10.1016/j.apgeochem.2010.04.013

Pyne, D. (2005). *Aquifer Storage Recovery: A Guide to Groundwater Recharge Through Wells*. Gainesville, FL: ASR Systems.

Reese, R., and Richardson, E. (2007). *Synthesis of the Hydrogeological Framework of the Floridan Aquifer System And Delineation Of A Major Avon Park Permeable Zone In Central And Southern Florida*. US Geological Survey Scientific Investigations Report 2007-5207. Reston, VA: US Geological Survey.

Scott, T. (1988). *The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida*. Tallahassee, FL: Florida Geological Survey.

So, H., Postma, D., Jakobsen, R., and Larsen, F. (2011). Sorption of phosphate onto calcite; results from batch experiments and surface complexation modeling. *Geochim. Cosmochim. Acta* 75, 2911–2923. doi: 10.1016/j.gca.2011.02.031

Stubbendieck, R., Vargas-Bautista, C., and Straight, P. (2016). Bacterial communities: interactions to scale. *Front. Microbiol.* 7:1234. doi: 10.3389/fmicb.2017.01234

Sunderland, R., Collins, B., and Anderson, S. (2011). *Hydrogeologic Investigation of the Floridan Aquifer System at the S-65C Site (Well OKF-105), Okeechobee County, Florida. Technical Publication WS-32, 1-384*. West Palm Beach, FL: South Florida Water Management.

Taylor, P., and Townsend, A. (2010). Stoichiometric control of organic carbon-nitrate relationships from soils to the sea. *Nature* 464, 1178–1181. doi: 10.1038/nature08985

Urschel, M., Kubo, M., Hoehler, T., Peters, J., and Boyd, E. (2015). Carbon source preference in chemosynthetic hot spring communities. *Appl. Environ. Microbiol.* 81:3834. doi: 10.1128/aem.00511-15

Vanderzalm, J., Page, D., Barry, K., and Dillon, P. (2013). Application of a probabilistic modelling approach for evaluation of nitrogen, phosphorus and organic carbon removal efficiency during four successive cycles of aquifer storage and recovery (ASR) in an anoxic carbonate aquifer. *Water Res.* 47, 2177–2189. doi: 10.1016/j.watres.2013.01.038

Vanderzalm, J., Page, D., Dillon, P., Barry, K., and Gonzalez, D. (2018). Nutrient removal during stormwater aquifer storage and recovery in an anoxic carbonate aquifer. *J. Environ. Q.* 47, 276–286. doi: 10.2134/jeq2016.12.0486

Waldron, M., and Horvath, L. (2010). *Construction of Proximal Monitor Well #18 (MW-18), Kissimmee River ASR Pilot Site, Okeechobee County, Florida. 61012.* Fort Myers, FL: Entrix Inc.

Whitman, W., Coleman, D., and Wiebe, W. (1998). Prokaryotes: the unseen majority. *Proc. Natl. Acad. Sci. U.S.A.* 95, 6578–6583. doi: 10.1073/pnas.95.12.6578

Wright, R. (1974). "Mineralization of organic solutes by heterotrophic bacteria," in *Effect of the Ocean Environment on Microbial Activity*, eds R. Colwell and R. Morita (Baltimore: University Park Press), 546–565.

Wright, R., and Burnison, B. (1979). "Heterotrophic activity measured with radiolabelled organic substrates," in *Native Aquatic Bacteria: Enumeration, Activity and Ecology*, eds J. Costerton and R. Colwell (West Conshohocken, PA: American Society for Testing and Materials), 140–155.

Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

APPENDIX F:
LOWRP ASR WELLS: PHASE I C-38N AND C-38S SITE EVALUATION REPORT

SFWMD Lake Okeechobee Watershed Restoration Project (LOWRP) Aquifer Storage and Recovery (ASR) Wells

Phase I C-38N and C-38S Site Evaluation Report

June 17, 2020

Prepared for:

South Florida Water Management District (SFWMD)

Prepared by:

Stantec

Revision	Description	Author		Quality Check		Independent Review	
1	First Draft	Nycole Sharma	NS	Rick Cowles	RC	Neil Johnson	NJ

PHASE I C-38N AND C-38S SITE EVALUATION REPORT

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ABBREVIATIONS

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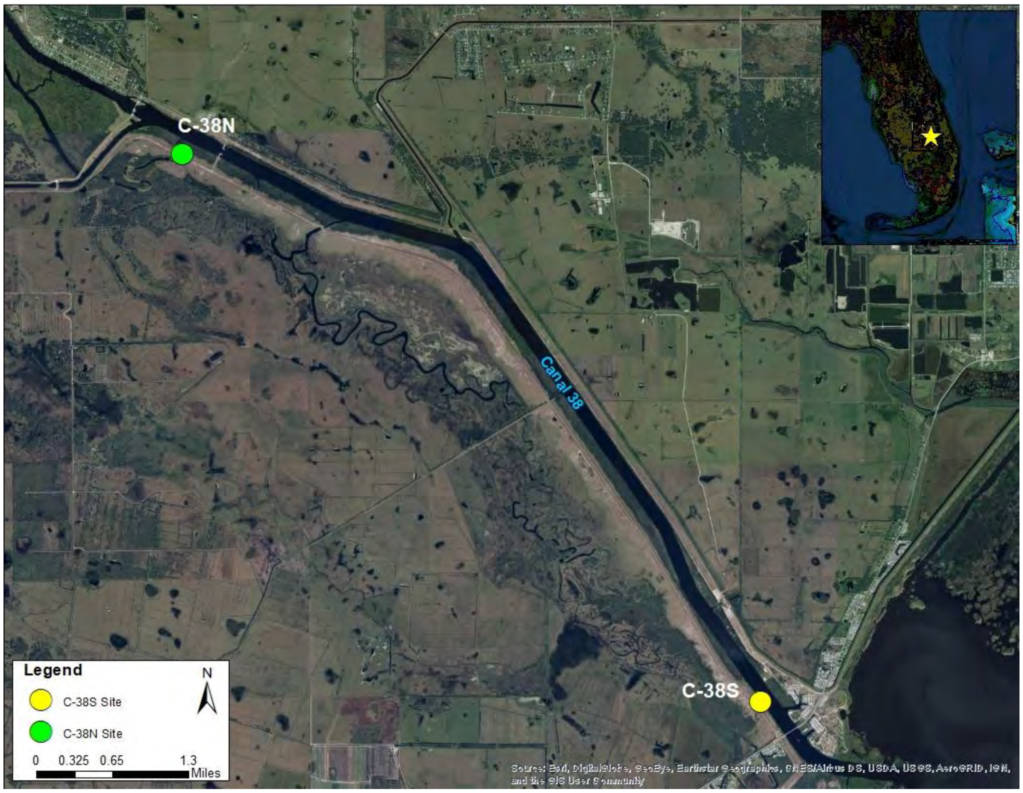
Abbreviations

APPZ	Avon Park Permeable Zone
APT	Aquifer Performance Test
ASR	Aquifer Storage Recovery
bls	Below land surface
DZMW	Dual Zone Monitoring Well
FDEP	Florida Department of Environmental Protection
FGS	Florida Geological Survey
FRP	Fiberglass Reinforced Plastic
ft^2/d	Feet squared per day
LFA	Lower Floridan aquifer
LiDAR	Light detection and ranging
LMZ	Lower monitoring zone
MGD	Million gallons per day
mg/L	Milligrams per Liter
NAVD	North American Vertical Datum
NGVD	National Geodetic Vertical Datum
PVC	Polyvinyl chloride
SAS	Surficial aquifer system
SFWMD	South Florida Water Management District
Stantec	Stantec Consulting Services Inc.
TDS	Total Dissolved Solids
UFA	Upper Floridan Aquifer

UIC	Underground Injection Control
UMZ	Upper Monitoring Zone
USDW	Underground Source of Drinking Water
USGS	United State Geological Survey

1.0 INTRODUCTION

The South Florida Water Management District (SFWMD) selected Stantec Consulting Services Inc. (Stantec) to review and evaluate existing data that will aid in the development of aquifer storage and recovery (ASR) wells along the Kissimmee River at the C-38N and C-38S sites. Location of the C-38N and C-38S are shown in **Figure 1**. This work includes the review of published and unpublished hydrogeological information on the area, development of a conceptual hydrogeologic model, development of preliminary ASR and monitoring well construction designs, development of preliminary site layout drawings that show intake and outfall (discharge) structures, piping layout, general treatment system layout, and wellfield layout. It is anticipated that each wellfield will consist of five ASR well clusters; five ASR wells completed in the Upper Floridan Aquifer (UFA) and five completed in the Avon Park Permeable Zone (APPZ). Each ASR well is anticipated to accept approximately five million gallons per day (MGD) of water during the storage cycle for a total capacity of 50 MGD at each wellfield.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1. C-38N and C-38S Location Map

2.0 SUMMARY OF C-38N AND C-38S SITING EVALUATION

An evaluation of the C-38N and C-38S sites was conducted to determine the general hydrogeologic conditions. These sites are approximately 7.5 miles apart and are located on the southwest side of the Kissimmee River (C-38 Canal). Published and unpublished hydrogeological documents were reviewed, and local cross-sections were developed for each site. Hydraulic and selected water quality data was superimposed over the cross-sections to allow comparison of these values between wells and across the area. These data were obtained from well completion reports, geophysical logs, ASR well system construction and testing reports, and other data. The DBHYDRO database was the primary source of this data; however, internet searches and conversations with District staff also were also major sources of data. Many of the documents and data reviewed overlap between the two sites. This includes modeling that was conducted at the Kissimmee ASR well site near C-38S. The results of this preliminary modeling effort were used to estimate the ASR well spacing at both sites. In addition, cross-section trends extend through both sites to connect the hydrogeologic settings.

The results of this evaluation were used in part in the preparation of the Underground Injection Control (UIC) Test Well Permit Applications for the C-38N and C-38S sites that was submitted to the Florida Department of Environmental Protection (FDEP).

2.1 HYDROGEOLOGICAL DOCUMENTATION REVIEW

2.1.1 Documentation Review

The SFWMD DBHYDRO Database was utilized to identify wells and boreholes within 25 miles of C-38N and C-38S. Because the targeted aquifers are the UFA and APPZ, data from wells shallower than 250 feet below land surface (bls) were not evaluated. Other data sources included the United States Geological Survey (USGS) and the Florida Geological Survey (FGS). This review included the following:

- Well construction reports
- Geophysical logs
- Geological data and interpretations
- Existing stratigraphic and hydrogeologic cross-sections
- Water quality data

- Hydraulic data
- Aquifer testing and modeling reports
- Interviews with SFWMD Staff

Although the a relatively large area was examined, only a few wells meeting these criteria were identified. References used in this evaluation are provided at the end of this report.

2.1.1.1 Review of Existing Wells

Documents produced during previous investigations near the C-38N and C-38S sites were reviewed. These data were used to prepare preliminary ASR well and monitoring well designs. Existing well documentation is referenced below.

Review of Existing Wells at C-38N

Currently, the only existing well at the C-38N site is dual zone monitoring well (DZMW) HIF-42, also known as the Paradise Run ASR DZMW (**Figure 2)**. Information for HIF-42 was obtained from the *Well Construction and Testing Report: Paradise Run Aquifer Storage and Recovery Test-Monitor Well HIF-42* (CH2M Hill, 2008). Well construction details at the C-38N DZMW are presented in **Table 1.**

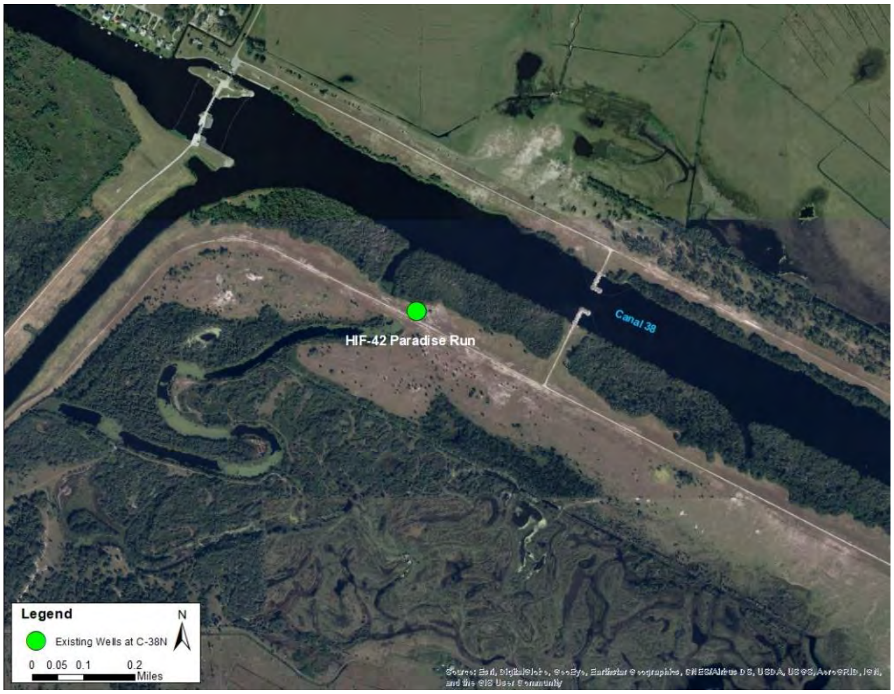


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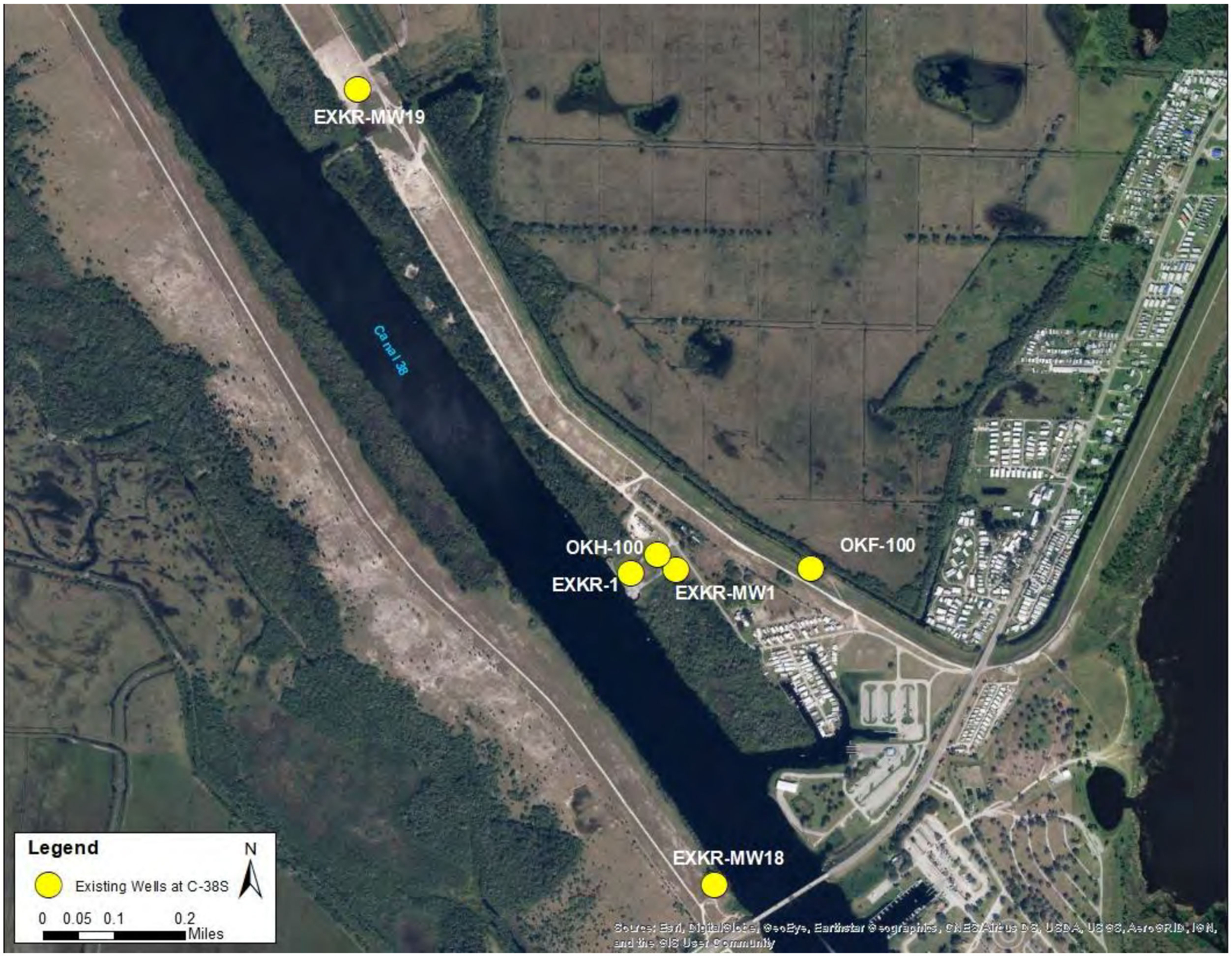
Figure 2. Existing Well at C-38N

Table 1. Existing Well Construction Details at C-38N

HIF-42		
Casing Size	**Depth of Casing (feet bls)**	**Monitoring Zone Interval (feet bls)**
42-inch diameter Steel Pit Casing	42	**Upper Monitoring Zone**
36-inch diameter Steel Surface Casing	180	560 - 1,049
24-inch diameter Steel Intermediate Casing	560	**Lower Monitoring Zone**
14-inch diameter Steel Final Casing	1,049	1,310 - 1,530
*Total drilled depth was 1,802 feet bls. Back filled with cement slurry to 1,530 feet bls.		

Review of Existing Wells at C-38S

There are several existing wells near the C-38S site. These wells are associated with the Kissimmee River ASR Well System. The ASR Well System is comprised of EXKR-1, EXKR-MW1, OKS-100, OKH-100, EXKR-18, EXKR-MW19, and DZMW OFK-100. *Lake Okeechobee ASR Pilot Project Volume 1 of 2* (CH2M Hill 2004), *Central and Southern Florida Project Comprehensive Everglades Restoration Plan Final Technical Data Report* by SFWMD and the United States Army Corps of Engineers (2013) and the Cardno Entrix *Rehabilitation of ASR Well (EXKR-1) Kissimmee River ASR Pilot Site Okeechobee, Florida Final Report* (2011) were reviewed and provided data for EXKR-1. The report entitled *Installation of MW0010 Site Characterization Report Lake Okeechobee ASR Regional Project Site 2 (Kissimmee River Site*) (Golder 2007) was the primary source of data for EXKR-MW1 (MW0010). Data was limited that could be obtained from DBHYDRO for Monitoring wells OKS-100 and OKH-100. The Entrix well construction report entitled: *Construction of Distal Monitor Well No. 18, Kissimmee River ASR Pilot Site, Okeechobee County, Florida* (2010) was reviewed and provided data on EXKR-MW18. The Entrix *Construction of Distal Monitor Well No. 19, Kissimmee River ASR Pilot Site, Okeechobee County, Florida* (2010) was the primary source for EXKR-MW19. The DZMW OKF-100 had two primary references; *Conversion of OKF-100 Site Characterization Report Lake Okeechobee ASR Regional Project Site 2 (Kissimmee River Site) Okeechobee County, Florida* by Golder Associates (2006), *Central and Southern Florida Project Comprehensive Everglades Restoration Plan Final Technical Data Report* by SFWMD and the United States Army Corps of Engineers (2013) and the *Sequence of Construction OKF Conversion Drawings* from Golder Associates (2006). **Table 2** presents well construction details for the Kissimmee River ASR system wells adjacent to the C-38S site (**Figure 3).**



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3. Existing Wells at C-38S

Table 2. Existing Southernmost Well Construction Details on the Northeast Bank of Canal 38 at C-38S

EXKR-1			
Casing Size	**Depth of Casing (feet bls)**	**Open Hole/Monitoring Zone Interval (feet bls)**	**Total Drilled Depth (feet bls)**
42-inch diameter Steel Pit Casing	36	562 - 875	950
34-inch diameter Steel Surface Casing	170	-	-
24-inch diameter Steel Final Casing	562	-	-
*Total drilled depth was 950 feet bls. Back plugged with 8% bentonite-cement slurry to 875 feet bls.			
EXKR-MW1			
Casing Size	**Depth of Casing (feet bls)**	**Open Hole/Monitoring Zone Interval (feet bls)**	**Total Drilled Depth (feet bls)**
24-inch diameter Steel Pit Casing	40	572 - 880	880
16-inch diameter Steel Surface Casing	207	-	-
10-inch diameter Steel Final Casing	572	-	-
OKS-100			
Casing Size	**Depth of Casing (feet bls)**	**Open Hole/Monitoring Zone Interval (feet bls)**	**Total Drilled Depth (feet bls)**
-	100	100-110	110
OKH-100			
Casing Size	**Depth of Casing (feet bls)**	**Open Hole/Monitoring Zone Interval (feet bls)**	**Total Drilled Depth (feet bls)**
-	347	347-387	387
EXKR-MW18			
Casing Size	**Depth of Casing (feet bls)**	**Open Hole/Monitoring Zone Interval (feet bls)**	**Total Drilled Depth (feet bls)**
24-inch diameter Steel Pit Casing	42	575 - 890	890
16-inch diameter Steel Surface Casing	217	-	-
Nominal 6-inch diameter SDR17 Certa-Lok PVC	575	-	-
EXKR-MW19			
Casing Size	**Depth of Casing (feet bls)**	**Open Hole/Monitoring Zone Interval (feet bls)**	**Total Drilled Depth (feet bls)**
24-inch diameter Steel Pit Casing	42	570 - 880	880
16-inch diameter Steel Surface Casing	218	-	-
Nominal 6-inch diameter SDR17 Certa-Lok PVC	570	-	-
OKF-100			
Casing Size	**Depth of Casing (feet bls)**	**Open Hole/Monitoring Zone Interval (feet bls)**	**Total Drilled Depth (feet bls)**
24-inch diameter Steel Pit Casing	90	**Upper Monitoring Zone**	2,043
18-inch diameter Steel Surface Casing	207	565 - 614	-
12-inch diameter Steel Intermediate Casing	565	**Lower Monitoring Zone**	-
6-inch, 8-inch, 4-inch diameter Final Steel Casing with Stainless Steel Screen	993, 997, 1,054	997 - 1,054	-
*Total drilled depth was 2,043 feet bls. Back filled with cement slurry to 1,054 feet bls.			

2.1.1.2 Geological Cross-Sections C-38N and C-38S

To map the UFA, the APPZ and to identify the bounding confining units in the area, cross-sections were produced for the C-38N and C-38S sites. Each cross-section is provided with a section trend. Wells included in the cross-sections were chosen based on data availability and completeness, and relative distance to both the project site and other nearby wells.

Data and cross-sections provided in the report entitled *Hydrogeologic Framework and Geologic Structure of the Floridan Aquifer System and Intermediate Confining Unit in the Lake Okeechobee Area, Florida* (Reese, 2014), reports obtained from DBHYDRO, and published and unpublished reports for the Kissimmee River ASR system were used in the development of the C-38N and C-38S cross sections.

C-38N Geological Cross-Sections

Two cross-sections were produced for the C-38N site, one generally projected south-to-north, and one generally projected west-to-east. Wells that are present in each C-38N cross-section are detailed in Error! Reference source not found. Cross-sections A-A′ and B-B′ are included in **Appendix A.1.1**.

Table 3. Wells in C-38N Cross-Sections

Cross-Section	Well Name			
A-A'	OKF-100	HIF-42	OKF-105	ROMP-29A
B-B'	HIF-42	LKOKEE_ASR	-	-

The cross-sections indicate relatively consistent hydrostratigraphic units throughout the area. From the geological cross-sections produced for C-38N, the UFA is anticipated to be encountered at approximately 560 to 800 feet bls. The APPZ is expected to extend from approximately 1,360 to 1,575 feet bls. Some variation in the position of the UFA and APPZ can be observed in the cross-sections. This variation may be due to the age of some the data and the accuracy of the survey of the wellhead. In some instances, the elevation was estimated and may result in some of the variability in the position of these units as depicted on the cross sections. The Lower Floridan Aquifer (LFA) is anticipated to be encountered at 1,660 to 1,700 feet bls. It is important to note that the elevation data from some wells were converted from National Geodetic vertical Datum (NGVD) 1929 to North American Vertical Datum (NAVD) 1988.

C-38S Geological Cross-Sections

Two cross-sections were produced for the C-38S site, C-C′ generally projected south-to-north, and D-D′ generally projected west-to-east. Data and cross-section provided in the report entitled *Hydrogeologic Framework and Geologic Structure of the Floridan Aquifer System and Intermediate Confining Unit in the Lake Okeechobee Area, Florida* by Reese (2014 Wells that are present in each C-38S cross-section are detailed in **Table 4**. Cross-sections C-C′ and D-D′ are included in **Appendix A.1.2**.

Table 4. Wells in C-38S Cross-Sections

Cross-Section	Well Name							
C-C'	EXKR-MW18	OKF-100	EXKR-1	EXKR-MW19	-	-	-	-
D-D'	GLF-5	W-15880	BREX-1	W-2396	GLF-1	W-5439	OKF-100	LKOKEE_ASR

Similar to the C-38N site, hydrostratigraphic layers are relatively consistent throughout the area. At the C-38S site, the UFA is anticipated to be encountered at approximately 575 to 800 feet bls. The APPZ is expected to extend from approximately 1,360 to 1,575 feet bls. Some variation in the position of the UFA and APPZ can be observed in the cross-sections. The LFA is anticipated to be encountered at 1,660 to 1,700 feet bls. In some instances, the elevation was estimated and may result in some of the variability of these units. It is important to note that the elevation data was converted from NGVD29 to NAVD88.

2.1.1.3 Geological Cross-Sections Summary

The cross-sections indicated relatively consistent hydrostratigraphic layers throughout the area covered by the cross-sections. However, the APPZ at well location W-15880 was assumed to be higher in the section than indicated by the USGS (Reese et al., 2007). From the geological cross-sections at both C-38N and C-38S, the UFA is anticipated to be encountered at approximately 575 to 800 feet bls. The APPZ is expected at approximately 1,340 to 1,570 feet bls.

2.1.1.4 Hydrogeologic Parameters

Documentation review included an investigation into local hydrogeologic parameters provided in construction and testing reports from aquifer performance tests, packer testing, slug tests, and cycle testing. Transmissivities and flow zones were identified and superimposed over the cross sections to provide correlation between wells and to determine consistencies in aquifer properties across the area.

Hydrogeologic Parameters at C-38N

Transmissivity identified in the available documents is presented on the C-38N cross-sections A-A′ and B-B′ and in **Appendix B**. These reported transmissivities are summarized below in **Table 5.**

Table 5. C-38N Cross-Section Transmissivities

Cross-Section A-A’			
Well Name	**UFA Transmissivity (ft^2/d)**	**APPZ Transmissivity (ft^2/d)**	**Other Zone Transmissivity (ft^2/d)**
OKF-100	-	-	36,494-40,095
HIF-42	11,998	17,998	-
OKF-105	-	-	-
ROMP29A	36,815-37,685	-	-
Cross-Section B-B’			
Well Name	**UFA Transmissivity (ft^2/d)**	**APPZ Transmissivity (ft^2/d)**	**Other Zone Transmissivity (ft^2/d)**
HIF-42	11,998	17,998	-
LKOKEE_ASR	-	620,238	-

Transmissivities are somewhat variable across the area within both the UFA and the APPZ, ranging from approximately 11,998 to 37,685 feet squared per day (ft^2/d) in the UFA, and from approximately 17,998 to 620,238 ft^2/d in the APPZ.

Hydrogeologic Parameters at C-38S

Transmissivity presented on C-38S cross-sections C-C′ and D-D′ (**Appendix B)** were obtained from the reviewed documents and reports. A summary of reported transmissivities is presented in **Table 6.**

Table 6. C-38S Cross-Section Transmissivities

Cross-Section C-C′			
Well Name	**UFA Transmissivity (ft^2/d)**	**APPZ Transmissivity (ft^2/d)**	**Other Zone Transmissivity (ft^2/d)**
EXKR-MW18	-	-	-
OKF-100	-	-	36,494-40,095
EXKR-1	43,443	-	-
EXKR-MW19	-	-	-
Cross-Section D-D′			
Well Name	**UFA Transmissivity (ft^2/d)**	**APPZ Transmissivity (ft^2/d)**	**Other Zone Transmissivity (ft^2/d)**
GLF-5	-	-	-
W-15880	-	-	-
BREX-1	11,228	-	-
W-2396	-	-	-
GLF-1	-	-	-
W-5439	-	-	-
OKF-100	-	-	36,494-40,095
LKOKEE_ASR	-	620,238	-

Transmissivities are somewhat variable across the area within both the UFA and the APPZ, ranging from approximately 11,228 to 43,443 ft^2/d in the UFA. Only one transmissivity of approximately 620,238 ft^2/d was identified for the APPZ near the C-38S site.

2.1.1.5 Hydrogeologic Parameters Summary

Transmissivities are somewhat variable across the study area within both the UFA and the APPZ, ranging from approximately 11,228 to 37,685 ft^2/d in the UFA, and from approximately 17,998 to 620,238 ft^2/d in the APPZ.

2.1.1.6 Water Quality

Available water quality parameters were reviewed, and total dissolved solids (TDS) was identified as a key parameter. TDS is presented on the cross-sections in order to visualize the distribution of the parameter within each aquifer and across the area. These data, as well as the hydraulic data discuss above, were used to evaluate aquifer consistency across the area and to inform the preliminary well designs.

Water Quality at C-38N

TDS concentrations are presented in the C-38N cross-sections A-A′ and B-B′ and in **Appendix C**. These reported TDS concentrations are summarized below in **Table 7.**

Table 7. C-38N Cross-Section TDS Concentrations

Cross-Section A-A’				
Well Name	**UFA TDS (mg/L)**	**APPZ TDS (mg/L)**	**TDS Other Zones (mg/L)**	**USDW (feet bls)**
OKF-100	1,300	-	-	1,640 feet bls
HIF-42	680	3,600	14,000 (1,703-1,763 feet bls)	1,600 feet bls
OKF-105	1,473	6,681	18,836 (2,130-2,251 feet bls)	1,660 feet bls
ROMP-29A	-	-	-	-
Cross-Section B-B’				
Well Name	**UFA TDS (mg/L)**	**APPZ TDS (mg/L)**	**TDS Other Zone (mg/L)**	**USDW (feet bls)**
HIF-42	680	3,600	14,000 (1,703-1,763 feet bls)	1,600 feet bls
LKOKEE_ASR	-	5,740	6,710	-

Within the UFA, TDS concentrations varied throughout the study area, with concentrations ranging from 680 to 1,473 milligrams per Liter (mg/L). Within the APPZ, TDS concentrations are highly variable, ranging from 3,600 to 6,681 mg/L.

In addition to water quality data, the identification of the base of the Underground Source of Drinking Water (USDW) was overlaid on the cross-sections where available. The USDW is the depth at which TDS concentrations are greater than or equal to 10,000 mg/L. Data from three wells had reported TDS concentrations that identified the base of the USDW. At HIF-42 (located on the C-38N site), the base of the USDW was identified at 1,600 feet bls (CH2M Hill, 2008), which is below the base of the APPZ. At OKF-105, the USDW was identified at approximately 1,660 feet bls in the middle of the LFA. The USDW was identified in OKF-100 at 1,640 feet bls (Reese, 2004). The USDW was not identified within the APPZ in the area.

Water Quality at C-38S

TDS concentrations are presented in the C-38S cross-sections C-C′ and D-D′ and in **Appendix C**. These reported TDS concentrations are summarized below in

Table 8.

Table 8. C-38S Cross-Section TDS Concentrations

Cross-Section C-C’				
Well Name	**UFA TDS (mg/L)**	**APPZ TDS (mg/L)**	**TDS Other Zones (mg/L)**	**USDW (feet bls)**
EXKR-MW18	540	-	-	-
OKF-100	1,300	-	-	1,640 feet bls
EXKR-1	820	-	-	-
EXKR-MW19	800	-	-	-
Cross-Section D-D’				
Well Name	**UFA TDS (mg/L)**	**APPZ TDS (mg/L)**	**TDS Other Zones (mg/L)**	**USDW (feet bls)**
GLF-5	-	-	3,574-4,203*	-
W-15880	-	-	-	-
BREX-1	1,750-1,770	1,720	-	1,650 feet bls (estimated)
W-2396	-	-	-	-
GLF-1	1,058	-	-	-
W-5439	-	-	-	-
OKF-100	1,300	-	-	1,640 feet bls
LKOKEE_ASR	-	5,740	6,710	-

*TDS values may be a mixture of formation water from both the UFA and APPZ since the open hole is from 290 to 1,624 feet bls.

Within the UFA, TDS concentrations varied throughout the study area, with concentrations ranging from 540 to 1,770 mg/L. Within the APPZ, TDS concentrations are highly variable, ranging from 1,720 to 5,740 mg/L.

Data from two wells had reported TDS concentrations that identified the base of the USDW. At BREX-1, the depth of the USDW was estimated to be 1,650 feet bls based on chloride concentrations, though the boundary was not encountered as the total drilled depth of the well was 1,618 feet bls (Missimer Groundwater Science, 2007). OKF-100 encountered the USDW interface at 1,640 feet bls (Reese, 2004). The USDW is expected to be encountered at approximately 1,640 feet bls, approximately 60 feet below the APPZ or approximately 20 feet above the LFA. Similar to C-38N, the USDW was not identified within the APPZ in the area.

2.1.1.7 Water Quality Summary

Within the UFA, TDS concentrations varied throughout the study area. TDS concentrations ranged from 540 to 1,770 mg/L in the UFA. Within the APPZ, TDS concentrations are highly variable ranging from 1,720 to 6,681 mg/L. The USDW was not identified within the APPZ in the area.

Overall, data reviewed from four wells had reported TDS concentrations that denote the base of the USDW. At HIF-42 (located on the C-38N site), the base of the USDW was identified at 1,600 feet bls (CH2M Hill, 2008), which is just below the APPZ. At OKF-105, TDS concentrations greater than 10,000 mg/L were identified at approximately 1,660 feet bls. At BREX-1, the depth of the USDW was estimated to be 1,650 feet bls based on chloride concentrations (Missimer Groundwater Science, 2007). OKF-100 encountered the USDW interface at 1,640 feet bls (Reese, 2004).

2.1.2 Wellfield and System Layout

C-38N and C-38S Test Well Program

The ASR test well program included the design of one UFA and one APPZ ASR well, DZMW and Surficial aquifer system (SAS) monitoring well. Also, an additional APPZ monitoring well will be constructed at the C-38S site. This plan also included aquifer performance tests (APT) and data analysis. Data from the APT will be used to develop a groundwater flow model for the area. This model will be used to confirm the ASR well spacing described below and will support future permitting efforts.

One existing UFA monitoring well is present at the C-38S site (EXKR-MW18). However, several monitoring wells are present on the Kissimmee ASR well site across the river. SFWMD has proposed the construction of two ASR test wells, one completed in the UFA and the other completed in the APPZ. Two monitoring wells are proposed with one monitoring the SAS and the other monitoring the APPZ. There also is one proposed DZMW to monitor the UFA and APPZ.

2.1.2.2 ASR System Layout

To prepare for the test ASR well system and the planned pre-application meeting with FDEP at both the C-38N and C-38S sites, Stantec developed an initial test well layout. As part of the FDEP UIC permit application, SFWMD developed a unique naming convention for the ASR and monitoring wells. These names are identified below in the figures. SFWMD property ownership information is also provided on each figure.

C-38N ASR System Layout

Figure 4 shows the proposed UFA and APPZ ASR test wells, A01C38NU and A02C38NL, respectively. There will be three DZMWs associated with the C-38N test program. These wells are outlined below:

- The ASR wells will be approximately 700 feet southeast of existing DZMW HIF-42,
- DZMW M01C38NU and M01C38NL, will be approximately 1,100 feet southeast of ASR wells A01C38NU and A02C38NL,
- The final DZMW, M02C38NU and M02C38NL, will be located approximately 2,000 feet northeast of A01C38NU and A02C38NL on the northeast bank of Canal 38,
- SAS monitoring well (M03C38NS) is anticipated to be approximately 250 feet southeast of ASR wells A01C38NU and A02C38NL.

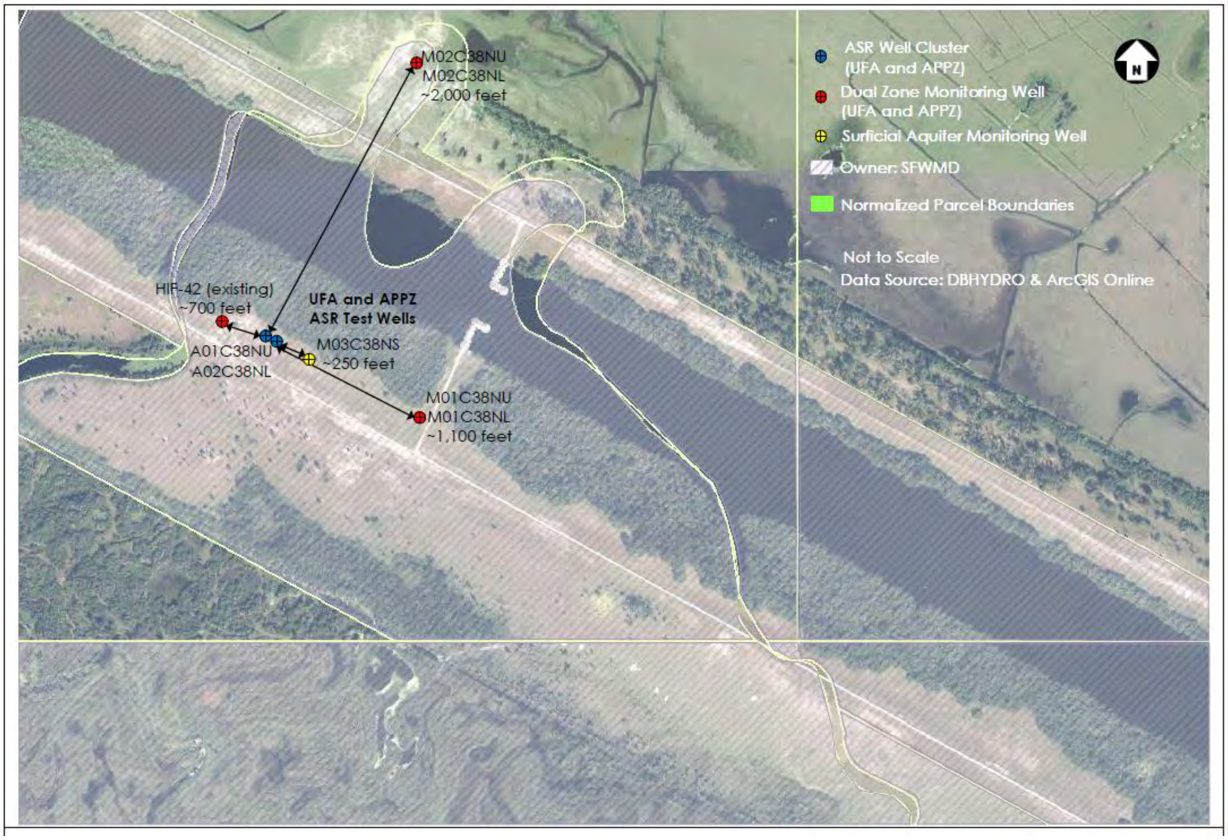


Figure 4. C-38N General Test ASR System Site Layout

C-38S ASR System Layout

The proposed UFA and APPZ ASR wells (**Figure 5**) are designated A01C38SU and A02C38SL, respectively. A number of new monitoring wells will be constructed as part of the test well program, and existing monitoring wells in the area will be used to monitor the UFA and APPZ response to pumping. These wells are outlined below:

New Monitoring Wells:

- APPZ Monitoring well M01C38SL will be approximately 700 feet from the ASR well and located near existing well EXKR-MW18
- The SAS monitoring well, M02C38SS, will be located approximately 250 feet northwest of the ASR wells.
- DZMW M03C38SU and M03C38SL will be constructed approximately 1,100 feet northwest of the ASR wells.

Existing Monitoring Wells:

- EXKR-MW19 is approximately 6,000 feet northwest of the proposed test ASR wells,
- EXKR-1 is approximately 2,000 feet north northwest of the test ASR wells,
- EXKR-MW10 is approximately 2,100 feet north of the test ASR wells,
- OKF-100 is approximately 2,300 feet northeast of the test ASR wells,
- EXKR-MW18 is approximately 700 feet southeast of the proposed test ASR wells.

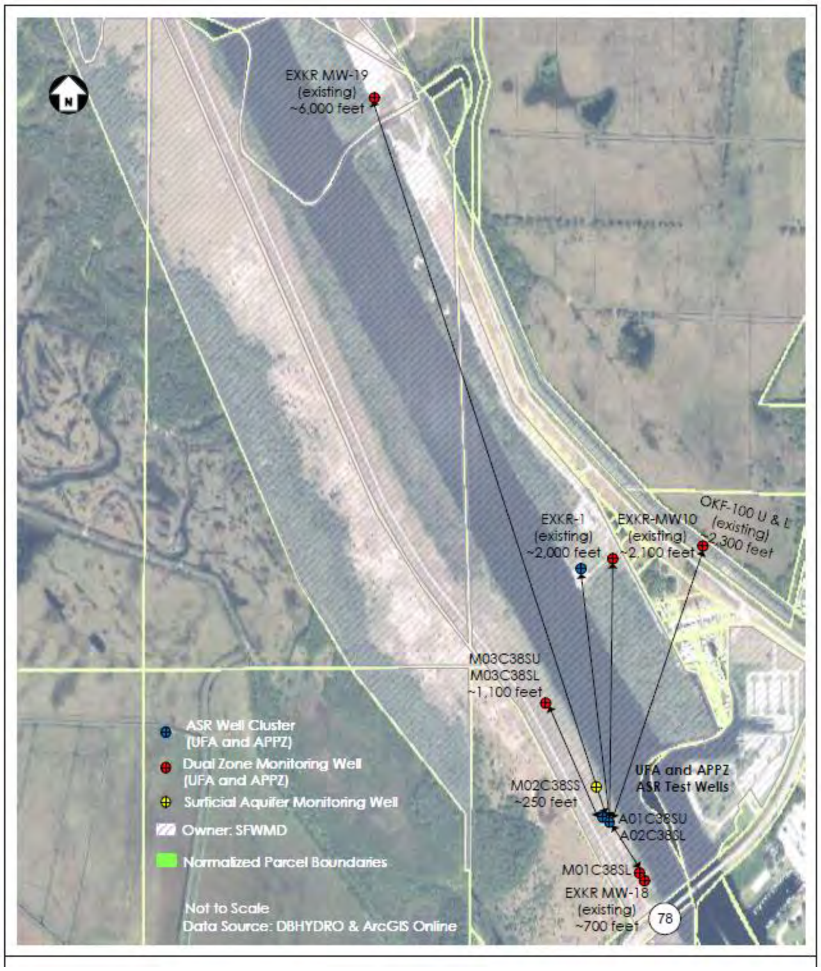


Figure 5. C-38S General ASR System Site Layout

2.1.2.3 General Site Layout

Based on the review of a local groundwater model prepared for the Kissimmee ASR (U.S. Army Corps of Engineers, 2013), it appears that an ASR well spacing of approximately 1,000 feet should be sufficient to accommodate interference effects associated with injection and recovery from the UFA and APPZ. However, this model is limited, and a detailed groundwater modeling will be needed to confirm this assumption. Based on this well spacing, a generalized ASR wellfield site plans were developed for the C-38N and C-38S sites (**Appendix D, Sheets 5 through 14**).

The preliminary site plans incorporated identified environmental conditions and concerns detailed by South Florida Engineering and Consulting, LLC (2020). In order to address these environmental conditions as part of the preparation of the site plans, these environmental features were superimposed over the drawings including wetlands and endangered species nesting grounds.

Light detection and ranging (LiDAR) data were obtained from SFWMD to aid in the development of the preliminary drawings. The topographic information aided in defining the levee and bench system in the area. All ASR system features are located off the levee and placed along the bench between the Kissimmee River (Canal 38) and the toe of the levee. Existing structures such as the S-65E spillway and lock, the S-65E tailwater weir and HIF-42 are also identified on these drawings.

C-38N General Site Layout

The C-38N ASR wellfield will consist of five UFA and five APPZ ASR wells. These plans also include SAS and DZMWs. The monitoring wells will be designated “storage zone monitoring wells” and will monitor the aquifer associated with each ASR well cluster.

ASR systems including the pipeline, intake/outfall structure, and treatment systems are included on the preliminary plan sets. The proposed 18-inch diameter pipeline that will connect the ASRs to the treatment system and the outfall structure is provided on each drawing. The intake and outfall structures at the C-38N site are located in the Kissimmee ancestral river channels to minimize disturbances to wetlands in the area. The general treatment system footprint is shown on these drawing near the northern most intake/outfall structure. The intake structures will be connected to the treatment system via an 18-inch diameter pipeline. A wildlife exclusion curtain will be installed at the mouth of each ancestral channel within the Kissimmee River. All preliminary site plans for C-38N are provided in **Appendix D, Sheets 10 through 14**.

C-38S General Site Layout

As with the C-38N site, the preliminary C-38S ASR system plans includes an 18-inch diameter pipeline extending between the wells, the treatment system and the intake/outfall structure. The UFA and APPZ ASR well, as well as the storage zone monitoring wells are also shown on these plans. All preliminary plans for C-38S are provided in **Appendix D, Sheets 5 through 9**.

2.1.3 Well Design

Based on the available hydrogeologic data for the area, Stantec developed preliminary ASR and monitoring well design diagrams for the C-38N and C-38S sites. These designs have been reviewed by SFWMD and submitted in the C-38N and C-38S FDEP UIC Test Well Construction Permit Applications. If needed, the preliminary ASR and monitoring well designs will be adjusted based on the results of a planned continuous coring program that is scheduled to be completed prior to the construction of the ASR test well system.

The proposed casing depths provided in the preliminary ASR well and monitoring well construction diagrams are based on site specific information for confining units and the position of the UFA and APPZ. In addition to the DZMW construction diagrams, SAS and APPZ monitoring well construction diagrams were also prepared using the same site-specific information. All well designs show diameters, approximate casing depths, and open intervals. The preliminary well diagrams for the C-38N and C-38S sites are provided in **Appendix D, Sheets 20 and 21**. These designs may change as site-specific hydrogeologic data is collected and designs may be adjusted in the field during construction.

2.1.3.1 Proposed Test/Exploratory Wells

Wells A01C38NU (C-38N) and A01C38SU (C-38S) are UFA ASR wells. The anticipated total depth of A01C38NU and A01C38SU is approximately 900 feet bls. The open hole interval for ASR wells A01C38NU and A01C38SU is expected to extend from approximately 600 to 900 feet bls in the UFA. Well construction details are shown in **Table 9**. The well design drawing is included in **Appendix D, Sheets 20 and 21**.

Well A02C38NL (C-38N) and A02C38SL (C-38S) are APPZ ASR wells with a total depth of approximately 1,600 feet bls. The open hole interval for ASR wells A02C38NL and A02C38SL is expected to extend from 1,300 to 1,600 feet bls in the APPZ. Well construction details are shown in **Table 9.**

Table 9. ASR Well Construction Details

A01C38NU and A01C38SU (UFA ASR Wells)			
Casing Size	**Depth of Casing (feet bls)**	**Casing Wall Thickness (inches)**	**Open Hole Interval (feet bls)**
44-inch diameter Steel Pit Casing	40	0.375	-
34-inch diameter Steel Surface Casing	150	0.375	-
24-inch diameter Steel Final Casing	600	0.500	-
Total Depth	900	-	600-900
A02C38NL (APPZ ASR Well)			
Casing Size	**Depth of Casing (feet bls)**	**Casing Wall Thickness (inches)**	**Open Hole Interval (feet bls)**
50-inch diameter Steel Pit Casing	40	0.250	
44-inch diameter Steel Surface Casing	150	0.375	-
34-inch diameter Steel Intermediate Casing	600	0.375	-
24-inch diameter Steel Final Casing	1,300	0.500	-
Total Depth	1,600	-	1,300-1,600

2.1.3.2 Proposed Monitoring Wells

The M01C38NU and M01C38NL (C-38N), M02C38NU and M02C38NL (C-38N), and M03C38SU and M03C38SL (C-38S) are UFA and APPZ DZMWs. The monitoring interval for the upper monitoring zone (UMZ) for all the DZMWs extends from 600 to 800 feet bls. The lower monitoring zone (LMZ) for the DZMWs will have a 100-foot monitoring zone interval extending from 1,400 to 1,500 feet bls. Well construction details are shown in

Table 10**.** Well M03C38NS (C-38N) and M02C38SS (C-38S) are SAS monitoring wells and will have a monitoring zone extending from approximately 100 to 120 feet bls. Well M01C38SL (C-38S) is an APPZ monitoring well with an open hole interval extending from 1,400 to 1,500 feet bls. The monitoring well design drawings is included in **Appendix D, Sheets 20 and 21**.

Table 10. Monitoring Well Construction Details

M01C38NU and M01C38NL, M02C38NU and M02C38NL and M03C38SU and M03C38SL (UFA and APPZ DZMWs)			
Casing Size	**Depth of Casing (feet bls)**	**Casing Wall Thickness (inches)**	**Monitoring Zone Interval (feet bls)**
34-inch diameter Steel Pit Casing	40	0.375	**Upper Monitoring Zone**
24-inch diameter Steel Surface Casing	150	0.375	600-800
16-inch diameter Steel Final Casing	600	0.375	**Lower Monitoring Zone**
6-inch diameter Fiberglass Reinforced Plastic (FRP) Tubing	1,400	TBD	1,400-1,500
Total Depth	1,500	-	-
M03C38NS and M02C38SS (SAS Monitoring Well)			
Casing Size	**Depth of Casing (feet bls)**	**Casing Wall Thickness (inches)**	**Monitoring Zone Interval (feet bls)**
12-inch diameter Steel Pit Casing	40	0.375	-
4-inch diameter SDR-17 polyvinyl chloride (PVC)	100	TBD	-
4-inch diameter PVC Screen	120	TBD	-
Total Depth	120	-	100-120
M01C38SL (APPZ Monitoring Well)			
Casing Size	**Depth of Casing (feet bls)**	**Casing Wall Thickness (inches)**	**Monitoring Zone Interval (feet bls)**
34-inch diameter Steel Pit Casing	40	0.375	-
24-inch diameter Steel Surface Casing	150	0.375	-
14-inch diameter Steel Final Casing	600	0.375	-
6-inch diameter FRP	1,400	TBD	-
Total Depth	1,500	-	1,400-1,500

3.0 REFERENCES

Anderson, S., Collins, B., and Sunderland, R. S. A., 2011. Hydrogeologic Investigation of the Florida Aquifer System at the S-65C Site (Wells OKF-105). South Florida Water Management District Technical Publication WS-32, July 2011.

Cardno and Entrix, 2011. Rehabilitation of ASR Well (EXKR-1) Kissimmee River ASR Pilot Site Okeechobee, Florida Final Report.

CH2M Hill, 1989. Construction and Testing of the Aquifer Storage Recovery (ASR) Demonstration Project for Lake Okeechobee, Florida. Report prepared for South Florida Water Management District, December 1989 p. tables, figures, appendices.

CH2M Hill, 2004. *Lake Okeechobee ASR Pilot Project Volume 1 of 2.*

CH2M Hill, 2008. Paradise Run Aquifer Storage and Recovery Test-Monitor Well HIF-42. Report prepared for South Florida Water Management District, November 2008, p. 1-1 to 6-1, plus figures, tables, and appendices.

DBHYDRO. (n.d.). Retrieved from sfwmd.gov.

DBHYDRO. Well Station Identification and Geophysical Logs GLF-1, dated October 1979.

DBHYDRO. Well Station Identification and Geophysical Logs GLF-5, dated September 1982.

Entrix, 2010a. Construction of Proximal Monitor Well No. 18 (MW-18), Kissimmee River ASR Pilot Site, Okeechobee County, FL. Report prepared for the US Army Corps of Engineers – Jacksonville District, dated July 2010, 11 p. plus tables, figures, and appendices.

Entrix, 2010b. Construction of Distal Monitor Well No. 19 (MW-19), Kissimmee River ASR Pilot Site, Okeechobee County, FL. Report prepared for the US Army Corps of Engineers – Jacksonville District, dated July 2010, 9 p. plus tables, figures, and appendices.

Fetter, C.W., 2001. Applied Hydrogeology, 4th Edition. Golder Associates, 2006. *Conversion of OKF-100 Site Characterization Report Lake Okeechobee Aquifer Storage & Recovery (ASR) Regional Project Site 2 (Kissimmee River Site) Okeechobee County, Florida.*

Golder Associates, November 2006. *Sequence of Construction OKF Conversion Drawings.*

Golder Associates, *Installation of MW0010 Site Characterization Report Lake Okeechobee ASR Regional Project Site 2 (Kissimmee River Site*).

Mallams, J.L., and Lee, R.A., 2005, ROMP 29A monitor well site, Highlands County, Florida—Final report, exploratory coring, monitor well construction, and aquifer testing: Southwest Florida Water Management District, Brooksville, Florida.

McMillian, C., Verrastro R., 2008. Construction and Testing of an Upper Floridan Aquifer Monitor Well L-63N Canal ASR Site Okeechobee, Florida. South Florida Water Management District Technical Publication WS-27, December 2008.

Missimer Groundwater Science, 2007, Seminole Tribe of Florida Brighton Reservation aquifer storage and recovery exploratory well program, p. 1-1 to 6-1, plus appendices.

Reese, R.S., 2004. Hydrogeology, Water Quality, and Distribution and Sources of Salinity in the Floridan Aquifer System, Martin and St. Lucie Counties, Florida.

Reese, R.S., 2014, Hydrogeologic framework and geologic structure of the Floridan aquifer system and intermediate confining unit in the Lake Okeechobee area, Florida: U.S. Geological Scientific Investigations Map 3288, 8 sheets, plus 12-p. pamphlet.

Reese, R. S. and Richardson E., 2007. Synthesis of the Hydrogeologic Framework of the Floridan Aquifer System and Delineation of a Major Avon Park Permeable Zone in Central and Southern Florida, U.S. Geological Survey Scientific Investigations Report 2007-5207.

South Florida Engineering and Consulting, LLC, 2020. Task 1 – Draft Report Biological/Ecological Evaluations of the Lake Okeechobee Watershed Restoration Project C-38 ASR Clusters.

Stantec, 2020a. Lake Okeechobee Watershed Restoration Project, Aquifer Storage and Recovery Constructability Evaluation, C-38N and C-38S Sites.

Stantec, 2020b. SFWMD Lake Okeechobee Watershed Restoration Project (LOWRP) Aquifer Storage and Recovery (ASR) Wells Water Treatment Technology Evaluation.

U.S. Army Corps of Engineers, 2002, Lake Okeechobee aquifer storage and recovery (ASR) pilot project—Hydrogeologic investigation of the Floridan aquifer system, Kissimmee River Site, Okeechobee County, Florida, in cooperation with the South Florida Water Management District.

U.S. Army Corps of Engineers, December 2013, Central and Southern Florida Project Comprehensive Everglades Restoration Plan Final Technical Data Report Aquifer Storage and Recovery Pilot Project, Kissimmee River ASR System and Hillsboro ASR System, in cooperation with the South Florida Water Management District.

William Ward, Michael Wacker, Kevin Cunningham, Janine Carlson, Robert Renken. (2002). Sequence-stratigraphic analysis of the ROMP 29A test corehole and its relation to the carbonate porosity and regional transmissivity in the Floridan aquifer system, Highlands County, Florida. Tallahassee, Florida: U.S. Geological Survey.

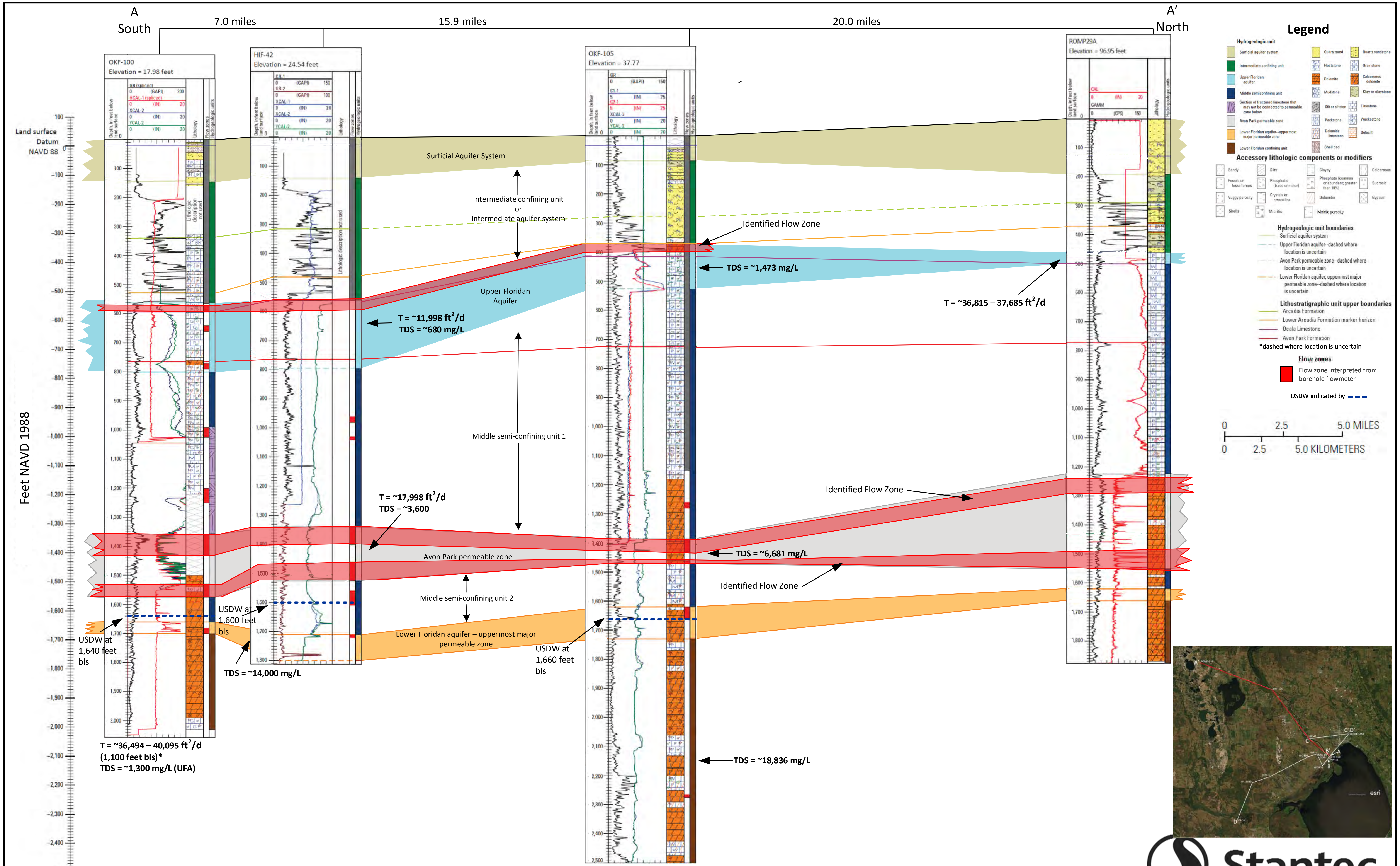
APPENDIX A

Cross-Sections

Appendix A

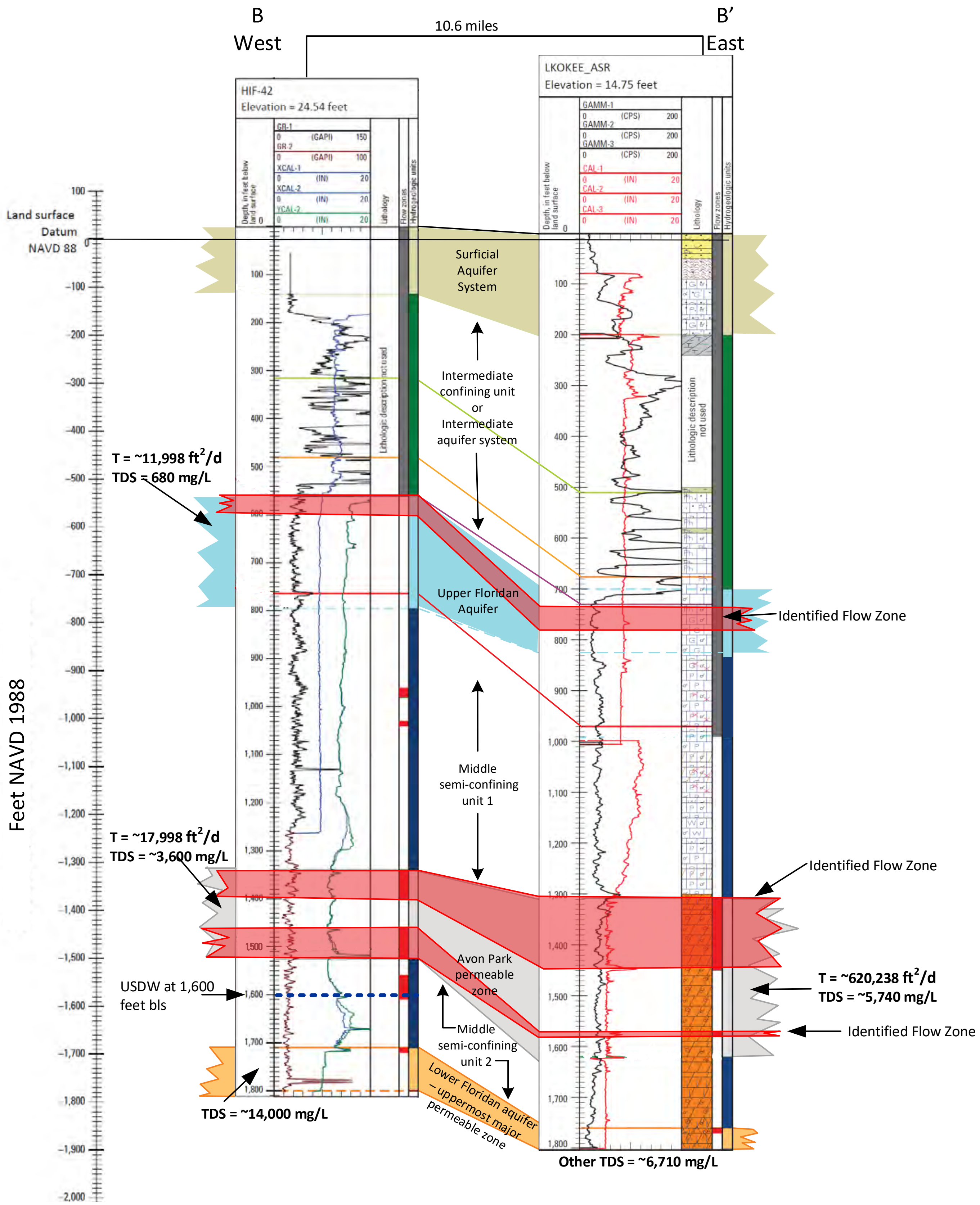
A.1 CROSS-SECTIONS

A.1.1 C-38N Cross-Sections



Stratigraphic and Hydrogeologic Cross Section A-A’
SFWMD C-38N Site

TDS = Total Dissolved Solids
T = Transmissivity
*Sources: modified from USGS and DBHydro



Legend

Hydrogeologic unit

- Surficial aquifer system
- Intermediate confining unit
- Upper Floridan aquifer
- Middle semiconfining unit
- Section of fractured limestone that may not be connected to permeable zone below
- Avon Park permeable zone
- Lower Floridan aquifer--uppermost major permeable zone
- Lower Floridan confining unit

Lithology

- Quartz sand
- Quartz sandstone
- Floatstone
- Grainstone
- Dolomite
- Calcareous dolomite
- Mudstone
- Clay or claystone
- Silt or siltstone
- Limestone
- Packstone
- Wackestone
- Dolomitic limestone
- Dolosilt
- Shell bed

Hydrogeologic unit boundaries

- Surficial aquifer system
- Upper Floridan aquifer--dashed where location is uncertain
- Avon Park permeable zone--dashed where location is uncertain
- Lower Floridan aquifer, uppermost major permeable zone--dashed where location is uncertain

Lithostratigraphic unit upper boundaries

- Arcadia Formation
- Lower Arcadia Formation marker horizon
- Ocala Limestone
- Avon Park Formation

*dashed where location is uncertain

Accessory lithologic components or modifiers

- Sandy
- Silty
- Clayey
- Calcareous
- Shells
- Micritic
- Fossils or fossiliferous
- Phosphatic (trace or minor)
- Phosphate (common or abundant; greater than 10%)
- Sucrosic
- Moldic porosity
- Vuggy porosity
- Crystals or crystalline
- Dolomitic
- Gypsum

Flow zones

🟥 Flow zone interpreted from borehole flowmeter

USDW indicated by - - -

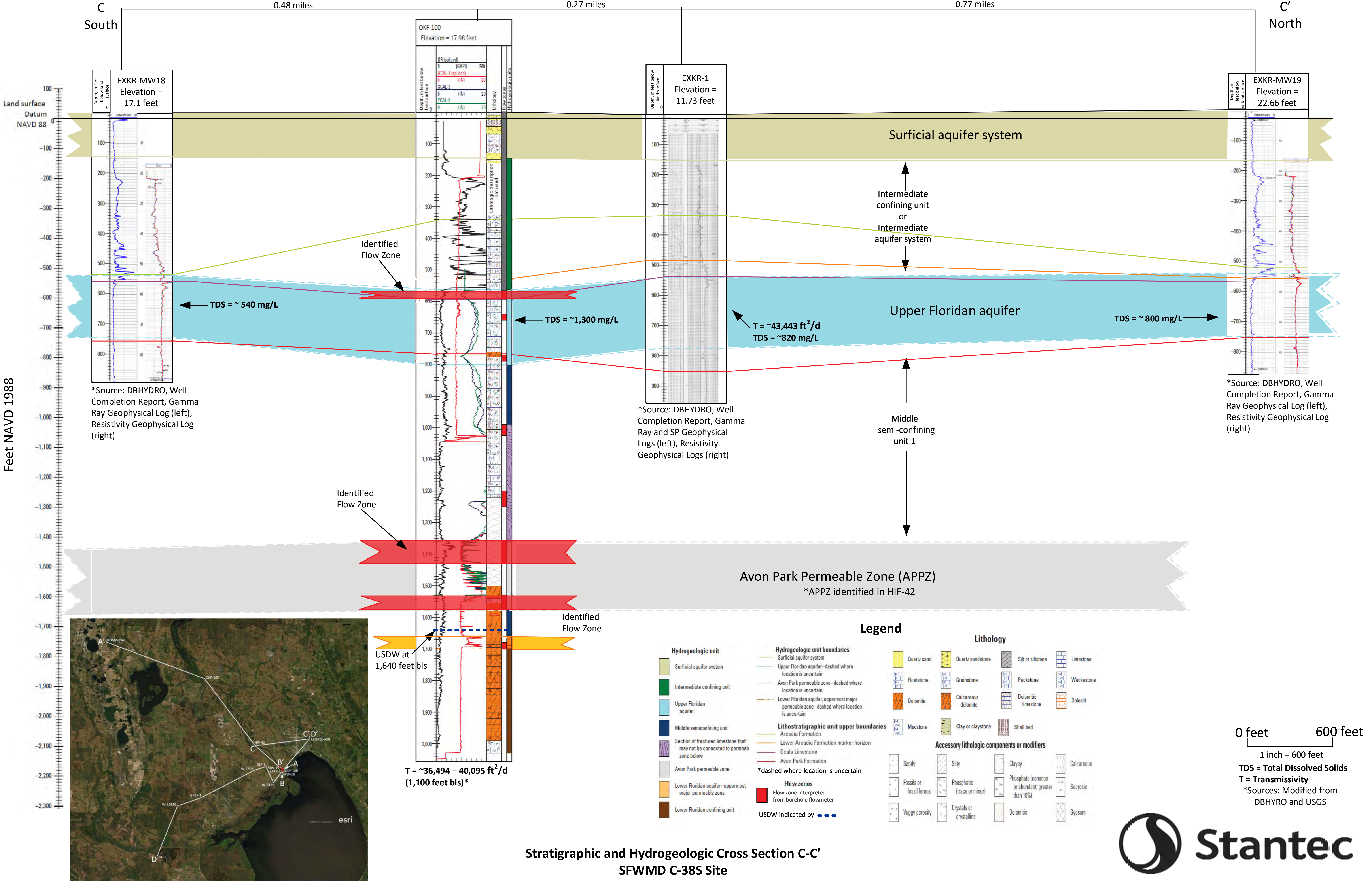
0 2.5 5.0 MILES
0 2.5 5.0 KILOMETERS

TDS = Total Dissolved Solids
T = Transmissivity
*Sources: modified from USGS and DBHydro

Stratigraphic and Hydrogeologic Cross Section B-B'
SFWMD C-38N Site

Stantec

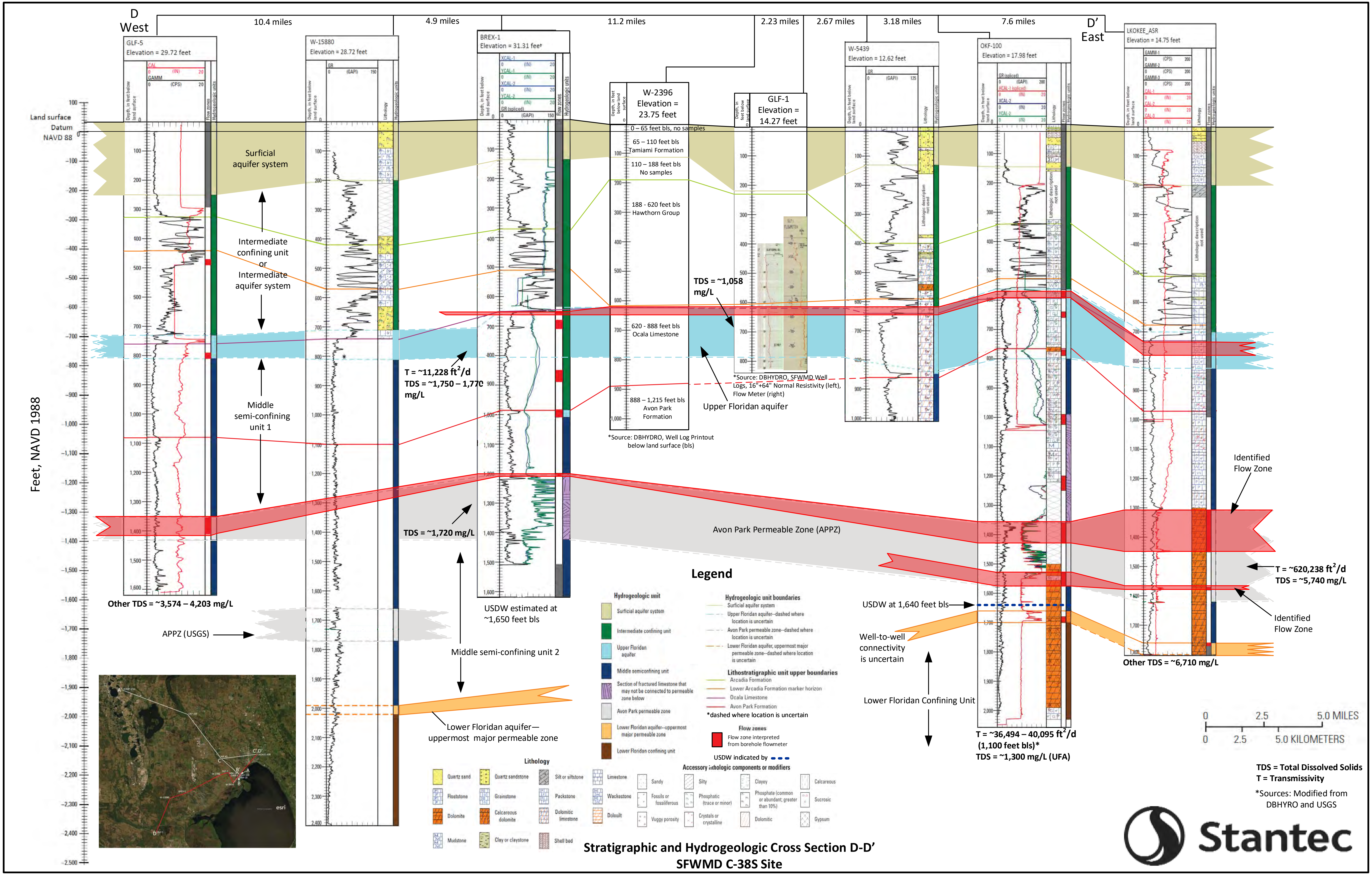
A.1.2 C-38S Cross-Sections



TDS = Total Dissolved Solids
T = Transmissivity
*Sources: Modified from DBHYRO and USGS

Stratigraphic and Hydrogeologic Cross Section C-C’
SFWMD C-38S Site

Stantec



Stratigraphic and Hydrogeologic Cross Section D-D'
SFWMD C-38S Site

APPENDIX B

Hydrogeologic Parameters

Appendix B

B.1 HYDROGEOLOGIC PARAMETERS

Summary of Estimated Transmissivity and Storage Coefficient Values - Kissimmee ASR Site

Parameter	ASR Cycle	Solution	MW-10 SZMW (350 ft) ft^2/day	MW-10 SZMW (350 ft) gpd/ft	OKF-100 SZMW (1,100 ft.) ft^2/day	OKF-100 SZMW (1,100 ft.) gpd/ft	Composite ft^2/day	Composite gpd/ft
Transmissivity	Recharge (injection) Cycle Test 1	Cooper-Jacob	32,500	243,100	40,100	299,948	33,900	253,572
		Hantush-Jacob	20,099	150,341	36,499	273,013	23,199	173,529
	Recovery (Extraction) Cycle 3	Cooper-Jacob	28,200	210,936				
		Hantush-Jacob	30,200	225,896				
	Average		**27,750**	**207,568**	**38,300**	**286,480**	**28,550**	**213,550**
Storage	Post Recovery (extraction) Cycle 1	Cooper-Jacob	7.49×10^{-5}	-	8.26×10^{-5}	-	8.34 x 10-^{5}	-
		Hantush-Jacob	1.44×10^{-4}	-	6.92×10^{-5}	-	1.00×10^{-4}	-
	Recovery (Extraction) Cycle 3	Cooper-Jacob	9.39×10^{-5}					
		Hantush-Jacob	5.11×10^{-5}					
	Log Average		**8.48×10^{-5}**		**7.56×10^{-5}**		**9.13×10^{-5}**	

Estimated Transmissivity

MW-10 350-ft SZMW (ft^2/day)	MW-10 350-ft SZMW (gpd/ft)	OKF-100 1,100-ft SZMW (ft^2/day)	OKF-100 1,100-ft SZMW (gpd/ft)
20,100	150,348	36,500	273,020
30,200	225,896	40,095	299,948

Well Name	Test	Depth (feet bls)	Estimated Transmissivity Drawdown (gpd/ft)	Estimated Transmissivity Drawdown (ft^2/day)	Estimated Transmissivity Recovery (gpd/ft)	Estimated Transmissivity Recovery (ft^2/day)
HIF-42	Step-Drawdown Test 1	560 - 880	14,960	2,000	--	--
HIF-42	Step-Drawdown Test 2	560 - 1,110	22,440	3,000	--	--
HIF-42	Constant Test 1	560 - 1,110	89,760	11,998	82,280	10,999
HIF-42	Step-Drawdown Test 3	1,310 - 1,530	14,960	2,000	--	--
HIF-42	Constant Test 2	1,310 - 1,530	134,640	17,998	41,888	5,599

Well Name	Transmissivity Range (UFA) (gpd/ft)	Transmissivity Range (UFA) (ft^2/day)	Transmissivity Range (MFA) (gpd/ft)	Transmissivity Range (MFA) (ft^2/day)
HIF-42	14,960 - 22,440	2,000 – 3,000	74,800 - 149,600	9,999 – 19,997

Well Name	Depth (feet bls)	Transmissivity (gpd/ft)	Transmissivity (ft^2/day)	Method	Test No.
OK-105	372 - 525	852	114	Hantush-Jacob method (1955)	Aquifer Test No. 1
OK-105	372 - 525	1,451	194	Theis (1935)	Aquifer Test No.1
OK-105	2,412 - 2,472	8,200	1,096	Empirical Formula - Driscoll, 1986	Packer Test No. 1
OK-105	2,170 - 2,230	280	37	Empirical Formula - Driscoll, 1986	Packer Test No. 2
OK-105	1,614 - 1,674	Could not be calculated due to lack of drawdown	--	Empirical Formula - Driscoll, 1986	Packer Test No. 3
OK-105	2,130 - 2,251	1,860	249	Empirical Formula - Driscoll, 1986	Packer Test No. 4

Table 1. Summary of Specific Capacity and Slug Testing Data from the Packer Tests.

Date	Test ID	Inflated Packer Depth (ft bls)	Total Core Depth (ft bls)	Slug Test Transmissivity (ft^2/day)	Slug Test Transmissivity (gpd/ft)	Specific Capacity Transmissivity (ft^2/day)	Specific Capacity Transmissivity (gpd/ft)	Comments
Corehole Drilling								
12/12/00	ST1	294	484	--	--	--	--	no water purged; no pacer set
12/19/00	PT1	366	484	--	--	--	--	no water purged
12/20/00	PT2	403	484	--	--	--	--	no water purged
12/20/00	PT3	462	484	--	--	--	--	no water purged
12/20/00	PT4	294	484	--	--	--	--	no water purged
01/03/01	PT5	484	494	--	--	--	--	
02/01/01	ST6	496	514	3	22	34	254	*no packer set, new csg cement depth
02/01/01	ST7	496	539	--	--	--	--	*no packer set, new csg cement depth
02/07/01	PT8	554	579	4	30	22	165	--
02/13/01	PT9	654	679	2	15	6	45	--
02/21/01	PT10	769	794	10	75	30	224	--
03/06/01	PT11	854	879	8	60	27	202	--
03/20/01	PT12	956	984	5	37	15	112	--
04/03/01	PT13	1054	1079	10	75	44	329	--
04/04/01	PT14	1074	1114	18	135	62	464	--
04/09/01	PT15	1165	1209	11	82	62	464	--
04/10/01	PT16	1219	1244	55	411	860	6434	--
UFA Exploratory Drilling								
06/19/01	PT17	1312	1352	7	52	--	--	--
06/26/01	PT18	1380	1447	6	45	--	--	--
06/28/01	PT19	1524	1550	2	15	--	--	--
07/09/01	PT20	1578	1650	46	344	--	--	--
07/18/01	PT21	1690	1750	20	150	--	--	--
07/25/01	PT22	1775	1820	2	15	--	--	--
08/13/01	PT23	1805	1875	5	37	--	--	--

ROMP 29A		
UFA APT	Transmissivities	
Test	ft^2/day	gpd/ft
Theis	37,690	281,921
Theis Corrected Recovery	36,820	275,414
Theis Corrected	37,290	278,929

Summary of 24-Hour Pumping Test Results – LOKEE_ASR				
Method of Analysis	Transmissivity (gpd/ft)	Transmissivity (ft^2/day)	Storativity	Leakance (day)
Onsite Monitor Well--Deep Zone				
Hantush and Jacob -- Drawdown (Curve Matching)	4.38 x 10^6	585,483	0.00125	0.01 to 0.001
Modified Jacob Recovery (Straight Line)	5.72 x 10^6	764,604	0.00019	--
ASR Well				
Modified Jacob Recovery (Straight Line)	4.64 x 10^6	620,238	--	--
*Note: Pumping rate = 6,500 gpm (9.36 mgd), adjusted drawdown at ASR well = 4.06 feet, Specific capacity = 1,600 gpm/ft				

Short-Term Pumping Test on the Onsite Monitor - LKOKEE_ASR			
Depth (feet bls)	Estimated Transmissivity (gpd/ft)	Estimated Transmissivity (ft^2/day)	Solution
990 - 1,800	360,000	48,122	Jacob straight-line method
1,175 - 1,227	5,280 (pumping)	706	--
1,175 – 1,227	22,000 (recovery)	2,941	--

EXKR-1 Transmissivities				
Test	Theis (gpd/ft)	Theis (ft^2/day)	Theis Recovery (gpd/ft)	Theis Recovery (ft^2/day)
Constant-Rate Test	325,000	43,443	275,000	36,760

Well Name	Date	Depth (feet bls)	Transmissivity (gpd/ft)	Estimated Transmissivity (ft^2/day)	Method	Aquifer Test No.
BREX-1	6/21/2007	640 - 936	1,825	244	Cooper-Jacob Method, as described by Driscoll, 1986, page 219	Aquifer Test No. 1
BREX-1	6/28/2007	640 - 1,216	84,000	11,228	Estimated from specific capacity values using formula (Driscoll, 1986; pg. 1021	Aquifer Test No. 2
BREX-1	7/4/2007	1,216 - 1,436	26,180 to 37,400	3,500 – 4,999	Did not specify	Aquifer Test No. 3
BREX-1	7/30/2007	640 - 1,616	209,440	27,996	Did not specify	Aquifer Test No. 4
BREX-1	8/27/2007	640 - 1,410	197,472	26,396	Estimated from specific capacity values using formula (Driscoll, 1986; pg. 1021	Aquifer Test No. 5
BREX-1	6/26/2007	900 - 1,200	--	--	--	Water Quality Analyses
BREX-1	8/27/2007	--	--	--	--	Analytical Report

APPENDIX C

Water Quality

Appendix C

C.1 WATER QUALITY

Summary of Detected Formation Water Analytical Quality Data from OKF-100		
Date	Depth (feet bps)	Total Dissolved Solids (mg/L)
4/12/2006	700	1,300
4/12/2006	800	1,300
4/12/2006	900	1,400
4/12/2006	1,000	1,500

Upper Floridan Aquifer Water Quality (Kissimmee ASR)			
Well Name	OKF-100U	MW-10	EXKR-1 (ASR)
	Mean	Mean	Mean
TDS (mg/L)	810	727	762
APPZ Water Quality			
OKF-100L	Mean	Maximum	Minimum
TDS (mg/L)	902	1,163	630

Well Name	Depth of Interval	TDS (mg/L)	Test
EXKR-1	562-875	820	APT

Well Name	Straddle Packer Test No.	Depth (feet bls)	TDS (mg/L)
HIF-42	PT-1	1,703 - 1,763 feet bls	14,000
HIF-42	PT-2	1,470 - 1,530 feet bls	4,900
HIF-42	PT-3	1,320 - 1,380 feet bls	1,900
HIF-42	PT-4	1,420 - 1,425	2,600

HIF-42	Upper Monitor Zone (560 - 1,049 feet bls)	Lower Monitor Zone (1,310 - 1,530 feet bls)	USDW (~1,600 feet bls)
Total Dissolved Solids	680 mg/L	3,600 mg/L	10,000 mg/L

Well Name	Depth (feet bls)	TDS (mg/L)	Test No.
OK-105	372 - 525	1,473	Aquifer Test No. 1
OK-105	372 - 525	--	Aquifer Test No.1
OK-105	2,412 - 2,472	31,033	Packer Test No. 1
OK-105	2,170 - 2,230	2,644	Packer Test No. 2
OK-105	1,614 - 1,674	6,681	Packer Test No. 3
OK-105	2,130 - 2,251	18,836	Packer Test No. 4

Aquifer Test Water Quality Field Data

Well Name	Date	Interval (feet bls)	TDS (mg/L)
OKF-105	10/31/2008	1,150 - 1,400	670

Final Monitor Zone Water Quality Data

Monitor Zone	Interval (feet bls)	Date	TDS (mg/L)
OKF-105U	373 - 525	12/10/2009	1,473
OKF-105M	1,150 - 1,468	12/10/2009	1,495
OKF-105L	2,130 - 2,251	7/24/2009	18,836

Field and Laboratory Water Quality Results Collected During Packer Tests.					
Well Name	Date	SAMPLE TIME (HH:MM)	INTERVAL (ft bls)	Laboratory	Sample Collection Methods/Remarks
				TDS (mg/L)	
ROMP 29A	04/24/02	14:00	50-80	177	Surficial OB well
ROMP 29A	12/11/00	15:49	294-394	128	4" steel HW @ 294. Stainless steel bailer 20 feet off bottom
ROMP 29A	01/02/01	10:50	484-494	146	Packer test, air lift sample
ROMP 29A	01/31/01	16:00	496-514	145	Packer test, air lift sample
ROMP 29A	02/07/01	16:00	554-579	157	Packer test, bailer sample
ROMP 29A	02/13/01	14:30	654-679	125	Packer test, air lift sample
ROMP 29A	02/21/01	11:00	769-794	165	Packer test, air lift sample
ROMP 29A	03/06/01	15:00	854-879	126	Packer test, air lift sample
ROMP 29A	03/20/01	14:00	956-984	112	Packer test, air lift sample
ROMP 29A	04/03/01	09:00	1,054-1,079	88	Packer test, air lift sample
ROMP 29A	04/04/01	09:00	1,074-1,114	107	Packer test, air lift sample
ROMP 29A	04/09/01	12:00	1,165-1,209	124	Packer test, air lift sample
ROMP 29A	04/11/01	09:00	1,219-1,244	86	Packer test, air lift sample
ROMP 29A	06/19/01	18:00	1,312-1,352	130	Packer test, air lift sample, during exploratory drilling
ROMP 29A	06/26/01	11:00	1,380-1,447	110	Packer test, air lift sample, during exploratory drilling, non-filtered
ROMP 29A	06/28/01	18:00	1,523-1,550	97	Packer test, air lift sample, during exploratory drilling, non-filtered
ROMP 29A	07/09/01	13:00	1,578-1,650	290	Packer test, air lift sample, during exploratory drilling, non-filtered
ROMP 29A	07/18/01	11:00	1,690-1,750	1,900	Packer test, air lift sample, during exploratory drilling, non-filtered???
ROMP 29A	07/25/01	19:30	1,775-1,820	3,600	Packer test, air lift sample, during exploratory drilling, non-filtered???
ROMP 29A	08/13/01	15:00	1,805-1,875	3,436	Packer test, air lift sample, during exploratory drilling, non-filtered???

Water Quality Results		
	Straddle Packer Tests	
Well Name	**Depth/Interval**	**TDS (mg/L)**
LKOKEE_ASR	1,175 to 1,227 feet	656
LKOKEE_ASR	1,288 to 1,354 feet	4,000
LKOKEE_ASR	1,347 to 1,370 feet	4,230
LKOKEE_ASR	1,358 to 1,508 feet	5,740
LKOKEE_ASR	1,540 to 1,662 feet	6,710
	Pilot Hole Drilling	
LKOKEE_ASR	1,277 feet	564
LKOKEE_ASR	1,339 feet	3,170
LKOKEE_ASR	1,465 feet	4,210
LKOKEE_ASR	1,619 feet	6,040

Water Quality Data from Reverse-Air Drilling		
Well Name	**Depth (feet bls)**	**TDS (mg/L)**
LKOKEE_ASR	1,050	508
LKOKEE_ASR	1,060	530
LKOKEE_ASR	1,093	508
LKOKEE_ASR	1,123	536
LKOKEE_ASR	1,155	506
LKOKEE_ASR	1,186	474
LKOKEE_ASR	1,217	488
LKOKEE_ASR	1,248	592
LKOKEE_ASR	1,277	564
LKOKEE_ASR	1,308	2,990
LKOKEE_ASR	1,339	3,170
LKOKEE_ASR	1,371	3,050
LKOKEE_ASR	1,402	3,210
LKOKEE_ASR	1,434	2,930
LKOKEE_ASR	1,465	4,210
LKOKEE_ASR	1,495	4,430
LKOKEE_ASR	1,526	4,060
LKOKEE_ASR	1,557	4,550
LKOKEE_ASR	1,588	5,670
LKOKEE_ASR	1,619	6,040
LKOKEE_ASR	1,649	--
LKOKEE_ASR	1,680	5,750
LKOKEE_ASR	1,711	5,670
LKOKEE_ASR	1,742	4,910
LKOKEE_ASR	1,773	4,820
LKOKEE_ASR	1,804	3,880

Well Name	Collection Date & Time	Depth (feet bls)	Total Dissolved Solids (mg/L)	Notes
EXKR-MW18	1/6/2010 18:35	--	540	Well Completion Report
EXKR-MW19	1/6/2010 13:35	--	800	Well Completion Report
EXKR-MW19	9/26/2018 14:30	880	734	DBHYDRO
EXKR-MW19	12/10/2019 14:04	570	709	DBHYDRO

Well Name	Collection Date & Time	Depth (feet bls)	Total Dissolved Solids (mg/L)	Notes
GLF-5	3/8/1982 16:30	1,624	3,574	DBHYDRO
GLF-5	9/12/1983 14:40	1,624	3,590	DBHYDRO
GLF-5	5/15/1984 14:39	1,624	3,120	DBHYDRO
GLF-5	9/17/1984 16:00	1,624	3,576	DBHYDRO
GLF-5	9/17/1984 16:00	1,624	3,576	DBHYDRO
GLF-5	5/14/1985 18:00	1,624	3,432	DBHYDRO
GLF-5	4/21/1986 13:30	1,624	3,574	DBHYDRO
GLF-5	5/11/1987 10:30	1,624	3,553	DBHYDRO
GLF-5	12/14/1988 14:20	1,624	3,752	DBHYDRO
GLF-5	9/8/1982	--	4,203	Value came from Well Survey Report - multiplied specific conductance by 0.67 (6,273 u-mho/cm X 0.67)

Well Name	Date	Depth (feet bls)	TDS	Aquifer Test No.
BREX-1	6/21/2007	640 - 936	2,280	Aquifer Test No. 1
BREX-1	6/28/2007	640 - 1,216	1,750 - 1,770	Aquifer Test No. 2
BREX-1	7/4/2007	1,216 - 1,436	1,720	Aquifer Test No. 3
BREX-1	7/30/2007	640 - 1,616	--	Aquifer Test No. 4
BREX-1	8/27/2007	640 - 1,410	--	Aquifer Test No. 5
BREX-1	6/26/2007	900 - 1,200	1,670	Water Quality Analyses
BREX-1	8/27/2007	--	1,700	Analytical Report

Well Name	Collection Date & Time	Depth (feet bls)	Total Dissolved Solids (mg/L)	Notes
GLF-1	7/10/1979 9:00	826	1,058	DBHYDRO
GLF-1	9/24/1979 15:35	826	1,101	DBHYDRO
GLF-1	5/12/1982 13:53	826	822	DBHYDRO
GLF-1	9/17/1984 12:00	826	829	DBHYDRO
GLF-1	9/17/1984 12:00	826	829	DBHYDRO
GLF-1	5/14/1985 9:15	826	1,073	DBHYDRO
GLF-1	4/24/1986 11:20	826	1,212	DBHYDRO
GLF-1	5/14/1987 11:00	826	1,113	DBHYDRO
GLF-1	10/29/1979	--	1,307	Value came from Well Survey Report - multiplied specific conductance by 0.67 (1,950 u-mho/cm X 0.67)

APPENDIX D

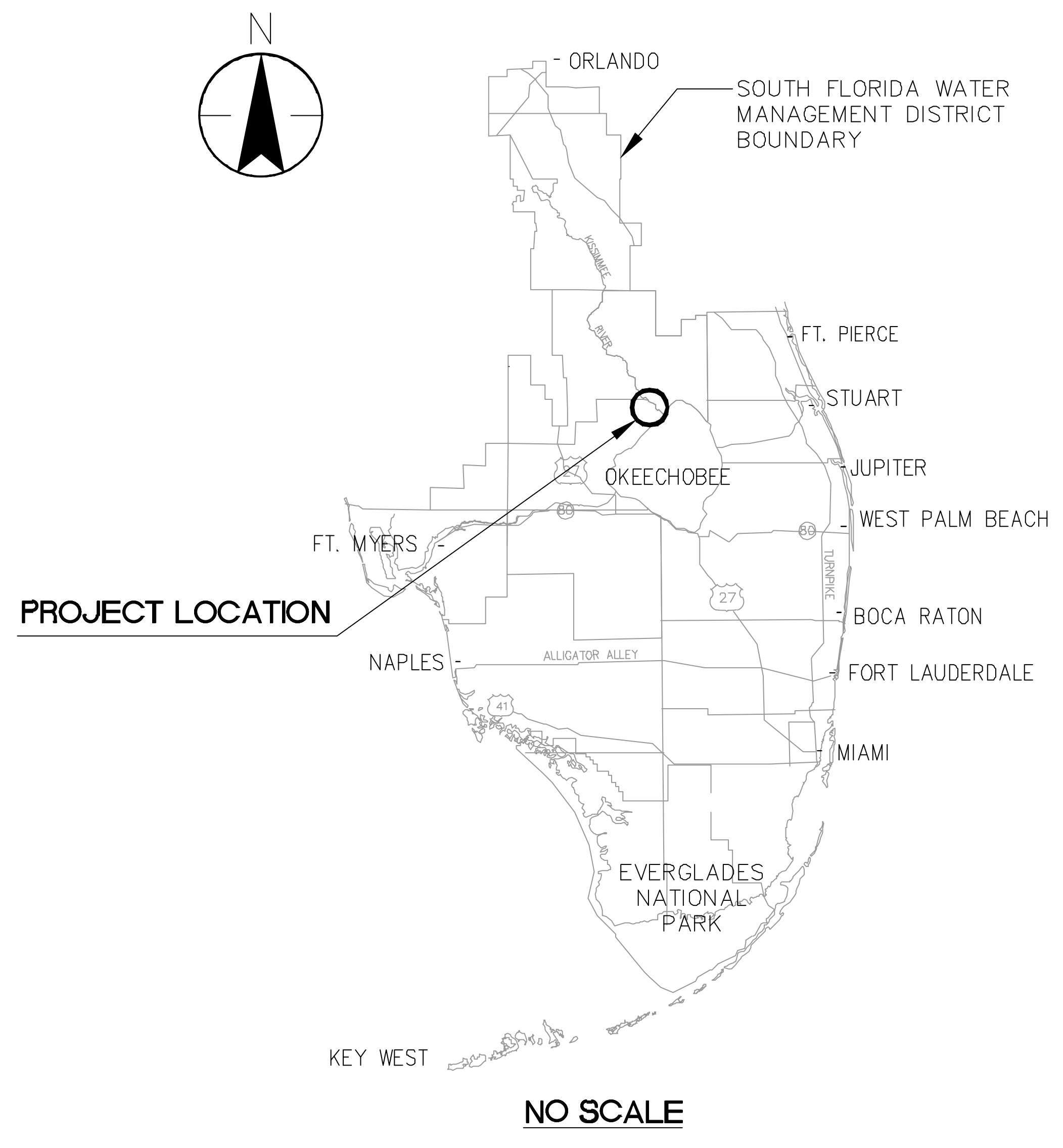
Preliminary Drawings

Appendix D

D.1 PRELIMINARY DRAWINGS

SOUTH FLORIDA
WATER MANAGEMENT DISTRICT

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT
AQUIFER STORAGE AND RECOVERY (ASR)
HIGHLANDS COUNTY AND GLADES COUNTY, FLORIDA



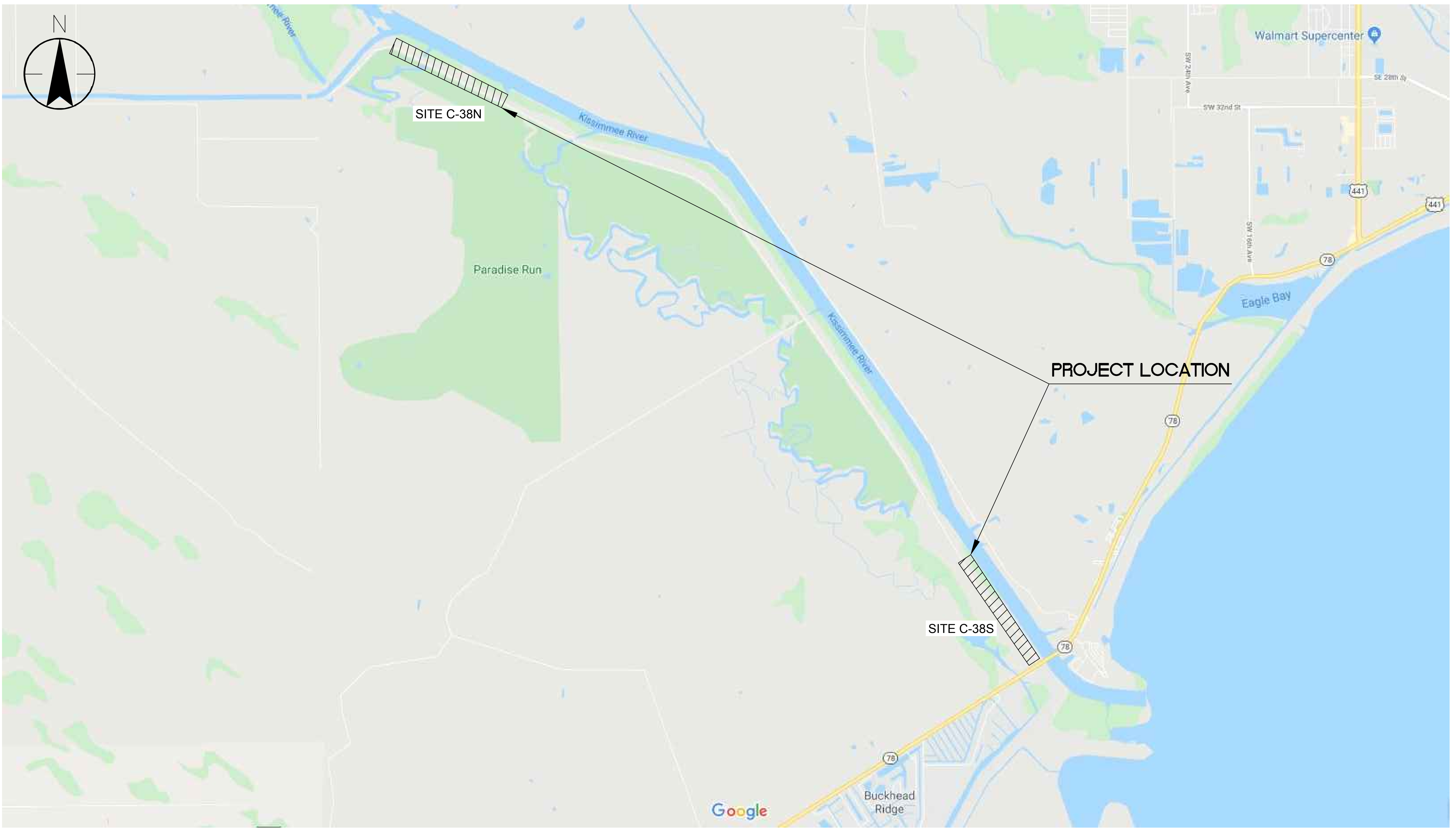
GOVERNING BOARD

EXECUTIVE OFFICE

DREW BARTLETT
EXECUTIVE DIRECTOR

APPROVED BY:

JOHN P. MITNIK, P.E.
CHIEF DISTRICT ENGINEER



LOCATION MAP

NO SCALE

DRAWING NUMBER	SHEET COUNT	SHEET TITLE
		GENERAL
G001	1	COVER
G002	2	GENERAL NOTES AND SYMBOLS
		CIVIL
C001	3	CIVIL NOTES AND SYMBOLS
C002	4	SURVEY CONTROL
C010	5	OVERALL SITE - C-38S
C011	6	C-38S - ENLARGED SITE PLAN - I
C012	7	C-38S - ENLARGED SITE PLAN - II
C013	8	C-38S - ENLARGED SITE PLAN - III
C014	9	C-38S - ENLARGED SITE PLAN - IV
C020	10	OVERALL SITE - C-38N
C021	11	C-38N - ENLARGED SITE PLAN - I
C022	12	C-38N - ENLARGED SITE PLAN - II
C023	13	C-38N - ENLARGED SITE PLAN - III
C024	14	C-38N - ENLARGED SITE PLAN - IV
C091	15	DETAILS - I
C092	16	DETAILS - II
		MECHANICAL
M001	17	C-38N AND C-38S APPZ ASR WELL AND DZMW WELL DETAILS
M002	18	C-38N AND C-38S UFA ASR WELL, APPZ MONITOR WELL AND SURFICIAL AQUIFER MONITOR WELL DETAILS
M091	19	DETAILS - I
M092	20	DETAILS - II

SFWMD PROJECT I.D. NO. 101185
STANTEC PROJECT I.D. NO. 177311458

Stantec

The consultant, contractor or other parties associated with this project shall comply with Florida Statutes Chapter 119. These plans are the property of the District and must be secured and maintained in a confidential manner. Review by any unauthorized individual or outside/third party not performing work necessary for this project is prohibited.

DATE	DRAWN	REF#	REVISION DESCRIPTION

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: NO SCALE

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT
AQUIFER STORAGE AND RECOVERY (ASR)

COVER

PROJECT ID NO.
177311458
DRAWING NUMBER
G001

SHEET
1 OF XX

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GENERAL NOTES

GENERAL

1. CONTRACTOR IS RESPONSIBLE FOR ALL DEWATERING ACTIVITIES
2. THE TOP OF ROCK SHOWN ON CONSTRUCTION DRAWINGS IS APPROXIMATE. THE CONTRACTOR SHALL PROVIDE INDEPENDENT VERIFICATION OF THIS DATA AND MAKE HIS OWN DETERMINATION AS TO THE ACTUAL TOP OF ROCK.
3. ELEVATIONS, UNLESS OTHERWISE NOTED, ARE BASED ON THE NORTH AMERICAN VERTICAL DATUM (NAVD 1988) AND ARE EXPRESSED IN FEET. BENCH MARK “PB25” (NGS PID #AJ8327). NGVD29 = NAVD88 + 1.42' FOR THIS LOCATION.
4. BENCHES BETWEEN EMBANKMENT AND CANALS SHALL SLOPE A MIN OF 2% AWAY FROM THE EMBANKMENT.
5. CONTRACTOR WILL RECEIVE ACCESS TO PORTIONS OF THE PROJECT SITE AS SHOWN ON DRAWING G005.
6. MUCK EXCAVATED FROM THE SOIL INVERSION AREA INDICATED ON G005 SHALL BE MANAGED ACCORDING TO THE SOIL MANAGEMENT PLAN PROVIDED BY THE DISTRICT.

ABBREVIATIONS

AASHTO	AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS
AC	ALTERNATING CURRENT
ACI	AMERICAN CONCRETE INSTITUTE
ADD'L	ADDITIONAL
AFF	ABOVE FINISH FLOOR
AISC	AMERICAN INSTITUTE OF STEEL CONSTRUCTION
ALT	ALTERNATE
ALUM	ALUMINUM
ANSI	AMERICAN NATIONAL STANDARDS INSTITUTE
API	AMERICAN PETROLEUM INSTITUTE
APPROX	APPROXIMATELY
APPZ	AVON PARK PERMEABLE ZONE
ASCE	AMERICAN SOCIETY OF CIVIL ENGINEERS
ASME	AMERICAN SOCIETY OF MECHANICAL ENGINEERS
ASS'Y	ASSEMBLY
ASTM	AMERICAN SOCIETY FOR TESTING AND MATERIALS
AWPA	AMERICAN WOOD PRESERVERS ASSOCIATION
AWS	AMERICAN WELDING SOCIETY
BLDG	BUILDING
BOTT	BOTTOM
CFM	CUBIC FEET PER MINUTE
CJ	CONSTRUCTION JOINT
CCA	CHROMATED COPPER ARSINATE
CIRC	CIRCUMFERENCE
CLR	CLEARANCE
CONN	CONNECTION
CONST	CONSTRUCTION
CONT	CONTINUOUS
COR	CORNER
CTRS	CENTERS
DBL	DOUBLE
DHW	DESIGN HIGH WATER
DIA	DIAMETER
DIST	DISTANCE
DWG	DRAWING
DZMW	DUAL ZONE MONITORING WELL
EW	EACH WAY
EA	EACH
ELEV	ELEVATION
EQ	EQUAL
EQ SP	EQUALLY SPACED
ETC	ET CETERA
FDOT	FLORIDA DEPARTMENT OF TRANSPORTATION FEDERAL
FED SPEC	SPECIFICATION
FIN FL	FINISHED FLOOR
FPL	FLORIDA POWER AND LIGHT
FT	FEET OR FOOT
GA	GAUGE
GAL	GALLON
GALV	GALVANIZED
HP	HORSEPOWER
HEX	HEXAGONAL
HORIZ	HORIZONTAL
HT	HEIGHT
HZ	HERTZ
ID	INSIDE DIAMETER
IN	INCH(ES)
kPa	KILO PASCALS
L	LENGTH
LB	POUND
LG	LONG
LOC	LIMITS OF CLEARING
LONGIT	LONGITUDINAL
LP	LIQUID PETROLEUM
LWSL	LOW WATER STORAGE LEVEL
MAX	MAXIMUM
MECH	MECHANICAL
MFGR	MANUFACTURER
MIN	MINIMUM
MM	MILLIMETER
MW	MONITORING WELL
MWSL	MAXIMUM WATER STORAGE LEVEL
NEMA	NATIONAL ELECTRICAL MANUFACTURERS
NIC	ASSOCIATION NOT IN CONTRACT
NFPA	NATIONAL FIRE PROTECTION ASSOCIATION
NFSL	NORMAL FULL STORAGE LEVEL
NO	NUMBER
OC	ON CENTER
OD	OUTSIDE DIAMETER
OPNG	OPENING
PC	POINT OF CURVATURE
PCC	POINT OF COMPOUND CURVE
PCF	POUNDS PER CUBIC FOOT
PROJ	PROJECTION
PSF	POUNDS PER SQUARE FOOT
PSI	POUNDS PER SQUARE INCH
PSIG	POUNDS PER SQUARE INCH GAUGE
PT	PRESSURE TREATED/POINT OF TANGENCY POLYVINYL
PVC	CHLORIDE
R	RADIUS
R/W	RIGHT-OF-WAY
RPM	REVOLUTIONS PER MINUTE
REF	REFERENCE
REIF	REINFORCEMENT
REQD	REQUIRED
SAS	SURFICIAL AQUIFER SYSTEM
S.F.W.M.D.	SOUTH FLORIDA WATER MANAGEMENT DISTRICT
SS	STAINLESS STEEL
SCH	SCHEDULE
SECT	SECTIONAL
SPA	SPACING
SPECS	SPECIFICATIONS
SST	STAINLESS STEEL TYPE 304
STD	STANDARD
STRUCT	STRUCTURE
TBD	TO BE DETERMINED
THK	THICK
TOC	TOP OF CONCRETE
TOS	TOP OF SHAFT
TYP	TYPICAL
UFA	UPPER FLORIDAN AQUIFER
UL	UNDERWRITERS LABORATORIES INC.
VAR	VARIOUS
VERT	VERTICAL

GENERAL SYMBOLOGY

▭	NEW CONSTRUCTION
▭	EXISTING (SCREENED)
⬚	FUTURE (PHANTOM)
▨	EXISTING TO BE REMOVED OR DEMOLISHED

MATERIAL SYMBOLOGY

▨	CONCRETE (PLAN AND SECTION)
▨	GROUT OR SAND (PLAN AND SECTION)
▨	CMU (PLAN AND SECTION)
▨	STEEL/METAL/FRP (SMALL SCALE SECTION)
▩	CHECKER PLATE OR SOLID FRP GRATING (PLAN)
▭	CHECKER PLATE (SECTION)
▦	GRATING (PLAN)
▦	GRATING OR SOLID FRP GRATING (SECTION)
▩	SAFETY GRATING (PLAN)
⌶	SAFETY GRATING (SECTION)
— - — - —	RAILING (PLAN)
▨	WOOD (PLAN OR ELEVATION)
⊠	LUMBER/FRAMING - NOMINAL
▭	LUMBER - TRIMMED (BLOCKING OR SHIMS)
▩ OR ▤	GLULAM (SECTION)
▤	GLULAM (ELEVATION)
▬ OR ▨	PLYWOOD (SMALL SCALE)
▨	FINISHED GRADE
▩	GRAVEL/DRAINROCK/AGGREGATE BASE
▨	CEMENT GROUT

MISCELLANEOUS

⬡ A	SHEET KEY NOTES
◇ ###	COORDINATE POINT
▽	WATER LEVEL

SYMBOLOGY

'	FEET
"	INCHES
#	NUMBER
%	PERCENT
&	AND
@	AT
o	DEGREES
Ø	DIAMETER
W/	WITH
X	BY
℄	CENTERLINE
BL	BOUNDARY LINE

STRUCTURAL SHAPES

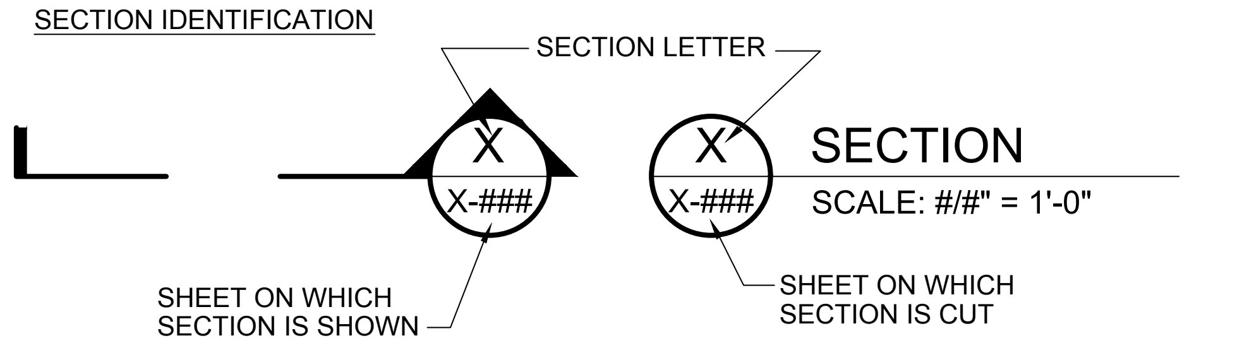
C	CHANNEL
L	ANGLE
PL	PLATE
W	W SHAPE

DISCIPLINE SPECIFIC SYMBOLS ARE SHOWN ON THE DISCIPLINE GENERAL NOTES AND SYMBOLS DRAWINGS.

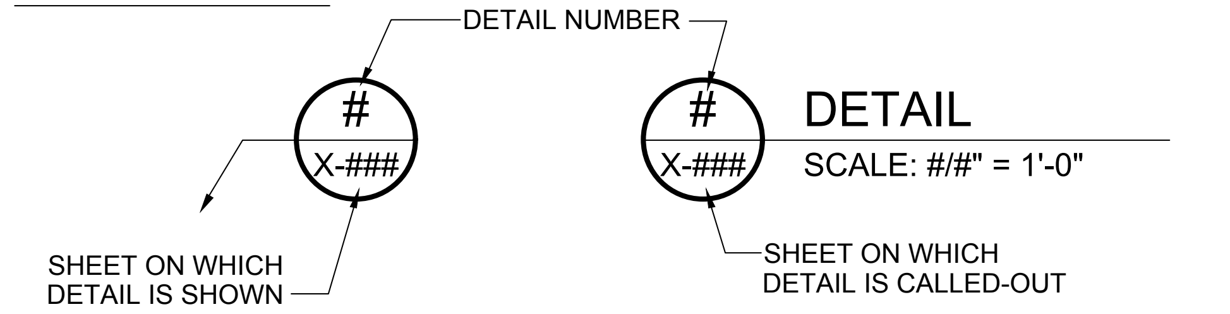
FOR WELDING SYMBOLS USE AMERICAN WELDING SOCIETY STANDARD SYMBOLS.

REFERENCE SYMBOLS

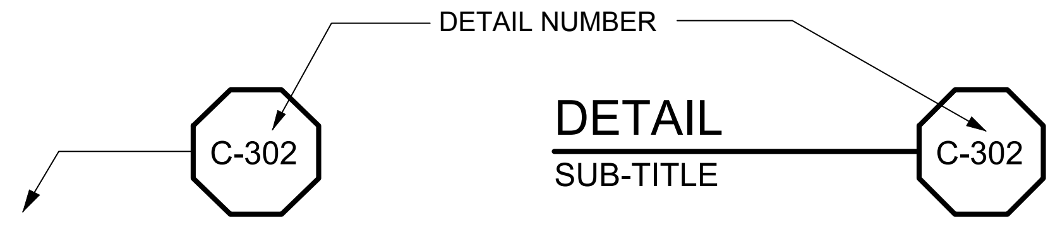
SECTION IDENTIFICATION



DETAIL IDENTIFICATION

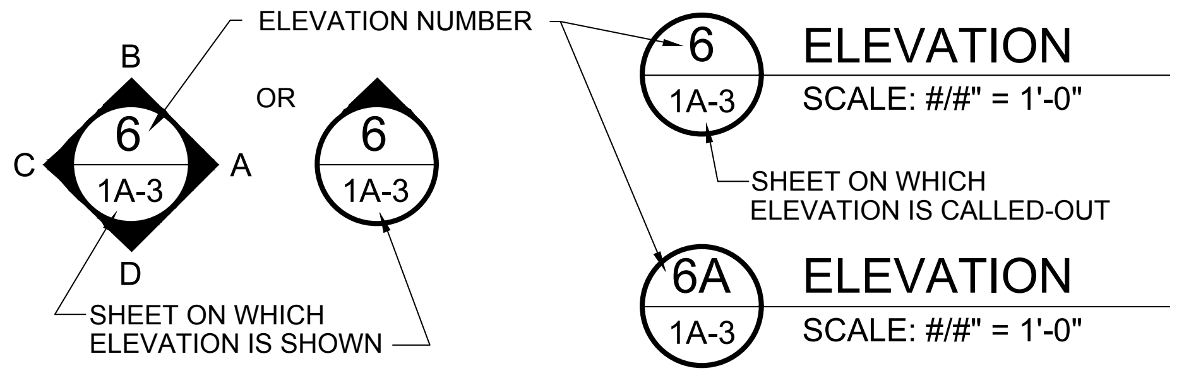


STANDARD DETAIL IDENTIFICATION



STANDARD DETAILS ARE LOCATED ON DISCIPLINE GENERAL SHEETS, IN NUMERICAL ORDER

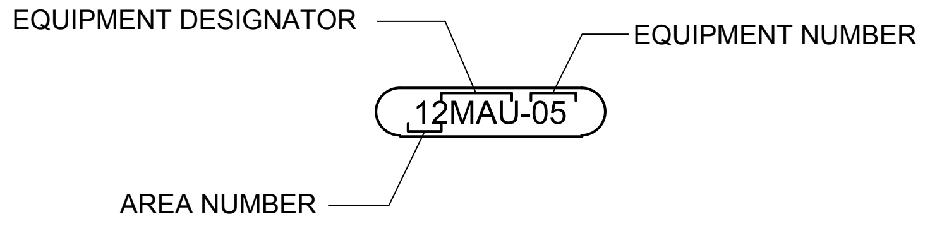
INTERIOR ELEVATION IDENTIFICATION



EXTERIOR ELEVATION IDENTIFICATION

EQUIPMENT IDENTIFICATION

SEE EQUIPMENT SCHEDULE/SPECIFICATIONS



Stantec

ENGINEER OF RECORD:

FL P.E. LICENSE NO.:

DATE:

DATE	DRAWN	REF#	REVISION DESCRIPTION

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: **JANUARY 31, 2020**
SCALE: NO SCALE

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED
RESTORATION PROJECT
AQUIFER STORAGE AND RECOVERY (ASR)

GENERAL NOTES AND SYMBOLS

PROJECT ID NO.
177311458
DRAWING NUMBER
G002

SHEET
2 OF XX

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CIVIL GENERAL NOTES

GENERAL

1. THE CONTRACTOR SHALL TAKE ALL PRECAUTIONARY MEASURES NECESSARY TO PROTECT FROM DAMAGE, ALL EXISTING IMPROVEMENTS WHICH ARE TO REMAIN IN PLACE. ALL IMPROVEMENTS DAMAGED BY THE CONTRACTOR'S OPERATIONS SHALL BE EXPEDITIOUSLY REPAIRED OR RECONSTRUCTED TO THE SATISFACTION OF DISTRICT AT THE CONTRACTOR'S EXPENSE WITH NO ADDITIONAL COSTS TO DISTRICT.
2. CONTRACTOR SHALL RESTORE ALL SURVEY MONUMENTS THAT ARE DAMAGED OR DESTROYED DURING CONSTRUCTION AT CONTRACTOR'S EXPENSE.
3. SEED AND MULCH ALL EMBANKMENT SIDE SLOPES AND DISTURBED AREAS AFTER COMPLETION OF EMBANKMENT AND CANAL GUARD RAILS IN ACCORDANCE WITH SPECIFICATION SECTION 02486.
4. RIP-RAP AND FILTER FABRIC SHALL BE INSTALLED IN ACCORDANCE WITH SPECIFICATION SECTION 02370.
5. IF ACTUAL FIELD CONDITIONS VARY SIGNIFICANTLY FROM THE CONSTRUCTION DRAWINGS, CONTRACTOR IS TO NOTIFY DISTRICT FOR VERIFICATION PRIOR TO PROCEDURE.

UTILITIES

1. PRIOR TO THE START OF CONSTRUCTION, THE CONTRACTOR SHALL LOCATE ALL EXISTING UTILITIES IN AND AROUND THE AREAS OF NEW CONSTRUCTION. THE CONTRACTOR SHALL POTHOLE FOR EXISTING UTILITIES PRIOR TO SUBMITTAL OF SHOP DRAWINGS, FOR POINTS OF CONNECTIONS.
2. THE CONTRACTOR SHALL PROTECT ALL REMAINING EXISTING UTILITIES.
3. THE CONTRACTOR SHALLVERIFY ALL LOCATIONS AND ELEVATIONS AND SHALL TAKE ALL PRECAUTIONARY MEASURES NECESSARY TO PROTECT UTILITY LINES WHETHER SHOWN OR NOT SHOWN.
4. PRIOR TO ANY CONNECTION TO AN EXISTING UTILITY, THE CONTRACTOR SHALL COORDINATE WITH THE UTILITY OWNER AND THE DISTRICT.

EROSION CONTROL

1. THE CONTRACTOR SHALL SUBMIT AN EROSION CONTROL PLAN FOR WORK DURING THE CONSTRUCTION, SIGNED AND STAMPED BY A REGISTERED CIVIL ENGINEER PRIOR TO THE START OF CONSTRUCTION.
    a. ALL SLOPES SHALL BE PROTECTED FROM EROSION DURING ROUGH GRADING OPERATIONS AND THEREAFTER, UNTIL INSTALLATION OF FINAL GROUNDCOVER .
    b. ALL SLOPE PROTECTION SWALES SHALL BE CONSTRUCTED AT THE SAME TIME AS BANKS ARE GRADED.
    c. THE CONTRACTOR IS RESPONSIBLE FOR IMPLEMENTATION AND MAINTENANCE OF EROSION CONTROL MEASURES CONTAINED WITHIN THE CONTRACT SPECIFICATIONS OR AS REQUIRED BY THE COUNTY, DISTRICT, OR OTHER REGULATORY AUTHORITY. THE CONTRACTOR SHALL ALSO PROVIDE ANY ADDITIONAL EROSION CONTROL MEASURES (E.G. HYDROSEEDING, MULCHING OF STRAW, SAND BAGGING, DIVERSION DITCHES, ETC.) DICTATED BY FIELD CONDITIONS TO PREVENT EROSION OR THE INTRODUCTION OF DIRT, MUD, OR DEBRIS INTO EXISTING PUBLIC STREETS, WATERWAYS, OR ONTO ADJACENT PROPERTIES DURING ANY PHASE OF CONSTRUCTION OPERATIONS.

GENERAL CIVIL SYMBOLS

━━━	NEW
───	EXISTING
‒ ‒ ‒	FUTURE
▨	EXISTING TO BE REMOVED OR DEMOLISHED
─ · ─	CENTERLINE
▨	EARTH (IN SECTION)
▨	COMPACTED EARTH (IN SECTION)
S=0.0123	SLOPE ON PAVED SURFACE
3H:1V	BERM SLOPE (HORZ TO VERT)
▶─	SLOPE INDICATOR
◣	FLOW ARROW

TOPOGRAPHY AND MAPPING SYMBOLS

125	MAJOR CONTOURS
───	MINOR CONTOURS
P/L	PROPERTY LINE
R/W	RIGHT-OF-WAY LINE
ESMT	EASEMENT LINE
TEMP ESMT	TEMPORARY EASEMENT LINE
LOC	LIMIT OF CONSTRUCTION
- - -	TRAIL OR DIRT ROAD
▸ · · ·	FLOW LINE
───	GUARDRAIL (PERMANENT)
─ ─ ─	GUARDRAIL (REMOVABLE)
	VEGETATION
	WETLANDS

DRAINAGE SYMBOLS

	RIPRAP
	HAY BALE
· · · ·	SILT FENCE

GEOTECHNICAL SYMBOLS

⊕	SPT FIELD VANE (FV)
▬	TEST PIT LOCATION (TP)
▲	PIEZOMETER CLUSTER (P)
◆	ROCK CORE (RC)

CONTROL SYMBOLS

▲ BM-XX	BENCH MARK
###	SITE COORDINATES (SEE TABLE ON DRAWINGS)
N XXXXXXX E XXXXXXX	SITE COORDINATES
⊕ EL XXXX.XX	MONUMENT
△	HORIZONTAL CONTROL POINT
⊙	VERTICAL CONTROL POINT
△	HORZ AND VERT CONTROL POINT
XXX.XX	FINISHED ELEVATION
(XXX.XX)	EXISTING ELEVATION
△	DELTA

STRUCTURES

─ · · · ─	SITE OR RETAINING WALL
─○─○	FLOATING TURBIDITY BARRIER
─ x ─ x	FENCE (CHAINLINK)
───	FENCE (WOOD)
▭	STRUCTURE
⬚	STRUCTURE (BELOW GRADE)
CB CB	CATCH BASIN
─•─	FLOAT BARRIER
▭ ▭ ▭	TUFFBOOM BARRIER
MW	DUAL ZONE MONITORING WELL
◉	ASR WELL CLUSTER (EACH CLUSTER IS ~1000' APART)
⬢	APPZ MONITORING WELL
✦	EXISTING MONITOR WELL

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ENGINEER OF RECORD:
WILLIAM WEBER, P.E.
FL P.E. LICENSE NO.: 61875

DATE:

DATE	DRAWN	REF#	REVISION DESCRIPTION

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: NO SCALE

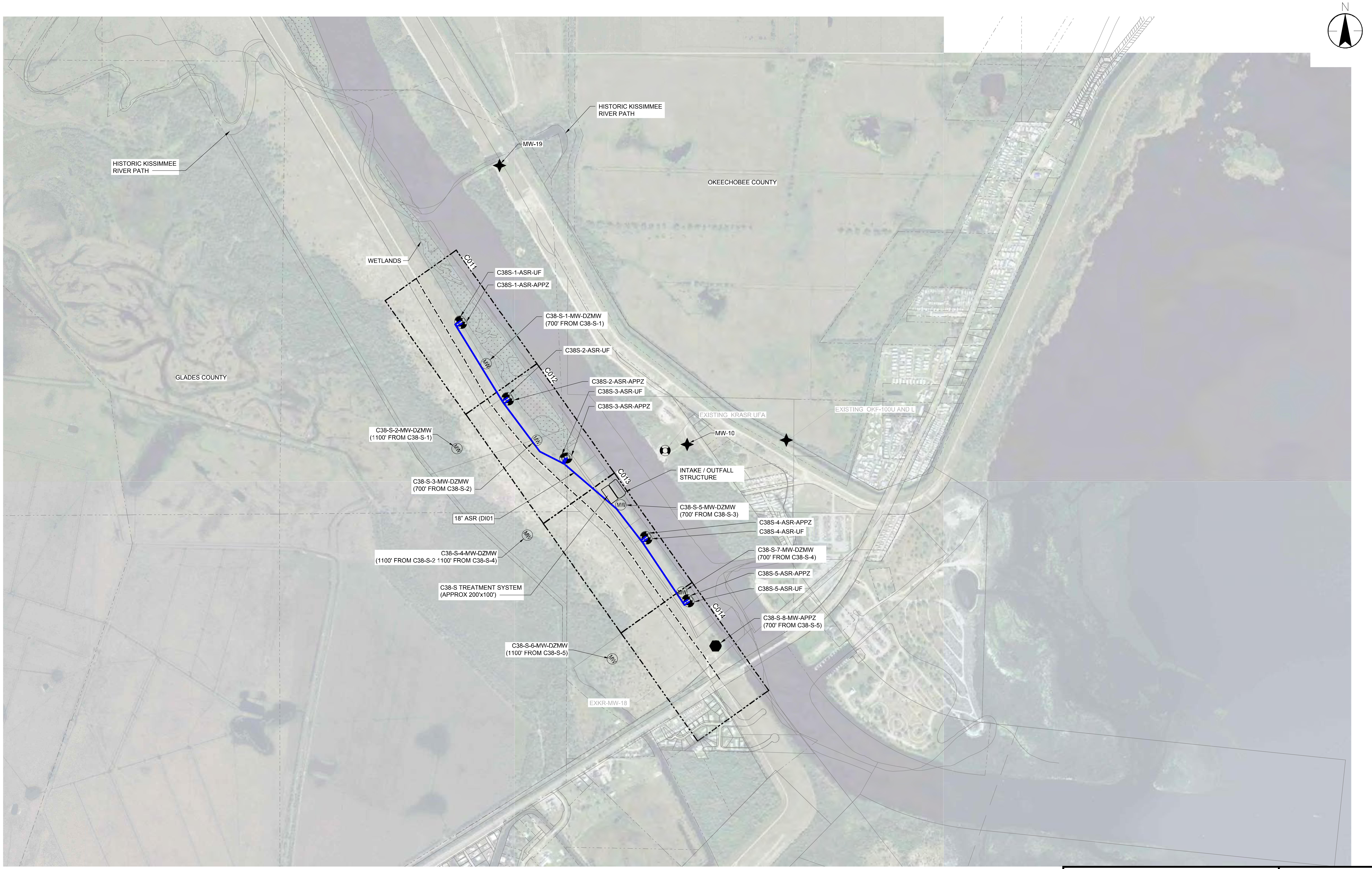
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED
RESTORATION PROJECT
AQUIFER STORAGE AND RECOVERY (ASR)

CIVIL NOTES AND SYMBOLS

PROJECT ID NO.
177311458
DRAWING NUMBER
C001

SHEET
3 OF XX



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SCALE IN FEET

Stantec

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ENGINEER OF RECORD:

FL P.E. LICENSE NO.:

DATE:

REVISION DESCRIPTION	REF#	DRAWN	DATE

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: 1" = 500'-0"

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)

OVERALL SITE - C-38S

PROJECT ID NO.
177311458
DRAWING NUMBER
C010

SHEET
5 OF XX

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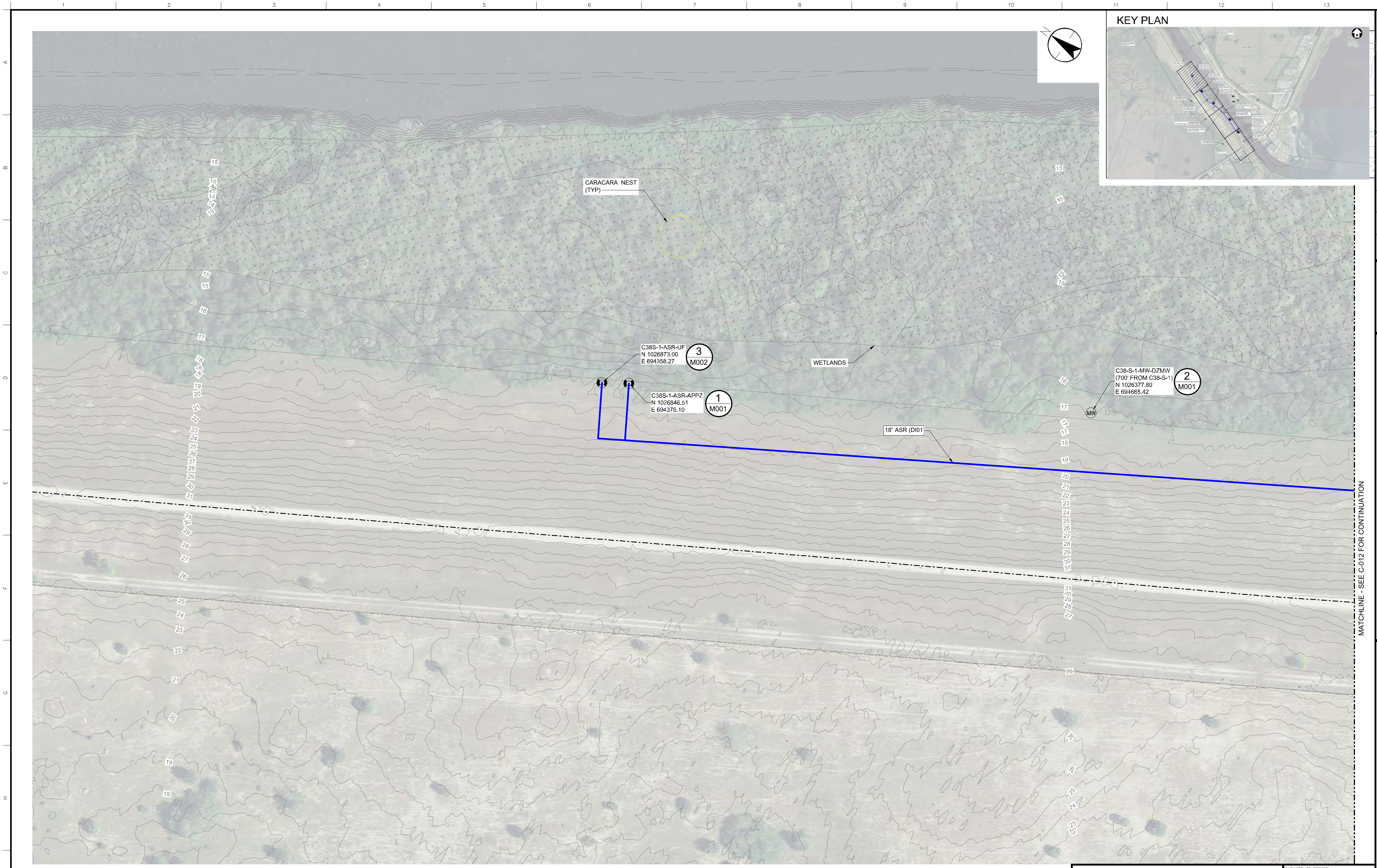

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SCALE IN FEET

Stantec

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ENGINEER OF RECORD:
FL P.E. LICENSE NO.:
DATE:

REVISION DESCRIPTION	DATE	DRAWN	REF#

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: **JANUARY 31, 2020**
SCALE: 1" = 50'-0"

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)

C-38S - ENLARGED SITE PLAN - I

PROJECT ID NO.
177311458
DRAWING NUMBER
C011

SHEET
6 OF XX

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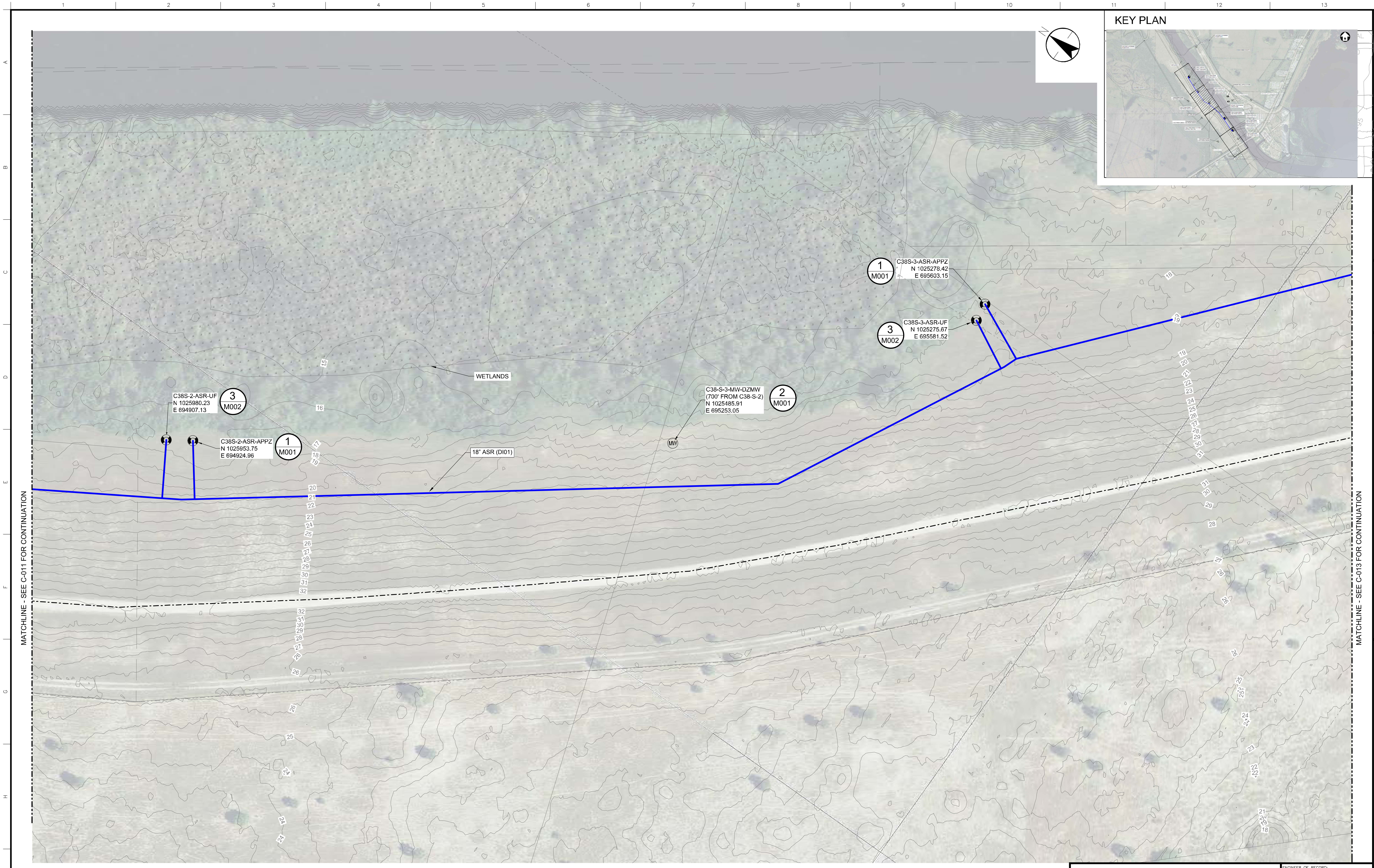

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SCALE IN FEET

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ENGINEER OF RECORD:
FL P.E. LICENSE NO.:
DATE:

DATE	DRAWN	REF#	REVISION DESCRIPTION

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: 1" = 50'-0"

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT
AQUIFER STORAGE AND RECOVERY (ASR)

C-38S – ENLARGED SITE PLAN – II

PROJECT ID NO.
177311458
DRAWING NUMBER
C012

SHEET
7 OF XX

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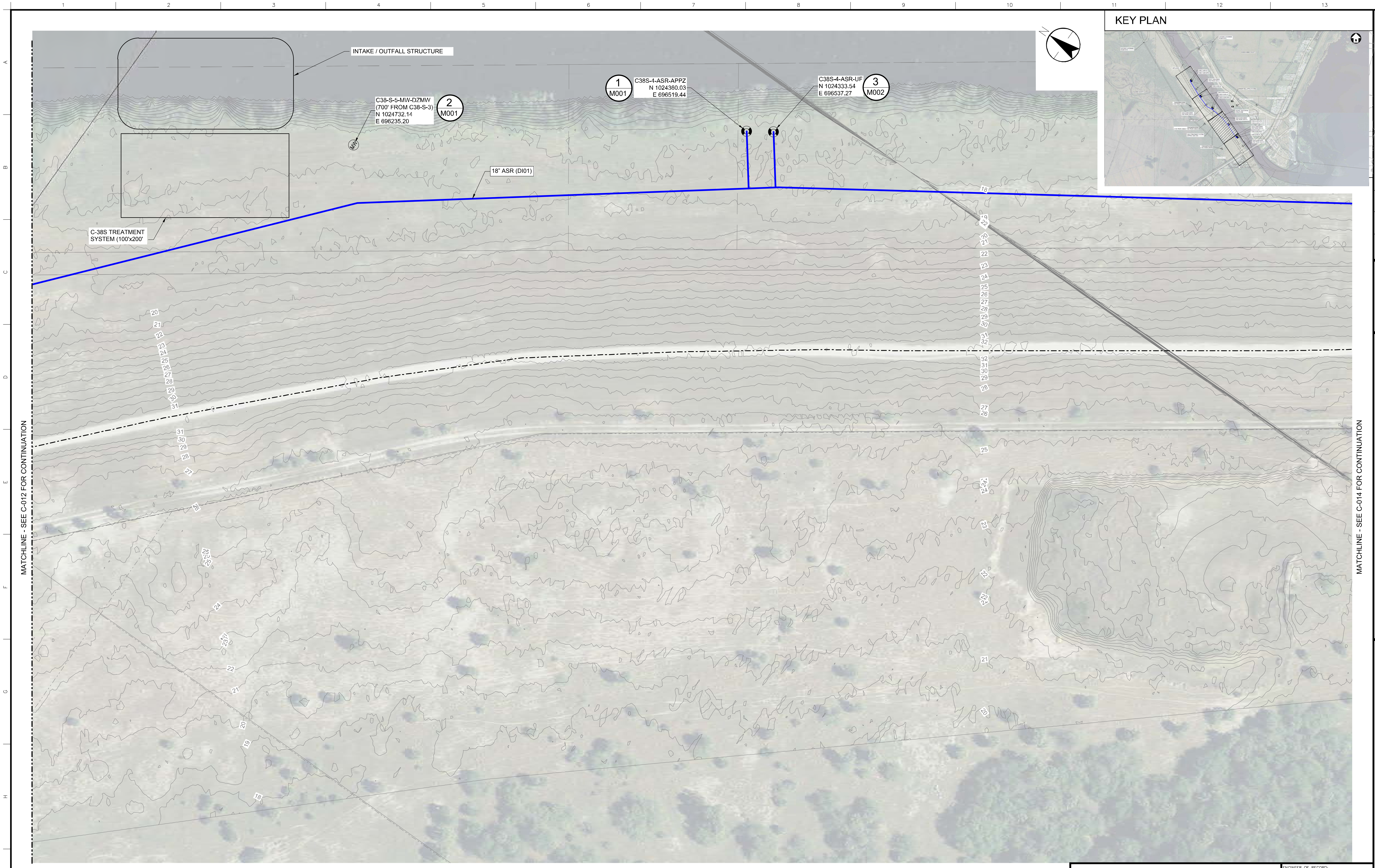

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SCALE IN FEET

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)

C-38S – ENLARGED SITE PLAN – III

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: 1" = 50'-0"

REVISION DESCRIPTION	REF#	DRAWN	DATE

Stantec

ENGINEER OF RECORD:
FL P.E. LICENSE NO.:
DATE:

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PROJECT ID NO.
177311458
DRAWING NUMBER
C013
SHEET
8 OF XX

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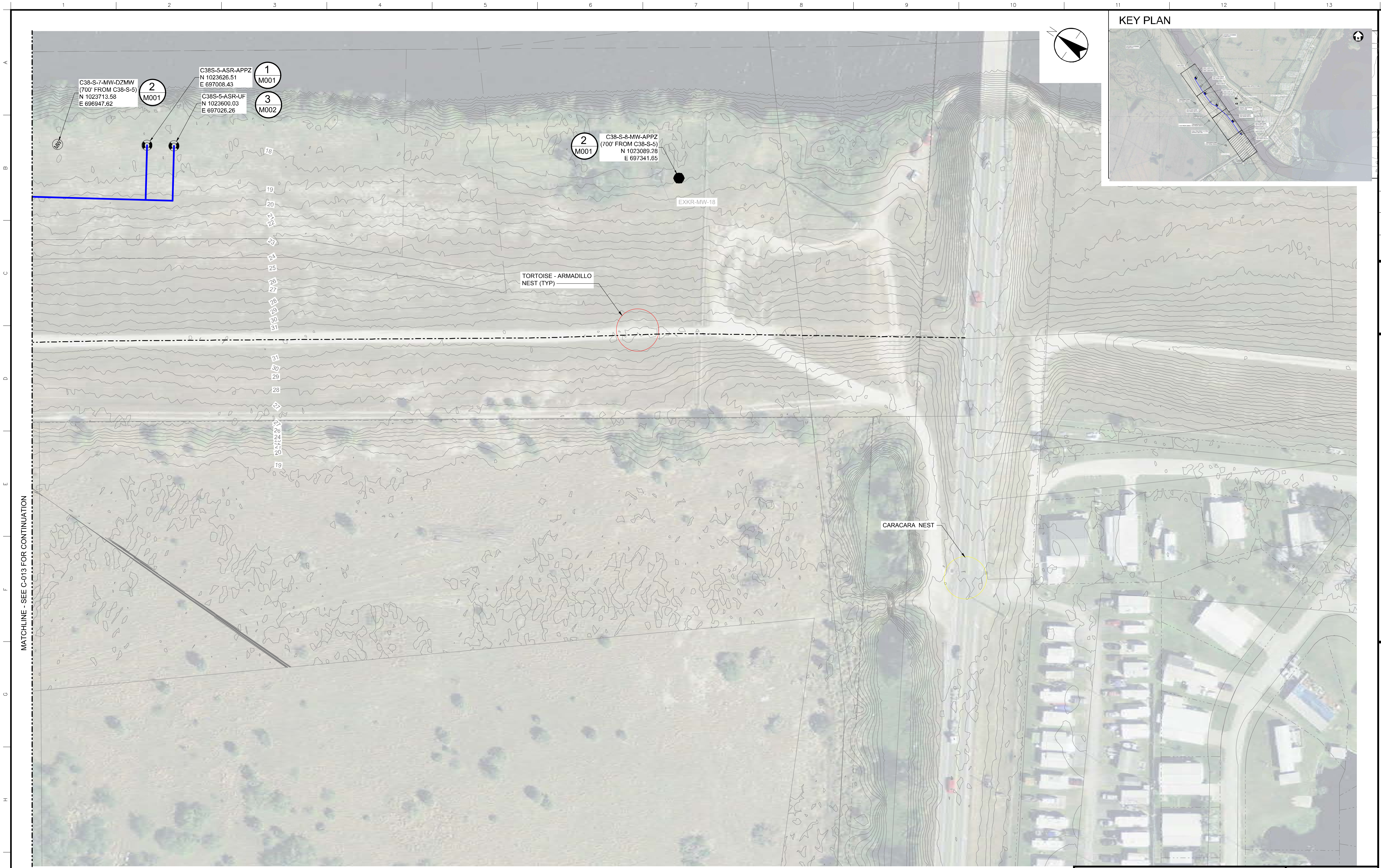

Always call 811 two full business days before you dig to have underground utilities located and marked.

Sunshine811.com

Stantec

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ENGINEER OF RECORD:

FL P.E. LICENSE NO.:

DATE:

REVISION DESCRIPTION	REF#	DRAWN	DATE

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: 1" = 50'-0"

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)

C-38S - ENLARGED SITE PLAN - IV

PROJECT ID NO.
177311458
DRAWING NUMBER
C014

SHEET
9 OF XX

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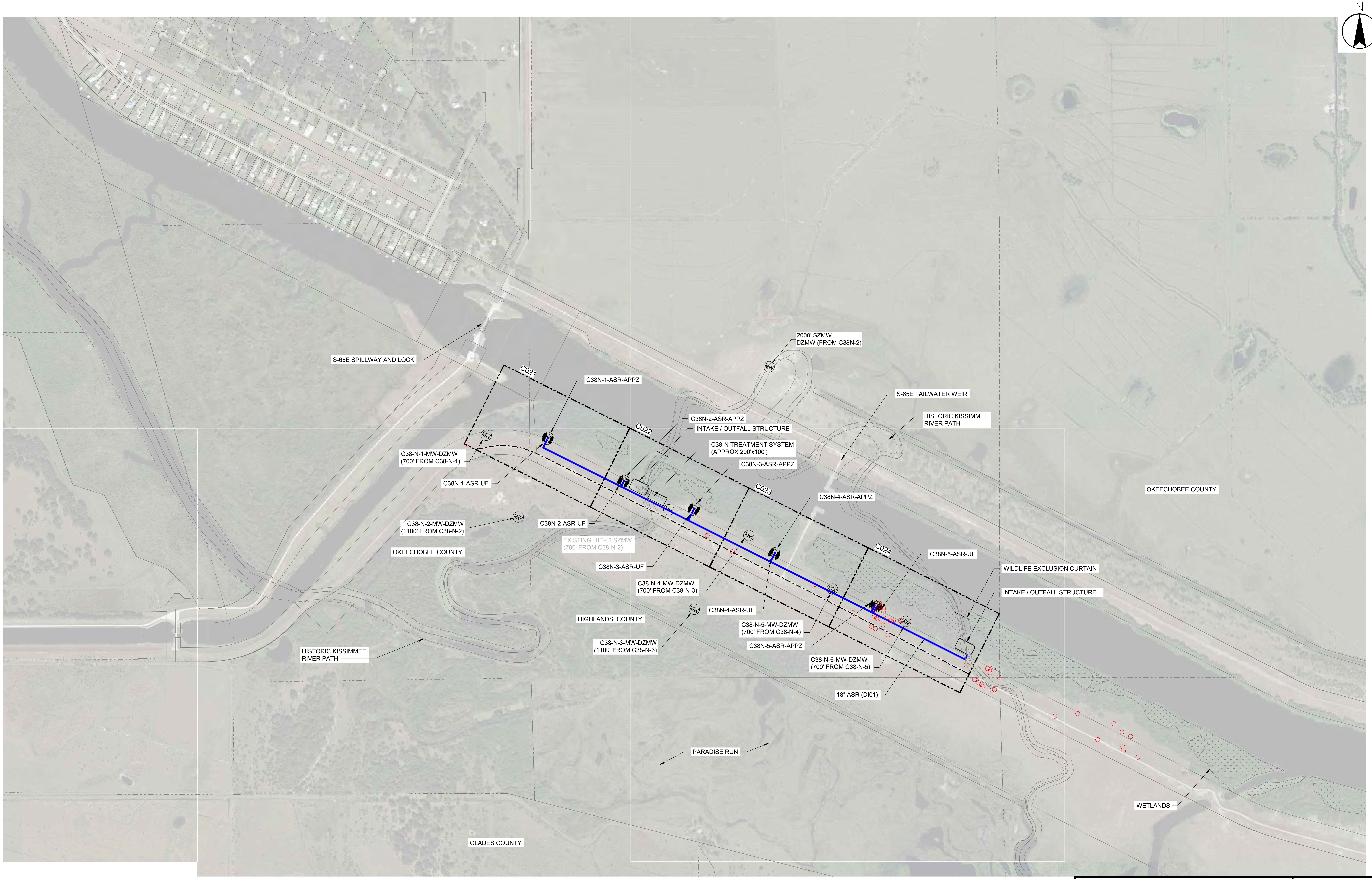

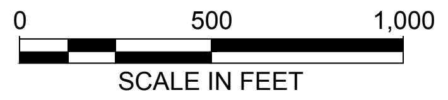

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ENGINEER OF RECORD:
WILLIAM WEBER, P.E.
FL P.E. LICENSE NO.: 61875

DATE:

DATE	DRAWN	REF#	REVISION DESCRIPTION

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: 1" = 500'-0"

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)

OVERALL SITE - C-38N

PROJECT ID NO.
177311458
DRAWING NUMBER
C020

SHEET
10 OF XX

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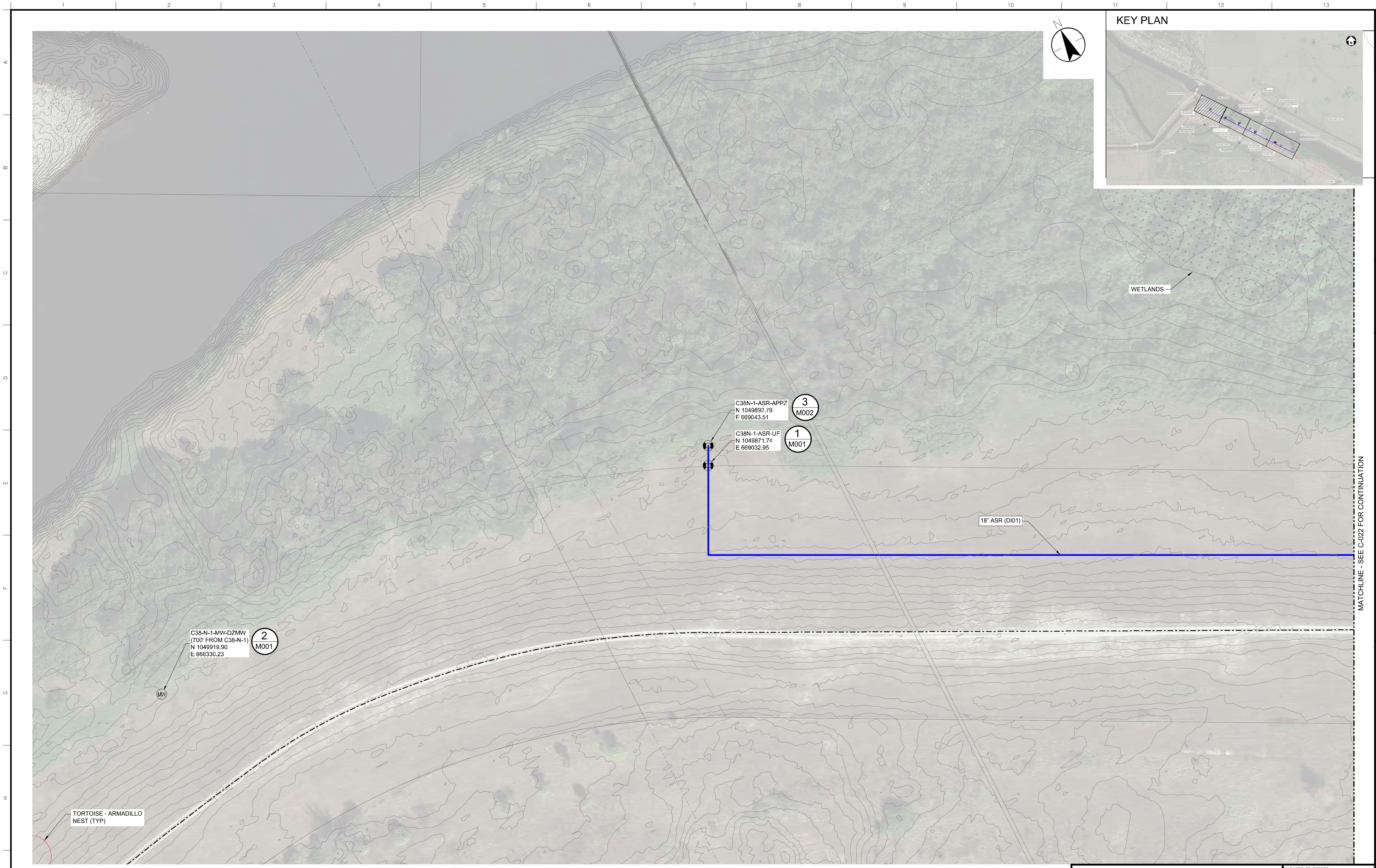

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Sunshine811.com

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Stantec

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WILLIAM WEBER, P.E.
FL P.E. LICENSE NO.: 61875

DATE:

REVISION DESCRIPTION	REF#	DRAWN	DATE

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: 1" = 50'-0"

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)

C-38N - ENLARGED SITE PLAN - I

PROJECT ID NO.
177311458
DRAWING NUMBER
C021

SHEET
11 OF XX

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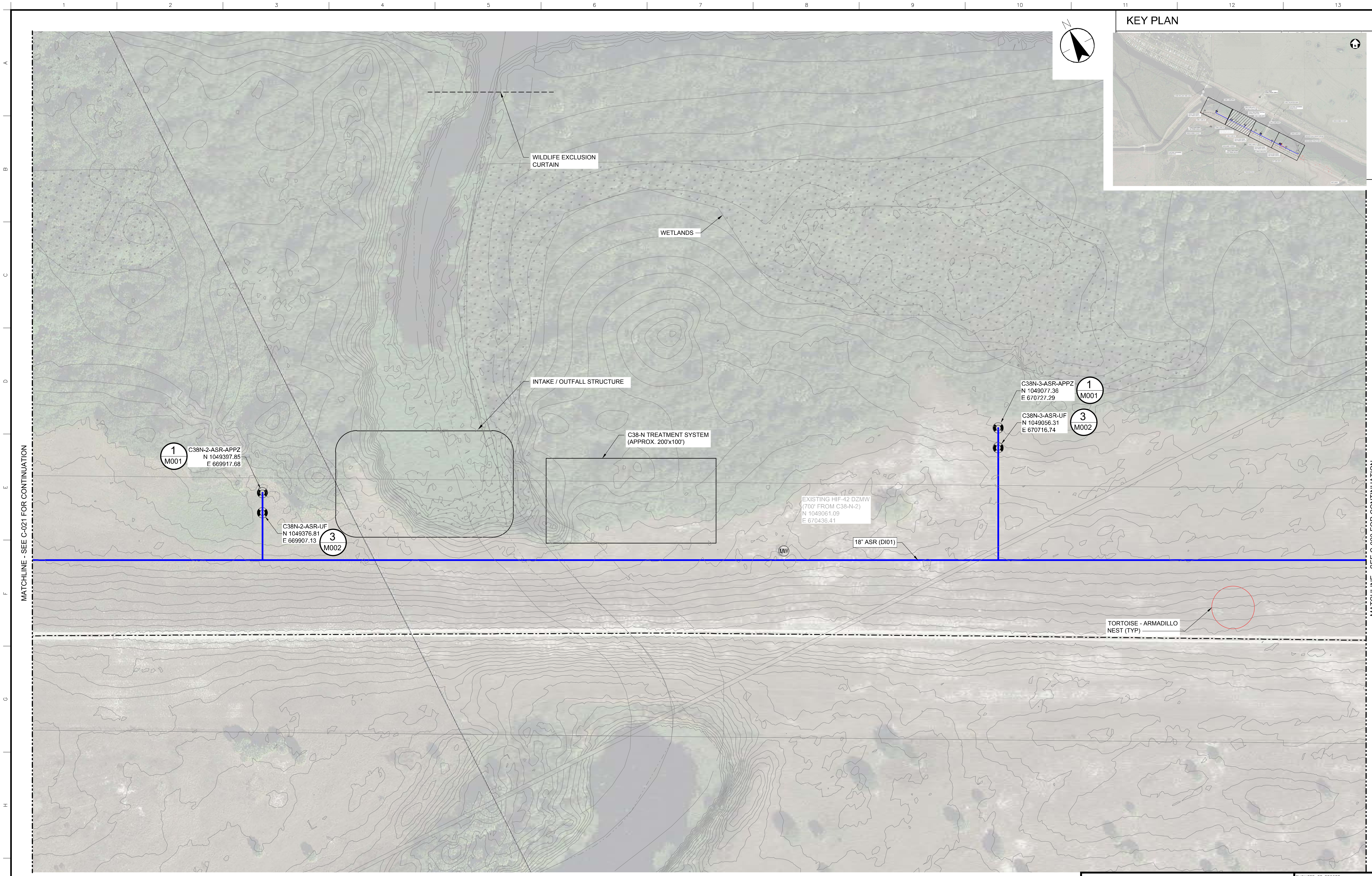

0 50 100
SCALE IN FEET

Stantec

ENGINEER OF RECORD:
WILLIAM WEBER, P.E.
FL P.E. LICENSE NO.: 61875

DATE:

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DATE	DRAWN	REF#	REVISION DESCRIPTION

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: 1" = 50'-0"

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)

C-38N - ENLARGED SITE PLAN - II

PROJECT ID NO.
177311458
DRAWING NUMBER
C022

SHEET
12 OF XX

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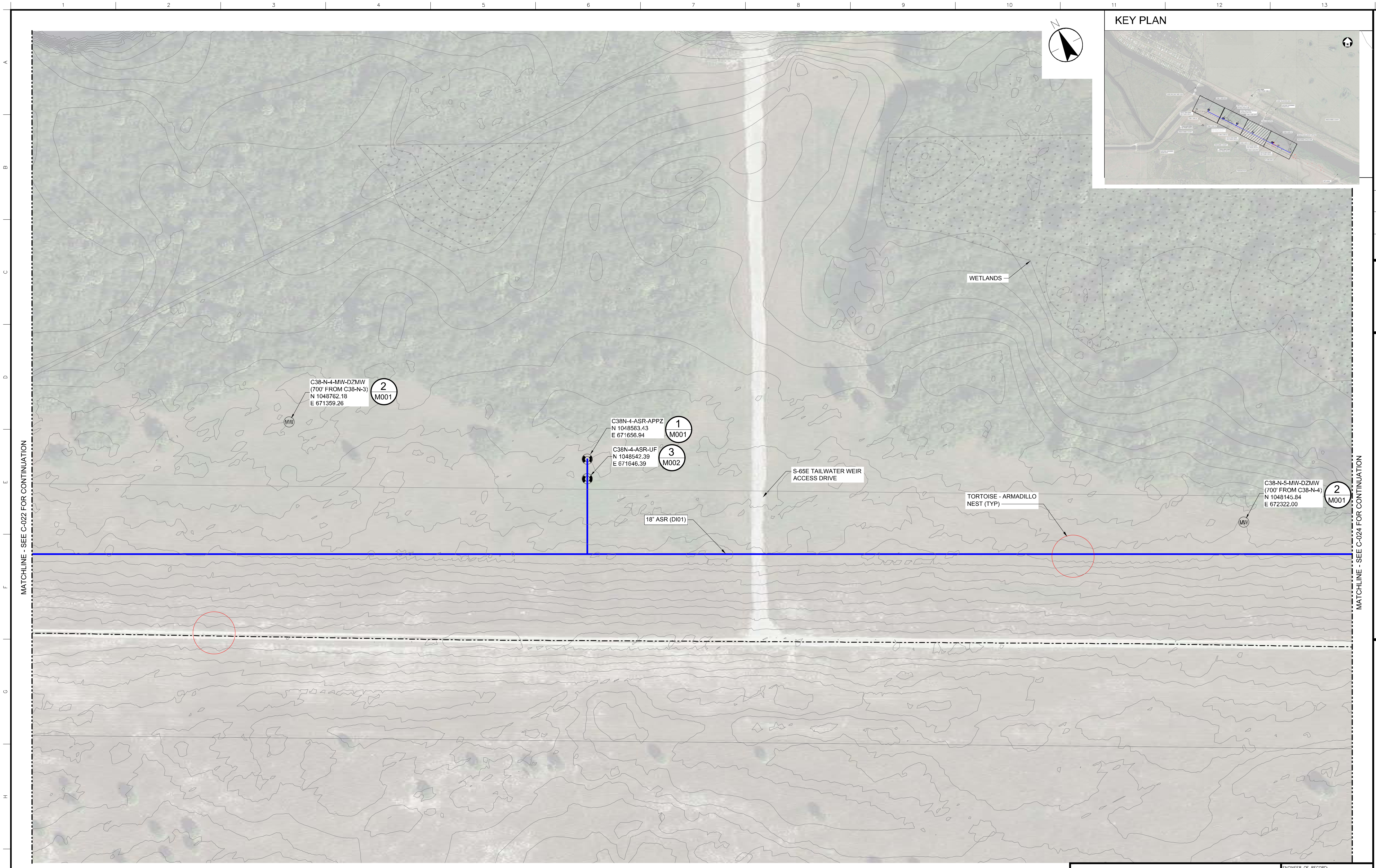

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ENGINEER OF RECORD:
WILLIAM WEBER, P.E.
FL P.E. LICENSE NO.: 61875

DATE:

REVISION DESCRIPTION

DATE	DRAWN	REF#

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: 1" = 50'-0"

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)

C-38N - ENLARGED SITE PLAN - III

PROJECT ID NO.
177311458
DRAWING NUMBER
C023

SHEET
13 OF XX

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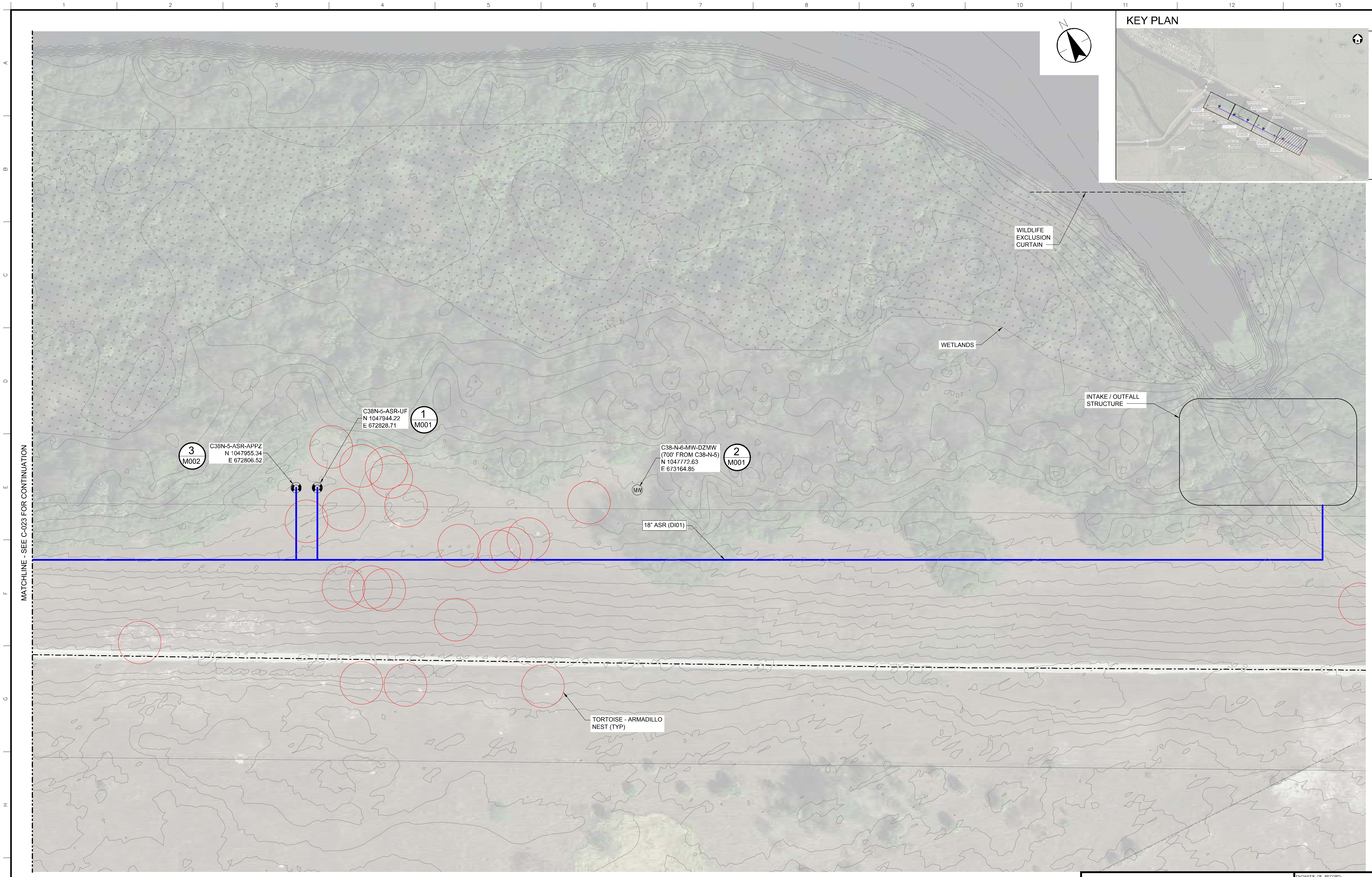

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SCALE IN FEET

Stantec

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WILLIAM WEBER, P.E.
FL P.E. LICENSE NO.: 61875

DATE:

REVISION DESCRIPTION

DATE	DRAWN	REF#

ENGINEER: H WINTZ
DRAWN: S NADKAR
CHECKED:
DATE: JANUARY 31, 2020
SCALE: 1" = 50'-0"

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)

C-38N - ENLARGED SITE PLAN -IV

PROJECT ID NO.
177311458
DRAWING NUMBER
C024

SHEET
14 OF XX

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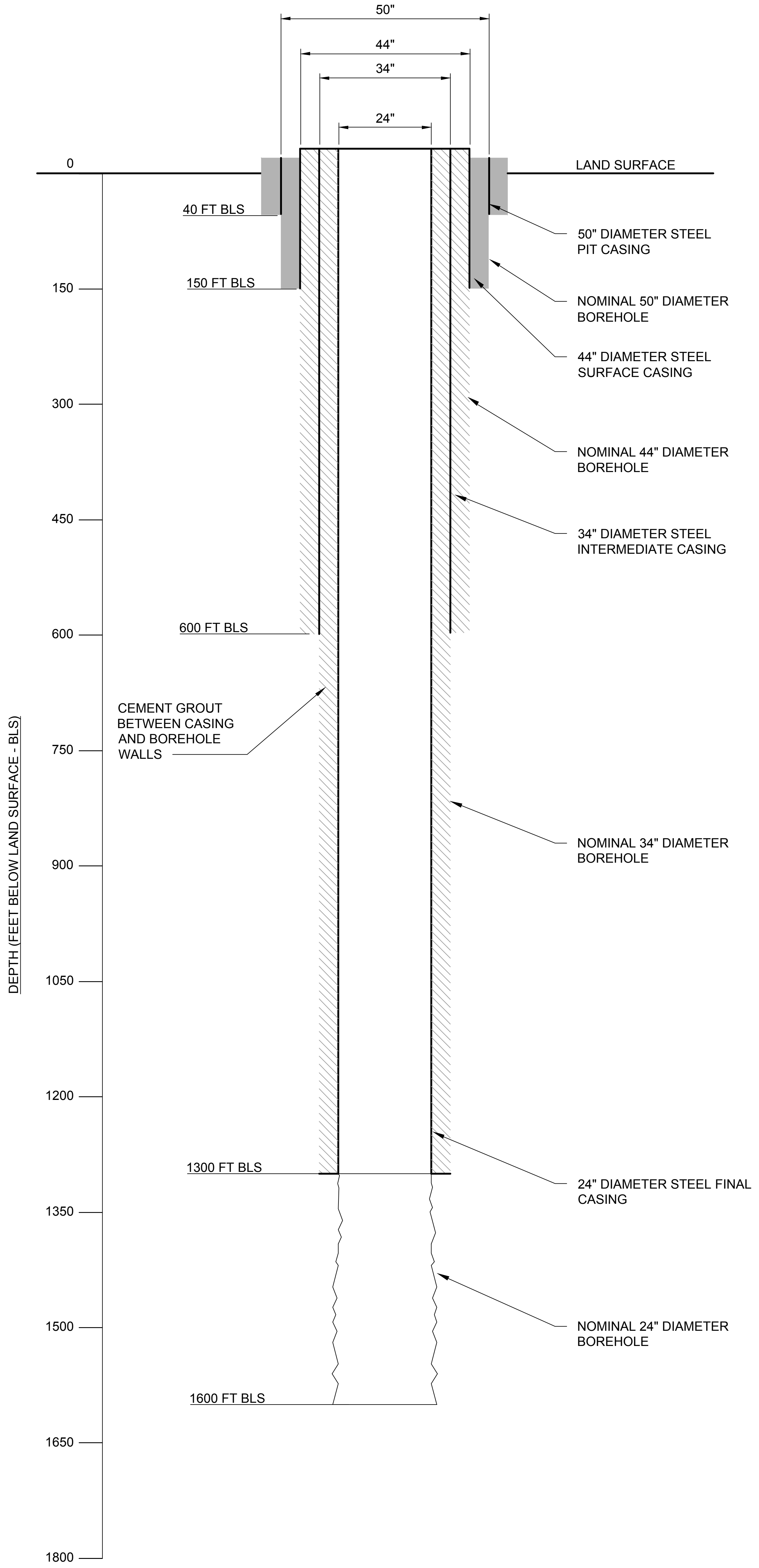
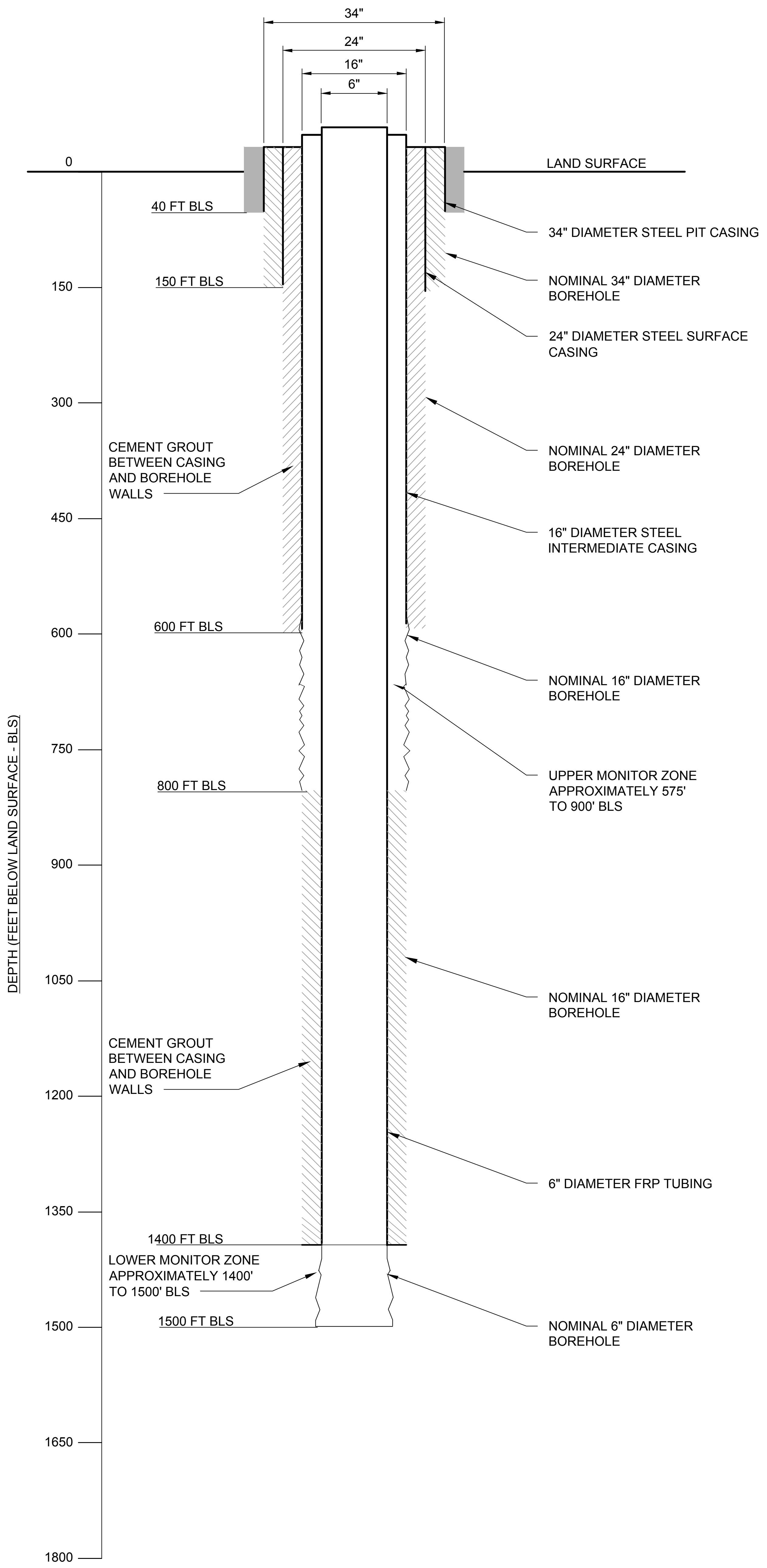


① VARIES **APPZ ASR WELL**

CONCEPTUAL DESIGN (C-38N AND C-38S)

NO SCALE



② VARIES **DUAL-ZONE MONITOR WELL (DZMW)**

CONCEPTUAL DESIGN (C-38N AND C-38S)

NO SCALE

***Note: The final design will be determined once the continuous core program is complete.**

Stantec

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ENGINEER OF RECORD:

FL P.E. LICENSE NO.:

DATE:

REVISION DESCRIPTION

DATE	DRAWN	REF#

ENGINEER: H WINTZ
DRAWN: A SAWARBANDHE
CHECKED:
DATE: **JANUARY 31, 2020**
SCALE: NO SCALE

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
OPERATIONS, MAINTENANCE & CONSTRUCTION
ENGINEERING & CONSTRUCTION BUREAU
PHONE: 561-686-8800
3301 GUN CLUB ROAD
WEST PALM BEACH, FLORIDA 33406

LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT
AQUIFER STORAGE AND RECOVERY (ASR)

C-38N AND C-38S APPZ ASR WELL AND DZMW WELL DETAILS

PROJECT ID NO.
177311458
DRAWING NUMBER
M001

SHEET
20 OF XX

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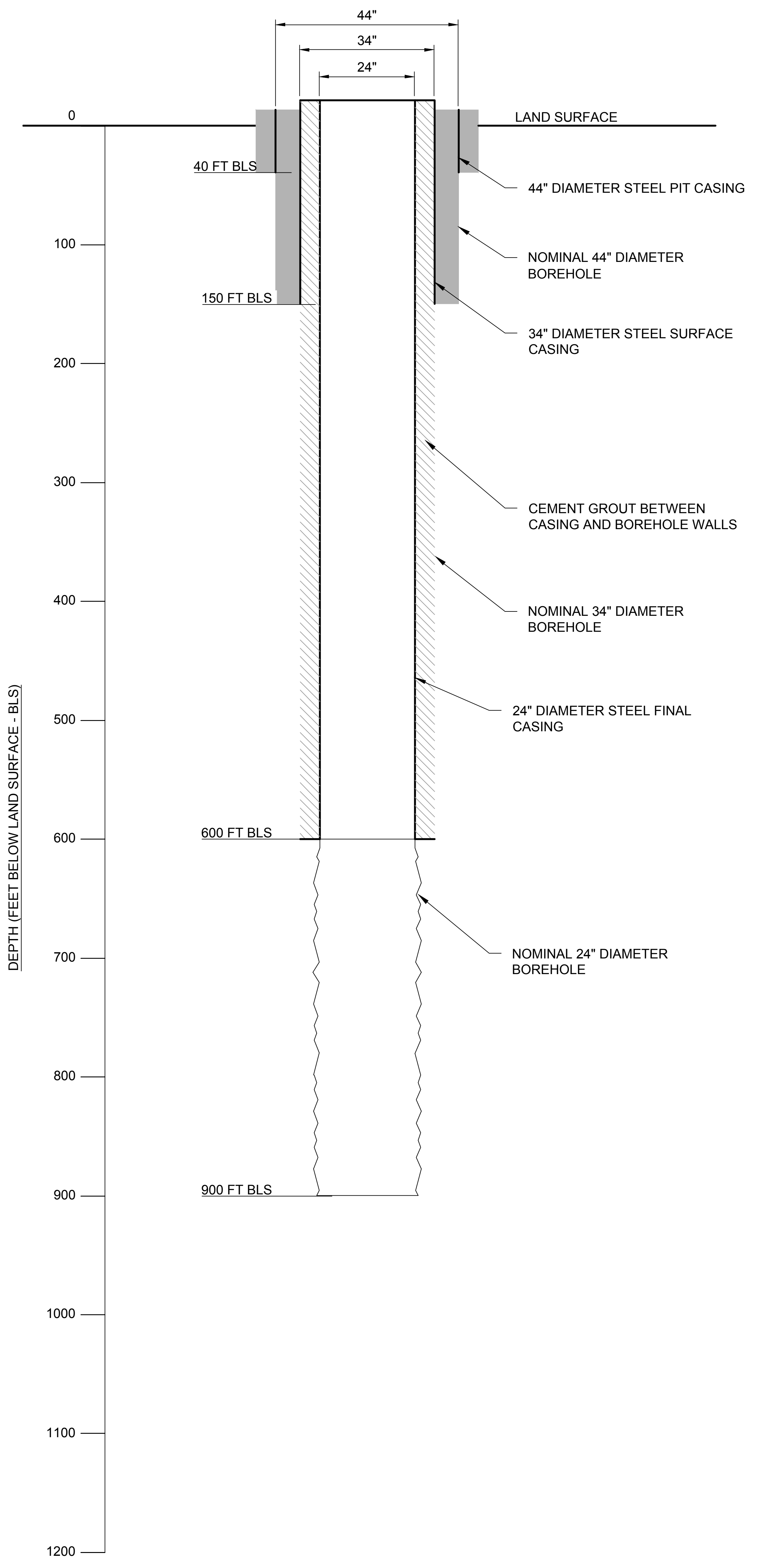
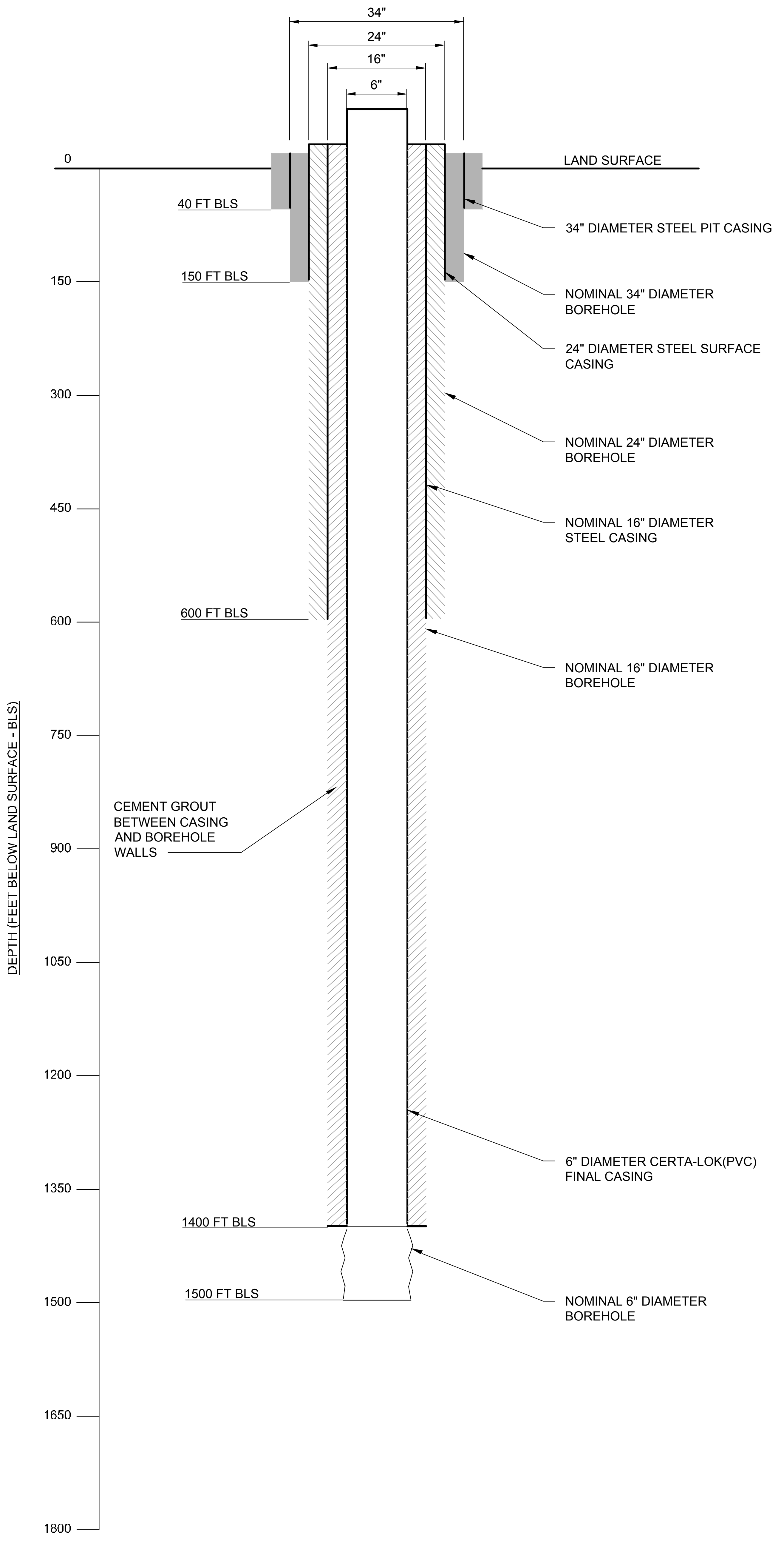


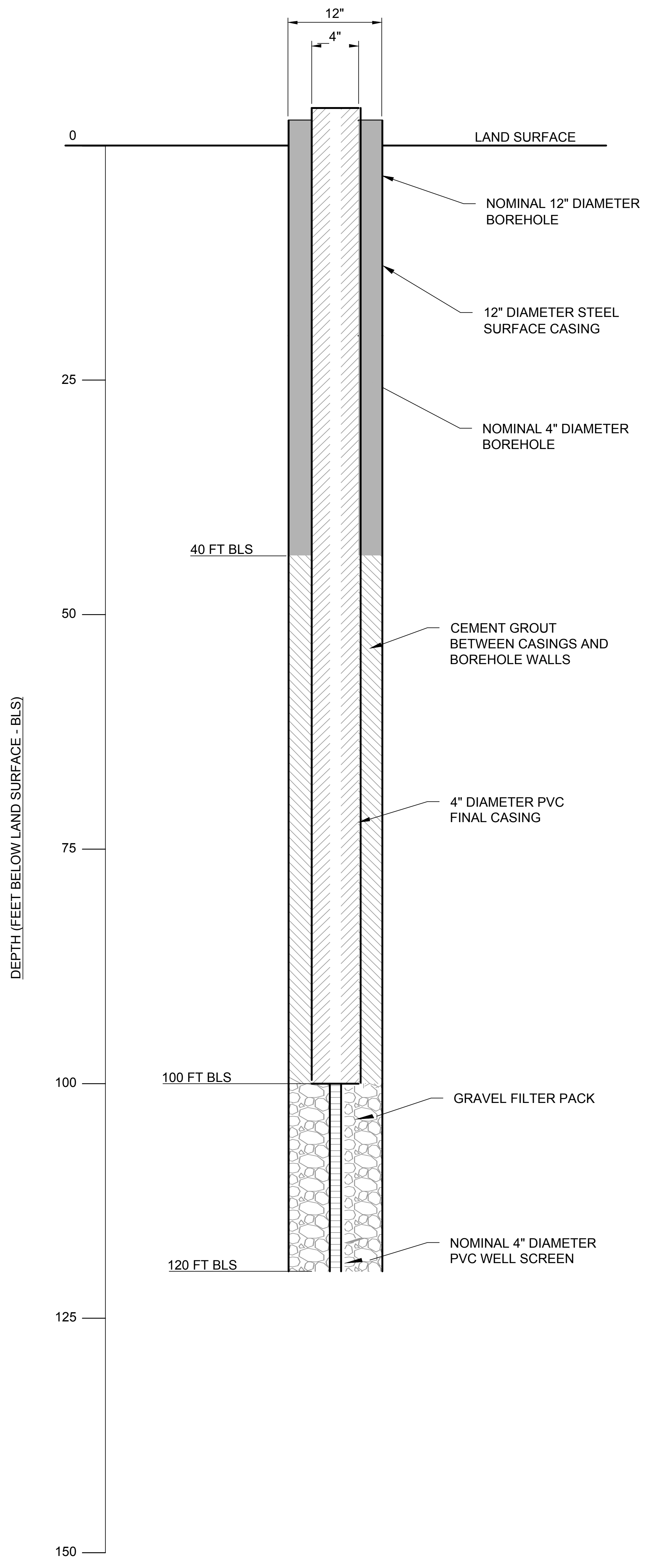
3 VARIES **UPPER FLORIDAN ASR WELL**

CONCEPTUAL DESIGN (C-38N AND C-38S)
NO SCALE



4 VARIES **APPZ MONITORING WELL**

CONCEPTUAL DESIGN (C-38S)
NO SCALE



5 VARIES **SURFICIAL AQUIFER MONITOR WELL**

CONCEPTUAL DESIGN (C-38N AND C-38S)
NO SCALE

Stantec

ENGINEER OF RECORD:
FL P.E. LICENSE NO.:
DATE:

REVISION DESCRIPTION
DATE | DRAWN | REF#

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LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE AND RECOVERY (ASR)
C-38N AND C-38S UFA ASR WELL, APPZ MONITORING WELL AND SURFICIAL AQUIFER MONITOR WELL DETAILS

PROJECT ID NO. 177311458
DRAWING NUMBER M002
SHEET 21 OF XX

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APPENDIX G:
LOWRP ASR WELLS: WATER TREATMENT TECHNOLOGY EVALUATION TECHNICAL MEMORANDUM

SFWMD Lake Okeechobee Watershed Restoration Project (LOWRP) Aquifer Storage and Recovery (ASR) Wells

Water Treatment Technology Evaluation
Technical Memorandum

Prepared for:

South Florida Water Management
District (SFWMD)

Prepared by:

Stantec Consulting Services Inc.

Rev	Description	Author		Quality Check		Independent Review	
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	Final TM Submittal	Heath Wintz	1/22/21	Brian Lamay	1/27/21	MMcWhirter	1/27/21

SFWMD LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT (LOWRP) AQUIFER STORAGE AND RECOVERY (ASR) WELLS

This document entitled SFWMD Lake Okeechobee Watershed Restoration Project (LOWRP) Aquifer Storage and Recovery (ASR) Wells was prepared by Stantec Consulting Services Inc. (“Stantec”) for the account of South Florida Water Management District (SFWMD) (the “Client”). Any reliance on this document by any third party is strictly prohibited. The material in it reflects Stantec’s professional judgment in light of the scope, schedule and other limitations stated in the document and in the contract between Stantec and the Client. The opinions in the document are based on conditions and information existing at the time the document was published and do not take into account any subsequent changes. In preparing the document, Stantec did not verify information supplied to it by others. Any use which a third party makes of this document is the responsibility of such third party. Such third party agrees that Stantec shall not be responsible for costs or damages of any kind, if any, suffered by it or any other third party as a result of decisions made or actions taken based on this document.

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Executive Summary

The Lake Okeechobee Watershed Restoration Project (LOWRP) Aquifer Storage and Recovery (ASR) Program seeks to construct clusters of ASR wells to improve the quantity and timing of discharges to the St. Lucie and Caloosahatchee estuaries; increase the spatial extent and functionality of wetlands; and improve water supply for existing legal water users. The project includes construction of ASR well systems located in clusters in five locations (C-38N, C-38S, L-63N, C-59, and L-63S) throughout the Lake Okeechobee watershed.

The planned ASR wells will utilize excess surface water during the wet season to recharge the Upper Floridan Aquifer (UFA) and Avon Park Permeable Zone (APPZ). This stored water will be recovered to the same water bodies during extended dry periods. Prior to injection into the UFA and APPZ, the water must be treated to dependably meet regulatory criteria for construction and operation of Class V, Group 7 Underground Injection Control (UIC) ASR facilities. Chapter 62-528, F.A.C, requires that water being recharged through an ASR well into an Underground Source of Drinking Water (USDW) must meet drinking water standards (DWS). This Technical Memorandum (TM) considers different treatment options for complying with the applicable standards and provides a recommended approach to treatment finalization.

Regulatory Requirements

For chemical constituents, it is anticipated that the treatment requirements during recharge (injection) will necessitate meeting federal primary drinking water standards, which are summarized in **Table 2-1 Primary Drinking Water Standards.** For biological constituents, rule 62-520.420(1), F.A.C., establishes a total coliform limitation of 4 cfu/100 mL as the ground water standard applicable for the UFA and APPZ. The Surface Water Treatment Rule (SWTR) applies in cases that require direct consumption of potable water, and not for ASR, but is used as a best practice guideline for level of treatment. Additionally, the District has expressed interest in the technical requirements and feasibility of treating water to comply with secondary drinking water standards, which are summarized in **Table 2-3 Secondary Drinking Water Standards**.

Raw Water Quality

Stantec obtained and reviewed available water quality data for the Kissimmee River from the South Florida Water Management District (SFWMD) DBHYDRO database and from the Florida Department of Environmental Protection (FDEP) WIN database for surface water quality stations located nearest the potential ASR clusters on the L-63 and C-59 canals. Water quality in the Lake Okeechobee Watershed is highly variable both spatially and temporally. As a basis for general discussion in this TM, available data were summarized on a weighted average basis and presented in **Table 2-4 Weighted Average Key Water Quality Parameters for ASR Sites**. **Appendix A** presents the values and number of samples by site which were rolled up into the summary. While pH, TDS, TSS and turbidity are relatively consistent, color levels in the Lake Okeechobee Watershed are highly variable. Color levels in Kissimmee River and L-63 canal range from 1 to over 500 PCU during the start of the rainy season. Coliform bacteria levels in Kissimmee River source water are highly variable, ranging from 600 to 15,000 CFU/100mL. Given the variability and the fact weighted averages have been used to facilitate discussion, future site specific water quality analysis may be required for individual facilities.

In general, the raw water does not contain constituents that exceed the primary DWS. For microbiological compliance, the surface water must be treated to remove solids and reduce color to allow for efficient inactivation of pathogens to meet the 4 coliforms per 100ml target. Limited data on iron and manganese was available from previous studies. However, iron levels near 0.3 mg/L are at the secondary drinking water standard and could be of concern, depending on the treatment technology selected.

SFWMD ASR Systems

The Kissimmee River ASR (KRASR) and Hillsboro ASR (HASR) pilot projects have demonstrated feasibility of ASR treatment systems in the Lake Okeechobee Watershed. KRASR utilizes direct media filtration, while HASR uses mechanical basket strainers alone. Both pretreatment processes are followed by disinfection with Ultraviolet (UV) reactors. Water treated by the KRASR generally met required standards during cycle test 1, with one period of coliform bacteria exceedance. However, during cycle tests 2 and 3, it became clear that the two-unit UV disinfection system failed to reduce total coliform levels to less than 4 cfu/100 mL. Reasons for this failure included an inability to quantify the UV dose; an inability to transfer UV performance data from the UV sensors to the SCADA system; and incomplete activation of total coliforms. Flow rate reduction did not improve inactivation of coliform bacteria, possibly due to high color surface water and coincident low UV Transmittance (UVT). As a result, the system was modified to add a third UV unit in series and bypass piping so that the system could be tested without sending partially disinfected, off-spec water to the ASR well. Similar challenges to inactivation at the HASR treatment system were also addressed by adding a third UV unit. Coliform bacteria inactivation challenges continued through all phases of cycle testing and are summarized in **Table 3-2 KRASR Off-Spec Water Summary.**

Regional ASR Systems

Stantec conducted a survey of ASR system owners throughout South Florida to understand water quality issues faced by these systems and treatment technologies utilized to overcome the issues. Peace River Manasota Regional Water Supply Authority treats water by coagulation with alum followed by filtration. Peace River, Marco Island and Naples use media filtration (pressurized or gravity filters) for pretreatment followed by disinfection using chloramines. The City of Naples treats a blend of wastewater and stormwater at the water reclamation facility prior to ASR storage. These utilities do not neutralize or dechlorinate prior to storage.

The City of Bradenton also uses chloramines and is the only utility which is using sodium bisulfite to dechlorinate. The City of Bradenton also removed remaining oxygen with degasifying membranes, but has since installed a vacuum stripping tower for their second ASR well at the WWTF. These processes were likely driven by mobilization of arsenic in the aquifer. Sodium hydrosulfide is used by the City of North Port to quench remaining DO from surface water prior to storage, likely to avoid mobilizing arsenic in the aquifer as well.

The City of West Palm Beach ASR well was originally designed and permitted to store fully treated surface water from the City’s WTP, but has been modified to allow for storage of partially treated and now undisinfected surface water under a Limited Aquifer Exemption (LAE). The treatment process consists of an 80-mesh strainer alone.

Technologies for Pretreatment Prior to Disinfection

Stantec conducted a review of and summarized six (6) best available technologies to treat surface water previously characterized and summarized in **Table 2-4 Weighted Average Key Water Quality Parameters for ASR Sites**. These technologies included: Pressure media filters, Mechanical Filters, Strainers (Disk and Basket), Bag Filter and Cartridge Filters, Membranes, and Ion Exchange. Membrane technologies summarized included microfiltration, ultrafiltration, and nanofiltration. A summary comparison of membranes is provided in **Table 4-1 Comparison of Membrane Features.** Pretreatment with mechanical strainers and filters can capture large suspended solids but are not recommended as they are ineffective at removing dissolved organic compounds, which create color. Pressure media filters can remove smaller particles but cannot remove dissolved organics without the aid of a coagulant. Coagulant addition for enhanced removal of DOC is also described and discussed in context of the 2009 jar testing conducted at the KRASR site. Pretreatment technologies are a significant cost driver for treatment and are summarized and compared in **Table 4-2 Comparison of Pretreatment Vendor Quotes.** Ceramic membranes offer a new technology to be considered in addition to polymer membranes given advancements over the past decade which have led to lower cost and more durable elements that have a smaller treatment process footprint when compared to polymer membranes.

Disinfection Technologies

Disinfection of treated surface water is required by UIC rules to reduce coliform bacteria to 4 cfu/100mL as described in Section 2.1.1. Stantec conducted a review of and summarized six (6) best available technologies to disinfect surface water. These technologies included chemical disinfection (chlorine, chloramines), pasteurization, membrane filtration, ultraviolet (UV), and advanced oxidation.

Chlorine is inexpensive and effective at achieving disinfection of coliform bacteria. However, during the wet season, coliform levels reaching up to 15,000 cfu/100mL would require significant doses of chlorine to reach the regulatory requirements (up to 4-log). Disinfection by-product formation potential (DBPFP) would be expected to be very high due to the high level of organic compounds in the source water, even with low disinfectant dosing. Chemical disinfection would not be favored because of the need for large onsite storage or generation of chlorine and/or ammonia; significant contact time, very high disinfection byproduct formation potential, and need for chemical quenching of disinfectant to mitigate risk of arsenic mobilization in the aquifer. For these reasons, chlorine/chloramine chemical disinfection was removed from further consideration.

Pasteurization is a proven disinfection method involving raising the temperature of the water to sub-boiling (minimum 60°C to 65°C) for pathogen inactivation. These processes are typically land intensive, relying on solar-thermal disinfection to provide low throughput water production. For ASR treatment sites being considered with their high volume of water to be treated a more intensive system would be needed. The estimated required heat input for pasteurization at one 10 MGD site would require over one (1) million kWh of electricity per day. This assumes a 100% efficiency of heat transfer with a starting temperature of 25°C and no reduction of the temperature from 60°C prior to aquifer injection. While a solar-driven system could be far more sustainable, the land-intensiveness of such a process would make it prohibitive at full scale (i.e., tens of acres). Furthermore, reliability of pasteurization is significantly less than other proposed options. For these reasons, pasteurization was removed from further consideration.

Membranes can be used to exclude pathogens from the treatment process based on size. Most bacteria are very small (~1 μm long). A single coliform is typically around 2 μm long and about 0.5 μm in diameter, while ultrafiltration (UF) membrane openings are on the order of 0.01 μm. As such, coliform bacteria can be rejected by these membranes openings which are 50 times smaller than the organism. Details on membrane sizes required for disinfection are described in Section 4.1.5.

Ultraviolet disinfection requires a similar approach to chlorine in that the UV dose and reactor retention time are key factors in achieving inactivation of pathogens. However, the required contact time for UV disinfection is much shorter than for chlorine or chloramine disinfection and is in the order of a few seconds. For UV disinfection, the UV dose (mJ/cm^2) is considered a **I**·T value, which represents the UV intensity (mJ/cm^2-s) multiplied by the time (T) spent in the reactor (seconds). A 4-log inactivation of E. Coli is achievable with a delivered UV dose of 20mJ/cm^2 as indicated in **Table 4-4 Ultraviolet Disinfection Requirements** however there are numerous factors of safety which must be carefully considered and applied to ensure this dose is delivered**.**

As UV Transmittance (UVT) of the pre-treated water increases, the cost of UV treatment decreases, along with number of reactors and lamps required to deliver a certain UV dose and this will impact both capital investment and long-term operations and maintenance costs. A key parameter that can decrease UV disinfection effectiveness is low ultraviolet transmittance, which is often caused by high DOC/TOC and associated with high color. Given characteristics of ASR source water, the raw water at the sites presents challenges to the use of UV disinfection, but it may be possible to overcome these with sufficient pretreatment.

The previously noted installation at the KRASR site was designed to deliver a dose of 40mJ/cm^2 once upgraded to three-reactors in series. However operational challenges can affect a UV system's ability to deliver its design dose and the KRASR site has still proven to be seasonally inadequate to provide total coliform reductions below the 4CFU/100mL regulatory requirement. Hence, a 50 mJ/cm^2 value has been used as the minimum recommended dose in this option analysis, and detailed design should review all water quality parameters that may lessen effectiveness of UV disinfection prior to implementation to properly account for low UVT and high DOC. While not highly correlated, true color and UVT data from cycle testing at the Kissimmee River ASR site is shown in **Figure 4-4 Relationship of True Color and %UVT in Kissimmee River ASR Cycle Testing**, which generally illustrates that higher UVT is achieved with lower true color of the source water. Additional design constraints, lamps, reactor design and other considerations are addressed in Section 4.2.4. UV disinfection technologies are summarized and compared with vendor equipment quotes in **Table 4-7 Comparison of UV Vendor Quotes**.

Ozone treatment is an oxidation process which can provide disinfection by itself and can also assist in the removal of color, which increases the UV transmittance of water. Ozone is among the most powerful oxidants and disinfectants available. For the SFWMD ASR raw water sources, a very high ozone dose will be required to meet disinfection goals because the ozone would interact with the high DOC and color in the water. Ozone treatment systems are very complicated, would require significant contact time, and are expensive to operate. Therefore, ozonation was removed from further consideration.

Advanced oxidation processes (AOP) use hydroxyl (OH-) radicals to oxidize pollutants. AOP processes include ultraviolet with hydrogen peroxide and ultraviolet with a photocatalyst. To achieve radical production, a reasonably high UVT must be provided in the source water, which is not characteristic of ASR site water quality. For this reason, AOP was deemed infeasible and was removed from further consideration.

Residuals Management Technologies

Many of the pretreatment processes will produce a residual stream which needs to be managed and the characteristics of these residual streams varies based on the pretreatment technology. There are different technologies available, ranging in complexity, that can be used for management of residuals streams. A backwash pond is one of the simplest technologies for residuals solids separation. It consists of settling of solids in an open basin. A decant pump draws water from the surface of the pond via a floating skimmer as water level fluctuates. This supernatant liquid can then be re-treated through the pretreatment process, while solids are periodically removed from the basins with equipment and trucked off-site for disposal. At the other end of the complexity spectrum, membranes in various forms can be used to dewater concentrate residual streams. For example, one ceramic membrane manufacturer uses flat sheet membranes to concentrate blowdown from the ceramic membrane system. Solids accumulate on the face of the flat sheet membranes. Periodically, the flat sheet membranes are withdrawn from their tank and the 15 to 20% dewatered cake solids are removed from the sheet and disposed of. Filtrate from this residual dewatering process can be directed back to the membrane treatment stream for re-treatment. Membrane loading rates can be much higher per square foot than gravity sludge thickening processes, so the footprint of this technology can be a fraction of conventional dewatering treatment processes.

Shortlisting of Technologies

Treatment technologies were excluded from further consideration or inclusion in potential treatment trains on the basis of the following fatal flaws:

1. Any process that is complex in nature compared to other processes and requires a high level of manned staffing, operator and maintenance attention

2. Any treatment process that produces levels of DBPs in excess of standards for Maximum Contaminant Levels (MCLs) and Maximum Residual Disinfectant Levels (MRDLs).

3. Technology or system is not scalable to 50 MGD.

4. Any process not suitable for high organic loads, algae, and high turbidity that are common characteristics of Lake Okeechobee tributary surface water.

Table 4-9 Treatment Technology Summary provides a summary of all technologies which were considered for evaluation and were excluded from consideration. **.**

Treatment Alternatives

Shortlisted technologies were arranged into five (5) potential treatment trains which could achieve the project goals. Each treatment train underwent consideration of treatment performance and evaluation in terms of economic and non-economic criteria. These treatment trains are summarized in **Table 5-1 Potential Treatment Trains**.

- Alternative 1A - Media Filtration, UV Channel Disinfection

Alternative 1A is reflective of the existing KRASR Treatment system. This system consists of intake screening, raw water pumping, and media filtration (22 pressure vessel units). However, because color and organics removal are negligible with this pretreatment technology, UVT would likely remain low (20%). Few UV vendors opted to quote a system for this low UVT, except open channel-type manufacturers.

Breaking pressure from closed pipes after the filters to an open channel for UV would necessitate intermediate pumping from the treatment process to ASR wells. At 50 MGD buildout capacity, open channel UV disinfection would require 11 (10+1) channels with 324 lamps, each with a nominal input of 1,000W for a total of 1,188 UV lamps and a total power draw of 1,137kW. While this alternative may appear operationally simple, there is no Color/DOC removal with this alternative and it would not meet the secondary drinking water standards for color. it carries the highest potential for aquifer plugging. This process would yield the lowest UVT for disinfection making it unreliable, .

- Alternative 1B – 2 Stage Media Filtration, Coagulation, UV Disinfection

Alternative 1B is similar to Alternative 1A with intake screening, raw water pumping, and media filtration (pressure vessel type). However, Alternative 2 separates filtration into two (2) stages. The first stage serves as roughing filters (16 vessels) while the second stage (18 vessels) provide fine (sand) media filtration. In seasons or during raw water quality events when it was required, coagulant could be dosed prior to the second stage to more effectively remove DOC with fine media filtration. Substantial color/DOC removal could be achieved with this alternative, resulting in a moderately higher UVT for disinfection. Since this process remains under pressure throughout the train, an intermediate pumping station is not necessary for storage.

One advantage of this alternative is the ability to reliably reach the 40% minimum UVT necessary to open up competition to pressure vessel type UV manufacturers including Trojan, Wedeco, Calgon and Aquionics. However, due to differences in lamp output between vendors a greater number of lamps would be required to deliver the dose when compared to Alternative 1A. For example, at 50 MGD buildout, 51 (50+1) Wedeco LBX1500 pressure vessels would be required with 60 lamps each to provide the required dose. This would require a total of 3,060 lamps with a total power draw of 1,062kW (over 2.5 times as many lamps as needed for Alternative 1A).

Advantages of Alternative 1B are similar to Alternative 1A in that it is operationally simple. When color levels are low, the chemical feed systems will remain in standby. However, during periods of marginal water quality, if color levels have not fallen to sufficient levels for direct filtration alone, the coagulant will provide

O&M staff with the ability to treat and begin storing water earlier in the season than without. Alternative 1B would not meet secondary drinking water standards for color.

- Alternative 1C – Ion Exchange (MIEX), UV Disinfection

Alternative 1C consists of intake screening and raw water pumping, followed by Magnetic Ion Exchange (MIEX). This alternative provides good color/DOC removal. With improved color/DOC removal, this alternative could reliably achieve 40% UVT for disinfection. The MIEX treatment system utilizes open basins (broken pressure) so reaching this 40% minimum UVT allows for open channel UV disinfection to be optimized, which could meet disinfection requirements with a total of 660 lamps with a total power draw of 750kW. This represents a reduction in the number of lamps required by Alternative 1A by 45%. .

Similarly to Alternative 1A, breaking pressure from closed pipes from the raw water pumps to an open basin for MIEX would necessitate intermediate pumping from the treatment process to the ASR wells. Since this intermediate pumping station would be necessary, it would allow for either UV channel or UV pressure vessel technology.

Advantages of Alternative 1C include reliable color/DOC removal and only one chemical (salt) required for the MIEX treatment process for resin regeneration. However, the MIEX resin is a proprietary consumable which cannot be competitively sourced. Additionally, the MIEX process involves a multi-story deck to access equipment which could become home to nuisance wildlife if not enclosed. Furthermore, MIEX is considered by some operators to be a mechanically intensive process requiring maintenance of multiple subsystems, including resin regeneration, virgin resin feed, brine makeup and submersible mixers. While the flow is small, the concentrated organic waste stream from this process would require disposal by deep injection well to avoid hauling and disposal costs in the long-term. Alternative 1C also would not meet secondary drinking water standards.

- Alternative 2A – Coagulation, Microfiltration/Ultrafiltration (MF/UF)

Alternative 2A consists of intake screening and raw water pumping to treatment. Raw water in this process is dosed with coagulant and recirculated in a solids contact reactor at approximately 10,000 mg/L upstream of microfiltration or ultrafiltration membranes. For this analysis, ceramic MF/UF membranes were considered for the following reasons: they are not subject to the same type of manufacturing irregularities as polymer membranes, they are warranted for a longer time period, they may require less space, and they may have lower cost. However compared to polymeric membranes they are less proven and a detailed comparison of ceramic to polymeric membranes has not been conducted. This comparison should be conducted should this option to be carried forward to pilot testing. The microfiltration process removes coliform size bacteria, so additional disinfection (UV or chemical) would not be required. Since water remains pressurized throughout the treatment process, Alternative 2A does not require a wet well or intermediate pumping prior to storage. Additionally, with a 97% recovery rate, residual flows are minimized compared to filter backwash flows associated with Alternatives 1A and 1B.

Similarl to Alternative 1B, this alternative includes the flexibility to add a coagulant prior to filtration for DOC removal. Dewatering of solids for Alternative 2A would be accomplished by thickening and centrifuge. Residuals management would be comparable or slightly less than Alternative 1B based on overall efficiencies. With one of the smaller overall footprints, this process would also be enclosed in a building to protect it from nuisance wildlife issues.

Advantages of Alternative 2A are that MF membranes are a reliable and proven process and similar to Alternative 1B can provide color/DOC removal through coagulation. During periods of marginal water quality, if color levels have not fallen to sufficient levels for filtration alone, coagulant will provide O&M staff with the ability to treat and begin storing water earlier in the season than without. When color levels are low, the chemical feed systems will remain in standby. This process provides a lower potential for potential aquifer plugging. Alternative 2A would also meet secondary drinking water standards. However, membrane treatment process are considered by some operators to be mechanically intensive processes requiring maintenance of systems with significant instrumentation and controls and chemical cleaning systems.

- Alternative 2B – Ultrafiltration, Nanofiltration

Alternative 2B consists of intake screening and raw water pumping, followed by straining, ultrafiltration and then nanofiltration. This alternative considers submerged ultrafiltration (UF) membranes. Breaking pressure from closed pipes after the strainers to open basins for submerged membranes would necessitate intermediate pumping to pull through UF membranes, push through NF membranes, and convey water to the ASR wells. Similar to Alternative 2A, the UF process excludes coliform size bacteria, so additional disinfection (UV or chemical) would not be required. Strainer backwash and residual backwash from the UF process would be directed to a backwash pond for dewatering, while high TDS concentrate from the NF process would require construction of a deep injection well.

Advantages of this reliable and proven process include excellent color/DOC removal, lowest potential for aquifer plugging, and no coagulant addition. Residuals management for Alternative 2B would be comparable to Alternative 1B. Unfortunately, due to the low recovery of UF and NF membranes, sizing of upstream processes flows is nearly 64 mgd. Chemical storage and feed systems will be required for periodic cleaning of the UF and NF membranes. This process has the highest capital cost and operating costs of all alternatives considered. Additionally, membrane treatment process are considered by some operators to be mechanically intensive processes requiring maintenance of systems with significant instrumentation and controls and chemical cleaning systems.

Ancillary Processes

Raw water pumps at each site will draw water through the intake screen and convey it to the treatment process downstream. Vertical turbine pumps are recommended over axial flow pumps due to their overall higher efficiencies. Sizing of these pumps would be dependent on the downstream treatment process head requirement.

For treatment process which involve open basins, including channel UV disinfection, MIEX, or submerged membranes, intermediate pumps would be needed. Intake, piping and other major head losses estimated through alternative treatment processes are summarized in terms of TDH, flow, and motor horsepower in **Table 5-3 Raw and Intermediate Pumps by Treatment Train.**

For recovery pumps, artesian pressure at the wellhead was assumed to be 20 ft. Head losses from the farthest well pair to the discharge structure were estimated as 20 ft. Recovery pumps were sized for 5 MGD assuming no artesian pressure.

Raw water and intermediate pumps will be constant speed with reduced voltage soft starters for motors, in accordance with FPL requirements. However, for Alternative 2B, the intermediate pumps will be equipped with VFDs to compensate for diminishing flux through UF and NF membranes.

Footprint

Alternatives were evaluated for differing process area requirements and pump station needs. A factor of 15% was added to the gross process/building area for driveways, parking, and civil improvements. Land requirements for differing alternatives are summarized in the table below. Smaller footprint alternatives (green) are considered more favorable than large footprint alternatives (red).

Table 1-1: Treatment Process Footprint

Process/Building Description	Treatment Process Alternative Area (sq ft)				
	Alt 1A	**Alt 1B**	**Alt 1C**	**Alt 2A**	**Alt 2B**
	Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, Ceramic MF	UF, NF
Total Footprint	**64,900**	**75,900**	**36,300**	**26,400**	**53,900**

Non-economic Evaluation

Treatment technologies were also evaluated and scored based on non-economic factors using a weighting criterion developed with participation of SFWMD staff. Criteria are described and summarized with weighting factors in **Table 5-7 Non-Economic Criteria Weighting.** Scoring of treatment alternatives is summarized in the table below. Higher scoring alternatives (green) are considered more favorable than lower scoring alternatives (red). A summary of advantages and disadvantages with treatment alternatives considered is provided in **Table 5-9 Potential Treatment Train Advantages and Disadvantages**.

Table 1-2 Treatment Alternative Non-Economic Scoring

Non-Economic Criteria		**Process/Treatment Alternative**				
	Weighting	**Alt 1A**	**Alt 1B**	**Alt 1C**	**Alt 2A**	**Alt 2B**
Criteria		Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, Ceramic MF	UF, NF
Color/Organics Removal	15	0	8	9	8	10
Simplicity of Residuals Mgmt	5	8	6	7	7	3
Operational Considerations	25	20	16	10	18	5
Staffing Requirements	5	5	5	4	5	3
Minimal Risk of Aquifer Plugging	10	0	8	6	8	10
Process Reliability	20	6	16	12	16	16
Environmental, Health and Safety	10	10	8	6	8	4
Constructability	10	8	7	5	9	4
Footprint	10	4	3	7	10	5
Subtotal	110	**61**	**77**	**66**	**89**	**60**

Intake Design Regulations

Since there are no codified regulations pertaining to ASR systems, this TM anticipates that FDEP and FWC will follow current industry practice and use Section 316(b) of the US Clean Water Act (CWA) as guidance for developing NPDES permit conditions. The Section 316(b) regulations are intended to address water intake used for cooling purposes to ensure incorporation of best technology available (BTA) for minimizing impingement mortality and entrainment impacts to aquatic life. As such, the Section 316(b) standards have also been used by water managers as guidelines for establishing permit conditions for water intakes used for other purposes. With this understanding, and consistent with the Kissimmee ASR Pilot Project, intake screen options presented in this evaluation are based on through-screen velocity of 0.25 fps and mesh size of 1.0 mm. These design criteria exceed the standards presented in the Section 316(b) and align with parameters needed to protect the eggs and larvae of the dominant fish species anticipated in the ASR source waterbodies.

Intake and Exclusion of Aquatic Life

The intake structure provides the initial course screening to reduce the quantity of solids, organic matter, and aquatic life entering the facility trough the raw water pump station. Five course screen technologies were identified as potentially suitable for the proposed ASR well raw water intakes including:

- Infiltration Galleries and/or Radial Collector Wells
- Stream Bed Filtration
- Aquatic Filter Barriers

- Fine Mesh Static Screens

From this initial list of potential technologies, only fine mesh passive screens (commonly referred to as wedge-wire screens) were identified as suitable for further evaluation as the ASR intake screen alternative. The arrangements presented is this TM are known as Cylindrical Wedge-Wire Screens (CWWS) which consist of V-shaped wire mesh formed into a cylindrical drum configuration and attached to an intake pipe. CWWS technology has been successfully installed in numerous facilities, including the Kissimmee River ASR Pilot Project, and has been accepted by many regulatory authorities as Best Technology Available (BTA) for both impingement reduction and entrainment exclusion.

The intake screen equipment included in this TM are considered suitable for protection of egg and larvae of the predominate fish species historically present at the ASR sites including black crappie, bluegill, largemouth bass, sunshine bass, catfish, brown bullhead, threadfin shad, and gizzard shad.

Discharge

During recovery operations, the ASR wells are used to pull water from the aquifer(s) and return it to the source waterbody. This recovery from the wells is generally expected to occur during the winter months (dry season) when water levels in Lake Okeechobee are projected to fall below desired levels. This presents two issues that must be addressed during discharge operations. First, operations should prevent creation of an area for manatee thermal refuge to prevent additional regulatory requirements. Second, the level of dissolved oxygen in the recovered water should be increased to meet water quality requirements.

Manatees are a warm water species that are susceptible to cold stress syndrome when exposed to water temperatures fall below 68° F for prolonged periods. When ambient water temperatures fall below this level, manatees will seek refuge at warm water outfall locations, such as powerplant discharges and water treatment facilities. Once this occurs, regulated discharges are typically required to maintain the warm water discharge until ambient water temperatures rise above the 68° F threshold. To prevent mandatory maintenance of warm water discharge during cold spells, ASR well discharge operations should be managed to prevent creation of manatee thermal refuge by reducing discharge in proportion to the flow and temperature differential in the Kissimmee River. If further analysis indicates that flow reductions will be too restrictive, incorporation of measures to cool ASR recovery by pre-mixing with water from the raw water intake may be necessary. Note that operation to prevent creation of manatee thermal refuge is only anticipate to apply to sites on the Kissimmee River (C-38N and C-38S), since the remaining sites are upstream of the control structure at S-191 which minimized upstream passage of manatees. The Kissimmee River is a Class III freshwater stream, which is currently not meeting standards for dissolved oxygen (DO). As a result, it is anticipated that permit conditions will require discharges to meet minimum dissolved oxygen limits. During periods of recovery, water will be discharged via a single pipe from each well pair to a concrete box on the adjacent canal bank. These discharge pipes would be approximately 20-inch diameter and incorporate an eductor and air intke pipe near the end to entrain air and increase DO prior to discharge.

Cost Estimates

CAPEX estimates for treatment alternatives ranged from approximately $80 million to $115 million. A breakdown of CAPEX costs by process area for each alternative is provided in **Table 7-1 CAPEX for Process/Treatment Alternatives (in Millions of Dollars).** OPEX costs for a 6-month annual operating period are broken down between energy, chemical, labor, sludge hauling and consumables in **Table 7-2 Summary of Annual Forecasted OPEX in 2022 (in Million Dollars)**. A summary of CAPEX, 6-month annual OPEX and a 50-year NPV for each alternative is provided in **Table 1-2 CAPEX, OPEX & 50-yr NPV Summary.**

Table 1-3 CAPEX, OPEX & 50-yr NPV Summary

Process/Treatment Alternative	Alt 1A	Alt 1B	Alt 1C	Alt 2A	Alt 2B
	Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, MF/UF	UF, NF
CAPEX (in millions of dollars)	$86	$113	$80	$103	$114
OPEX (6-month annual operation, in millions of dollars, 2022)	$1.77	$3.39	$2.89	$2.24	$3.44
NPV (50-year operation, in millions of dollars)	$180	$269	$223	$203	$284

The 50-year NPV cost difference between the lowest cost alternative (1A) and the highest non-economic scoring alternative (2A) is $23 million. The 50-year NPV for each alternative is illustrated in **Figure 7-5 Net Present Value of Alternatives during 50 years of Operation.**

Recommendation

With a cost differential of $23 million dollars, the benefits of Alternative 2A in terms of reliable coliform disinfection, color removal to meet secondary drinking water standards and a 60% smaller footprint than Alternative 1A appear strongly advantageous. The next best option xiipprox.xiinat 1C has a similar net present value but scored significantly worse on non-price attributes such as foot-print and the risk of clogging in the aquifer.Therefore, Stantec recommends further investigation of Alternative 2A including pilot testing and procurement strategy development to qualify MF/UF membrane manufacturers.

Next Steps

Pilot scale testing of the selected alternative is recommended to allow demonstration of technology over a range of water quality conditions prior to full-scale investment and implementation.

MF/UF membrane pilot testing goals should be defined to confirm maximum sustainable flux (and possibly how much greater flux is for ceramic than polymeric), and determine fouling characteristics, cleaning frequency, and irreversible fouling of membranes. The piloting period will also allow the improvement of definition of likely water quality for parameters such as iron, for which limited data currently exist.

Issue Request for Qualifications (RFQ) to MF/UF membrane manufacturers to confirm experience with removal of organics with coagulants, express interest in systems which can be warrantied for longer periods so a list of pre-selected manufacturers can be developed. This should also be used to determine if the vendor can supply a 50 MGD system within given footprint available and allow teaming arrangements between membrane Original Equipment Manufacturers (OEMs) and Integrators.

Develop Pilot Testing Protocols to determine duration of pilot testing, potential standby period, duration of remaining testing; confirm performance as proposed in response to RFQ; determine coagulant dose/response for varying raw water quality; and determine additional water quality sampling to confirm manganese levels and allow for speciation of iron should treatment for removal become necessary.

Design-bid-build or design-build of the pilot can be done through a General Constractor (GC) or a smaller specialty firm, allowing for planning and layout of process connections for ancillary equipment, intake screening, raw water pumping, holding tank, pilot pad, shade, protection. This can also ensure accommodations for containerized or skid-mounted pilot units, determine permeate discharge location and pump-out frequency for backwash holding tank; and allow for bench scale testing of thickened organic-coagulant backwash sludge to determine dewaterability of residuals for mechanical dewatering system design.

Development of a Pilot Operation Scope will determine who operates the pilot, conducts water quality sampling and testing, and other staffing requirements in accordance with defined protocol.

Abbreviations

μg/L	Micrograms per Liter
AACE	Association for the Advancement of Cost Engineering
ASR	Aquifer Storage and Recovery
AOP	Advanced Oxidation Process
BW	Backwash
CAPEX	Capital Expense
CERP	Comprehensive Everglades Restoration Plan
cfu	Colony Forming Units
CMF	Ceramic Microfiltration
CT	Contact Time
CWWS	Cylindrical Wedge Wire Screens
DBP	Disinfection Byproduct
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EPA	Environmental Protection Agency
F.A.C	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FTE	Full Time Equivalents
Fps	feet per second
gal	Gallon
gfd	Gallons per square foot per day (flux)
gpd	Gallons per day
gpm	Gallons per minute
HAA	Halogenic Acetic Acids
HASR	Hillsboro Aquifer Storage and Recovery
KRASR	Kissimmee River Aquifer Storage and Recovery
LAE	Limited Aquifer Exemption
LOWRP	Lake Okeechobee Watershed Restoration Program
MCL	Maximum Contaminant Level
MF	Microfiltration
MIEX	Magnetic Ion Exchange
MGD	Millions of Gallons per day
MRDL	Maximum Residual Disinfectant Levels
NPDWS	National Primary Drinking Water Standards
NF	Nanofiltration
NSDWR	National Secondary Drinking Water Regulation
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Units

OPEX	Operating Expense
O&M	Operations and Maintenance
PCU	Platinum Cobalt Units
PRF	Peace River Facility
R2T	River to Tap
SFWMD	South Florida Water Management District
sf	Square feet
THM	Trihalomethane
TM	Technical Memorandum
TMP	Transmembrane Pressure
TOC	Total Organic Carbon
TSV	Through Screen Velocity
UIC	Underground Injection Control
USACE	United States Army Corps of Engineers
UF	Ultrafiltration
UV	Ultraviolet
UVA	Ultraviolet Absorbance
UVT	Ultraviolet Transmittance
WHO	World Health Organization
WRF	Water Reclamation Facility
WQCE	Water Quality Criteria Exemption

1.0 BACKGROUND

The Lake Okeechobee Watershed Restoration Project (LOWRP) Aquifer Storage and Recovery (ASR) Program is a component of the LOWRP parent project. The LOWRP is a Comprehensive Everglades Restoration Plan (CERP) planning effort designed to improve water levels in Lake Okeechobee; improve the quantity and timing of discharges to the St. Lucie and Caloosahatchee estuaries; increase the spatial extent and functionality of wetlands; and improve water supply for existing legal water users. The project includes construction of ASR well systems located in clusters in five locations throughout the Lake Okeechobee watershed (C-38N, C-38S, L-63N, C-59, and L-63S), Figure 1-1 LOWRP ASR Well Cluster Sites.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1-1 LOWRP ASR Well Cluster Sites

The planned ASR wells will utilize excess surface water during the wet season to recharge the Upper Floridan Aquifer (UFA) and Avon Park Permeable Zone (APPZ). This stored water will be recovered to the same water bodies during extended dry periods. The selected water treatment process should dependably meet regulatory criteria for operation of Class V, Group 7 Underground Injection Control (UIC) ASR facilities. It is anticipated that the treatment requirements during recharge (injection) will necessitate meeting federal primary drinking water standards.

Water quality in the Lake Okeechobee Watershed is highly variable in quantity and quality. During the rainy season when water is to be stored, water may be of the lowest quality. Surface water quality parameters that are most impactful on treatment system design, operation, and maintenance include: suspended solids, turbidity, total and dissolved organic carbon (TOC, DOC), color; and bacterial loading.

SFWMD LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT (LOWRP) AQUIFER STORAGE AND RECOVERY (ASR) WELLS

Background

The project will conceptually be completed in phases with intake and outfall structures completed first, and modular treatment systems expanded as wells are completed and connected by piping systems. The objective of this Technical Memorandum I is to provide an evaluation of a suite of water treatment technologies that will meet the requirements of the project to provide safe, economical, and reliable operation of multi-well ASR systems.

2.0 WATER QUALITY

Operation of ASR systems using surface water and storage of water within the Underground Source of Drinking Water (USDW) requires compliance with primary drinking water standards. In the interest of environmental stewardship, the District wishes to ensure stored water meets primary drinking water standards.

2.1 TREATED WATER QUALITY GOALS

2.1.1 Regulatory Requirements

ASR wells are regulated under Chapter 62-528, F.A.C, Underground Injection Control (UIC) as Class V, Group 7 wells. UIC rules administered by FDEP require water being recharged through an ASR well into an Underground Source of Drinking Water (USDW) must meet drinking water standards (DWS). A USDW is defined in the rule“as "an aquifer or its portion: (a) Which supplies drinking water for human consumption, is classified by Rule 62-520.410(1), F.A.C., as Class F-I, G-I or G-II ground water, or contains a total dissolved solids concentration of less than 10,000 mg/L; and (b) which is not an exempted aqui”er."

There are two exceptions. The primary drinking water standards for bacteriological quality and asbestos do not apply as ground water standards. In place of the drinking water bacteriological standards, Rule 62-520.420(1), F.A.C., establishes a total coliform limitation of 4 cfu/100 mL as the ground water standard for G-I and G-II ground water.

While they are not regulatory requirements, treatment goals include minimizing turbidity, natural organic matter (NOM), algae and iron as practicable to avoid aquifer plugging.

2.1.1.1 Primary Drinking Water Standards

National Primary Drinking Water Standards are legally enforceable standards and treatment techniques intended to protect public health by limiting the levels of contaminants in public water systems. Primary standards are addressed in Florida Administrative Code (F.A.C.) Chapter 62-550.310 Primary Drinking Water Standards: Maximum Contaminant Levels (MCL) and Maximum Residual Disinfectant Levels (MRDL). These standards also apply to groundwater quality standards in accordance with Chapter 62-520, F.A.C. Primary Drinking Water Standards MCL and MRDL are summarized below in **Table 2-1 Primary Drinking Water Standards.**

Table 2-1 Primary Drinking Water Standards

Constituent	Maximum Residual or Contaminant Level	Unit
Chlorine Residual	4.0	mg/L (as Cl_2)
Chloramines Residual	4.0	mg/L (as Cl_2)
Chlorine Dioxide Residual	0.8	mg/L (as ClO_2)
Bromate	0.01	mg/L
Chlorite	1.0	mg/L
TTHM	0.08	mg/L
HAA5	0.06	mg/L
Arsenic	0.01	mg/L
Combined radium226 and radium228	5	pCi/L
Gross alpha particle activity including radium226, (excluding radon and uranium)	15	pCi/L
Uranium	30	µg/L
Tritium	20,000	pCi/L

2.1.1.2 Surface Water Treatment Rules

Pathogen removal is a primary standard addressed by the Surface Water Treatment Rules (SWTRs) in order to reduce illnesses caused by pathogens in drinking water. These rules require public water systems to filter and disinfect surface water sources. Chapter 62-550.817, F.A.C. deals with the minimum removal levels of pathogens from surface water for drinking water systems.

The Long-Term (2) Enhanced Surface Water Treatment Rule (LT2ESWTR) was promulgated in 2006 to reduce illness linked with the contaminant Cryptosporidium. Chapter 62-550.817, F.A.C. specifies a minimum removal/inactivation of 4-log removal for viruses, 3-log removal for Giardia and 2-log removal of Cryptosporidium, as summarized in **Table 2-2 Disinfection Requirements: Log Removal.**

Table 2-2 Disinfection Requirements: Log Removal

Pathogen / Contaminant	Log-Removal / Concentration	Applicable Regulation
Virus	4-Log (99.99% Removal)	SWTR /1
Giardia	3-Log (99.9% Removal)	SWTR /1
Cryptosporidium	2-Log (99% Removal)	SWTR /1
Total Coliform	Removal to 4CFU/100mL	62-520.420(1), F.A.C.

Note: The Surface Water Treatment Rule (SWTR) applies in cases that require direct consumption of potable water, and not for ASR, but is used as a best practice guideline for level of treatment. The only legal requirement for this source water is the Total Coliform reductions to 4cfu/100mL.

While the ASR systems operated by the District recover water to Lake Okeechobee as a source water for some communities, the ASR systems are not directly connected to these public water systems, and not subject to the requirements of Subpart H. Thus, while the District ASR systems operated by the District are designed for 3-log total coliform inactivation, they are not explicitly required to meet 4-log removal of viruses, 3-log removal of Giardia or 2-log removal of cryptosporidium because the direct use of the water is not for potable public consumption.

2.1.1.3 Secondary Drinking Water Standards

In addition to meeting the primary drinking water standards, the District has expressed interest in the technical requirements and feasibility of treating water to comply with secondary drinking water standards.

National Secondary Drinking Water Standards are guidelines regulating contaminants in public water systems that may cause cosmetic effects (skin or tooth discoloration) or aesthetic effects (taste, odor, or color) in drinking water. These standards may also apply to groundwater quality standards in accordance with Chapter 62-520, F.A.C. Secondary Drinking Water Standards are addressed in F.A.C, Chapter 62-550.320 Secondary Drinking Water Standards: Maximum Contaminant Levels. Secondary Drinking Water Standards levels are presented in **Table 2-3 Secondary Drinking Water Standards.**

Table 2-3 Secondary Drinking Water Standards

Contaminant	Maximum Contaminant Level	Unit
Iron	0.3	mg/L
Color	15	PCU
TDS	500	mg/L
Aluminum	0.2	mg/L
Chloride	250	mg/L
Copper	1.0	mg/L
Fluoride	2.0	mg/L
Manganese	0.05	mg/L
Silver	0.1	mg/L
Sulfate	250	mg/L
Zinc	5	mg/L
Odor	3	threshold odor number
Foaming Agents	0.5	mg/L
pH	6.5-8.5	-

2.2 RAW WATER QUALITY

Surface water quality is a key concern and challenge for the Lake Okeechobee watershed. Surface water quality constituents that most impact treatment design and operation include: total and dissolved organic carbon (TOC, DOC), color; and bacterial loading. Raw water quality was reviewed from previous CERP studies and summarized for sites along the Kissimmee River (C-38 sites), Taylor Creek and Nubbins Slough (L-63 and C-59 sites).

2.2.1 Water Quality by ASR Site

Stantec obtained and reviewed available water quality data for the Kissimmee River from the South Florida Water Management District (SFWMD) DBHYDRO database and from the Florida Department of Environmental Protection (FDEP) WIN database for surface water quality stations located nearest the potential ASR clusters. Water quality parameters were reviewed for a 10-year period where available from DBHYDRO and the single year available from WIN, focusing on Q3 (July-September), which represent the period when water will be withdrawn, treated and stored.

Water quality data from DBHYDRO monitoring station S65E was most applicable to C-38N and summarized for Q3 (2010-2020). Data from DBHYDRO monitoring station KISSR0.0 was most applicable to C-38S and summarized for Q3 (2010-2020). Data from FDEP WIN monitoring station G1SE0023 was most applicable to L-63N and summarized for Q3 (2019). Water quality data from FDEP WIN monitoring station G1SE0029 was most applicable C-59 and summarized for Q3 (2019). Water quality data from FDEP WIN monitoring station G1SE0022 was most applicable to L-63S and summarized for Q3 (2019). These data summaries are included in **Appendix A: Raw Water Quality**, and presented on a weighted average basis below in **Table 2-4 Weighted Average Key Water Quality Parameters for ASR Sites.**

Table 2-4 Weighted Average Key Water Quality Parameters for ASR Sites

Constituent	Unit	Std	Median	25-%ile	75-%ile	Min	Max	No. Samp
pH	std units	6.5-8.5	7.0	6.7	7.3	5.5	9.1	535
TDS	mg/L	500	176	143	213	80	395	47
TSS	mg/L	-	6	4	8	2	22	89
Turbidity	NTU	-	3.1	2.3	4.4	0	27	538
Color	PCU	15	128	91	181	1	580	513
DOC. Carbon	mg/L	-	18	16	21	12	40	344
TOC	mg/L	-	18	16	21	12	39	359

While pH, TDS, TSS and turbidity are relatively consistent, color levels in the Lake Okeechobee Watershed are highly variable. Color levels in Kissimmee River and L-63 canal range from 1 to over 500 PCU during the start of the rainy season.

2.2.2 Constituents of Concern

Based on the data available, this subsection highlights the constituents of most concern for meeting treatment goals. Most of the available data is relatively old and provides an incomplete picture of the current surface water quality. As such, it is recommended that further raw water quality testing be conducted.

2.2.2.1 Bacteria

Coliform bacteria levels in Kissimmee River source water are highly variable, ranging from 600 to 15,000 cfu/100mL. This bacterial loading coupled with organics and color present significant challenges to ensuring the minimum transmissivity necessary to successfully disinfect with UV. Bacteria removal issues experienced at the existing Kissimmee River ASR pilot site are discussed in Section 3.1.1.3: Disinfection Challenges.

2.2.2.2 Natural Organic Matter and Dissolved Organic Carbon

Natural organic matter (NOM) is often the source of color in water and is of particular concern in meeting secondary treatment goals. Surface water in Florida has high levels of plant decay that releases humic and fulvic acid molecules, which are common types of NOM. This organic matter is measured as part of total organic carbon (TOC) measurements. A portion of the TOC is made of very small particles that can pass through a 0.45 micron filter, which classifies them as dissolved organic carbon (DOC). Based on the nearly equivalent levels of TOC and DOC observed in the water feeding Lake Okeechobee, most of the coloration is attributable to DOC from NOM. To meet secondary drinking water standards and make disinfection more effective, pretreatment technologies will need to be effectively remove DOC.

Due to their small size, DOC is challenging to capture and remove. There are multiple ways to remove DOC, including: adsorption to media, coagulation to create larger particles, oxidative processes (such as ozonation), ion exchange, and filtration via size exclusion. Due to the likely short media life of adsorption, this method is not assessed in this report. Similarly, ozone is not considered as a pretreatment technology due to process complexity and high operating cost?.

2.2.2.3 Iron and Manganese

Iron and manganese are also constituents of concern for meeting secondary drinking water standards. Sampling data from the Regional Aquifer Storage and Recovery Technical Data Report (USACE and South Florida Water Management District, 2015) noted iron levels at the 0.3 mg/L mark, which is worth noting since 0.3 mg/L is the Secondary Drinking Water Standard MCL and levels above this will exceed the secondary treatment regulations and may also increase the likelihood of blockages in the wells or aquifer if oxidation occurs. It is unknown whether the iron that was reported was dissolved or particulate.

Since the data available for iron and manganese is very limited and was not reported at particularly high levels, removing these constituents was not a goal in evaluating treatment technologies. However, since both these constituents have secondary drinking water standard limits, they should be monitored in future sampling efforts. Specifically, iron sampling should be conducted to provide speciation to determine treatment methods for removal.

3.0 EXISTING ASR SYSTEM REVIEW

Stantec conducted a review of treatment systems of existing ASR well systems. Stantec reviewed information for two SFWMD ASR treatment systems and contacted utility staff for six municipally owned and operated ASR treatment systems.

3.1 SFWMD ASR SYSTEMS

As part of the CERP, ASR pilot studies were conducted to treat and store water from and recover water to the Kissimmee River and Hillsboro Canal. The results of these studies were reported in the CERP Final Technical Data Report ASR Pilot Project and the Regional Aquifer Storage and Recovery Technical Data Report (USACE and South Florida Water Management District, 2015). Results from pilot studies supported the construction of demonstration scale ASR systems at these sites. In this regard, a brief summary is provided for these ASR systems.

3.1.1 Kissimmee River ASR

The Kissimmee River ASR (KRASR) pilot project is located on the eastern bank of the C-38 Canal, approximately five (5) miles west of the City of Okeechobee. The system was designed to withdrawal and treat five (5) MGD for storage in the UFA during the wet season and recover water to the Kissimmee River during the dry season. Construction was completed in 2007 at a cost of approximately $6.1 million.

3.1.1.1 Treatment

Surface water is drawn through a wedge wire screen by a vertical turbine pump and treated by media filtration and UV disinfection to meet primary drinking water standards. Media in the horizontal pressure vessel filter consists of a combination of gravel, sand and anthracite. Filtered water is conveyed downstream to UV disinfection by three Aquionics InLine 7500+ UV units in series. UV intensity from the 12 UV lamps in each reactor is measured with a U-vector sensor. A quartz sleeve over each bulb is mechanically cleaned without chemicals. The treated water is pumped into the ASR well for storage in the UFA. Stored water is recovered and discharged through to a constructed cascade aerator to increase DO for compatibility with surface water in the Kissimmee River.

3.1.1.2 KRASR Water Quality

Raw water quality for the KRASR has been summarized from Regional Aquifer Storage and Recovery Technical Data Report and is presented as **Table 3-1 KRASR Water Quality (S65E) 2000-2014.** Key water quality parameters including color and DOC are highlighted in this table for discussion later in this section.

Table 3-1 KRASR Water Quality (S65E) 2000-2014

Constituent	Unit	Std	Median	25-%ile	75-%ile	Min	Max	No. of Samples
Major Inorganic Constituents								
pH	**std units**	6.5-8.5	7	6.7	7.4	5.5	9.1	393
Cond	**µS/cm**	-	185	153	217	1.3	6.7	393
Tot. Alkalinity	**mg/L as CaCO3**	-	38	30	44	14	68	406
Calcium	**mg/L**	-	16.9	13.5	19.6	8	32.2	109
Magnesium	**mg/L**	-	3.9	3.3	4.7	2.1	7.3	109
Sodium	**mg/L**	-	12.7	11	14.8	6.7	23.8	109
Potassium	**mg/L**	-	3	2.5	3.5	1.5	233	110
Chloride	**mg/L**	250	22.7	19.1	26.5	11.4	63.3	390
Silica	**mg/L**	-						
Sulfate	**mg/L**	250	11.4	8.8	14.4	3.9	38.3	391
Total Dissolved Solids	**mg/L**	500	139	112	170	80	237	36
Turbidity	**NTU**	-	2.9	2.2	4	0.1	26.7	401
Color	**PCU**	15	118	77	166	29	467	388
Organics, Nutrients, and Trace Inorganics Constituents								
Dissolved Organic Carbon	**mg/L**	-	18	16	21.4	11.8	39.7	344
Total Organic Carbon	**mg/L**	-	18	16	20.9	11.7	36.9	348
Total Kjeldahl N	**mg/L**	-	1.08	0.99	1.19	0.62	2.35	406
Total Ammonia	**µg/L**	-	34	19	68	< 5	541	395
Nitrite + Nitrate – N	**µg/L**	-	54	14	158	< 5	755	389
Nitrate	**µg/L**	-	46	10	149	< 2	575	361
Phosphate, Total as P	**µg/L**	-	71.5	55	106	31	435	408
Phosphate, Ortho as P	**µg/L**	-	-	-	-	-	-	-
Iron	**µg/L**	300	347	77.3	166	92	1,040	57
Arsenic	**µg/L**	10	< 1.5	-	-	-	-	5
Mercury	**µg/L**	-	< 0.2	-	-	-	-	5

It should be noted that data throughout this 14-year period included many samples collected outside of the wet season during which the KRASR treatment system was typically operated. For this reason, median color and organic carbon levels may be skewed downward.

3.1.1.3 Disinfection Challenges

Water treated by the KRASR generally met primary drinking water standards during cycle test 1, with one period of coliform bacteria exceedance. However, during cycle tests 2 and 3, it became clear that the two-unit Aquionics UV disinfection system failed to meet performance requirements for coliform inactivation. Regulatory compliance is defined as total coliform concentrations less than 4 cfu/100 mL) as measured at the ASR wellhead during recharge. Reasons for this failure included:

1. Inability to quantify the UV dose
2. Inability to transfer UV performance data from the UV sensors to the SCADA system
3. Incomplete activation of total coliforms

Flow rate reduction from 4.0 to 2.5 MGD did not improve inactivation of coliform bacteria, possibly due to high color surface water and coincident low UV Transmittance (UVT), which limits light passage through the water and hinders UV disinfection. As a result, the system was modified to add a third UV unit in series and bypass piping so that the system could be tested without sending off-spec water to the ASR well. Coliform bacteria inactivation challenges continued through all phases of cycle testing and are summarized in **Table 3-2 KRASR Off-Spec Water Summary.**

Table 3-2 KRASR Off-Spec Water Summary

Cycle	Number of Periods Sampled	Number of Periods > 4 cfu/100mL
1	4	1
2	16	6
3	24	17
4	10	9

Bacteriological exceedances were experienced when biogrowth in the system reached high levels, requiring the system be taken offline and UV reactors cleaned in place using a muriatic acid solution. However, the project team also suspected that coliform inactivation challenges persisted through testing due to high organics (DOC and TOC) and coincident color (a secondary standard).

3.1.1.4 Pretreatment (Color) Challenges

Based on conversations with SFWMD field staff and representatives from River 2 Tap (R2T), a contract operations and maintenance vendor, the KRASR was shut down when color levels exceeded 110 PCU. In 2009, jar testing and field testing was conducted at KRASR using different coagulants with polymer and pH adjustment (R2T, Inc., 2009). General performance is addressed further in Section 4.1.7.

Operational data from Cycle 4 (2011-2012) was provided by R2T which included true color data (PCU) and corresponding %UVT. A scatter plot of this data is illustrated in Figure 3-1 KRASR Cycle 4 UVT vs True Color.

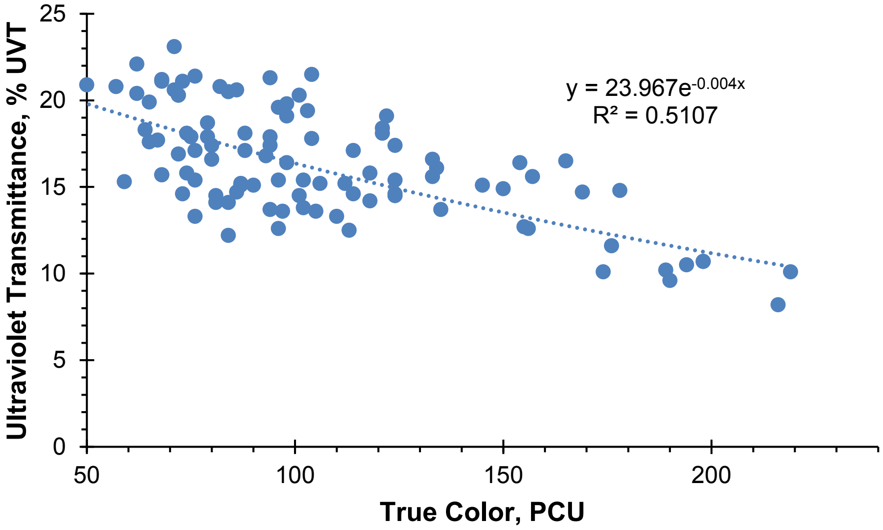

Figure 3-1 KRASR Cycle 4 UVT vs True Color

While these parameters showed a poor correlation, a general trend of UVT percentage decreasing as true color increases is evident. This was used for preliminary screening of treatment alternatives purposes of this TM. The poor correlation of UVT to true color is not surprising as their presence or detection rely on different parts of the light spectrum. Additional testing should be conducted prior to design.

Th^{e} 75th percentile, median, an^{d} 25th percentile color and DOC data from Table 31 were compared with the UVT and color data from Figure 31. The Kissimmee River DOC data had all relatively low UVT and as such, a meaningful trend was not observed. Therefore, these data points were augmented with DOC and UVT data available from the Hap Cremean Water Treatment Plant in Columbus, Ohio for relatively lower DOC and higher UVT data. This combined data is presented in Table 3-3 Kissimmee River and Hap Cremean DOC and UVT.

Table 3-3 Kissimmee River and Hap Cremean DOC and UVT

	Color (PCU)	DOC (average)	UVT
Kissimmee River 75 percentile	166	21.2	21.0%
Kissimmee River median	118	18	15.8%
Kissimmee River 25 percentile	77	16	17.3%
Hap Cremean Raw Water		4.9	68.5%
Hap Cremean Recarb Water (Pre-filter)		2.05	91.0%
Hap Cremean Ozonated Water (Post-filter)		1.6	96.2%

The UVT and DOC data (Hap Cremean facility data points shown in orange) were then plotted and trended with an exponential regression as illustrated in Figure 3-2 UVT vs DOC for Raw and Treated Water.

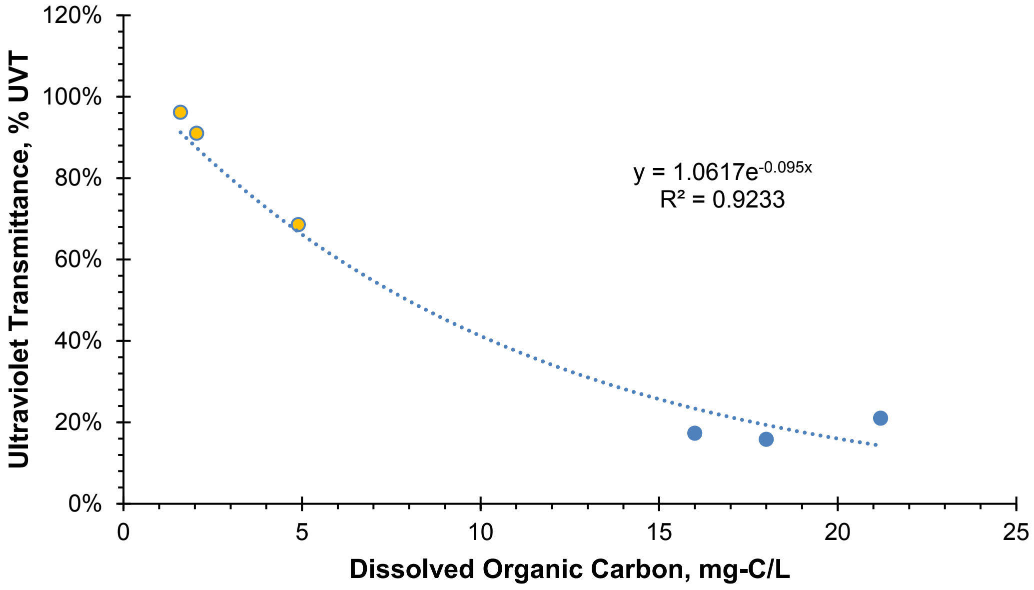

Figure 3-2 UVT vs DOC for Raw and Treated Water

While again not a highly reliable comparison, the resulting curve gives an indication of target levels of DOC to meet a minimum level of UVT to open competition between competing UV technologies and vendors, reducing equipment costs during bidding.

However, it is likely that any ASR system would require a Water Quality Criteria Exemption (WQCE) for operations because color values almost certainly will exceed the SDWA secondary standard for color (15 PCU) during the rainy season (USACE and South Florida Water Management District, 2015).

3.1.1.5 Other Operational Challenges

While the quartz sleeves of the UV reactors were provided with mechanical wipers, these did not include a chemical cleaning ring as some later generation units do. Additionally, operators noted the wiper motors wore out and required replacement along with quartz sleeves at a cost of $100/ea.

3.1.2 Hillsboro ASR

The Hillsboro ASR (HASR) pilot project is located west of Boca Raton on the north bank of the Hillsboro canal adjacent to the Loxahatchee National Wildlife Refuge. Like the KRASR, the system was designed to withdrawal and treat five (5) MGD from the canal for storage in the UFA during the wet season and recover water to the Hillsboro Canal during the dry season. Construction was completed in 2008 at a cost of approximately $2.3 million.

3.1.2.1 Treatment

Surface water is drawn through a bar rack by a vertical turbine pump and passed through pressurized self-backwashing strainers. Eight (8) Amiad strainers (14-inch diameter) remove suspended solids with 80-micron (200 mesh) screens and are automatically backwashed when head losses reach 6 to 7 psi. However, due to the small size of most particles in the raw water (≤ 1-μm), the strainers at the HASR are not able to reduce the concentration of colloidal-sized particles as noted in the CERP Aquifer Storage and Recovery Pilot Project (USACE and South Florida Water Management District, 2013). Treated water is conveyed downstream to UV disinfection by three Aquionics UV units (same as KRASR) in series. Stored water is recovered and discharged through a pipeline with an eductor to increase DO for compatibility with surface water in the Hillsboro Canal.

3.1.2.2 HASR Water Quality

Raw water quality for the HASR has been reformatted and reproduced from Regional Aquifer Storage and Recovery Technical Data Report (USACE and South Florida Water Management District, 2015) and is presented as **Table 3-4 HASR Water Quality (Structure S-39 Hillsboro canal at WCA-1/2) 2004-2014.**

Table 3-4 HASR Water Quality (Structure S-39 Hillsboro canal at WCA-1/2) 2004-2014

Constituent	Unit	Std	Median	25-%ile	75-%ile	Min	Max	No. of Samples
Major Inorganic Constituents								
pH	**std units**	6.5-8.5	7.70	7.40	7.90	6.75	8.50	245
Cond	**μS/cm**		588	411	743	160	1,202	246
Tot. Alkalinity	**mg/L as CaCO3**		127	96	170	42	347	211
Calcium	**mg/L**		38.2	27.4	50.1	14.5	92.7	130
Magnesium	**mg/L**		11.7	6.9	17.0	3.1	29.5	133
Sodium	**mg/L**		54.0	34.4	71.3	14.3	115	135
Potassium	**mg/L**		4.8	2.9	6.7	0.8	12.6	135
Chloride	**mg/L**	250	85.2	55.0	111	23.7	170	227
Silica	**mg/L**		8.1	4.4	12.4	1	12.6	128
Sulfate	**mg/L**	250	24.1	12.1	42.9	1.8	83.3	146
Total Dissolved Solids	**mg/L**	500						
Turbidity	**NTU**		1.3	0 .9	2.1	0.4	11 .1	243
Color	**PCU**	15	76	65	94	43	200	114
Organics, Nutrients, and Trace Inorganics Constituents								
Dissolved Organic Carbon	**mg/L**		21 .6	18 .0	25.0	9.9	35.9	94
Total Organic Carbon	**mg/L**		22.0	1.4	25.5	9.S	36.5	94
Total Kjeldahl N	**mg/L**		1.39	1.16	1.59	0.77	2.71	245

Constituent	Unit	Std	Median	25-%ile	75-%ile	Min	Max	No. of Samples
Total Ammonia	**µg/L**		16	11	23	< 5	167	214
Nitrite + Nitrate – N	**µg/L**		9	5	18	<4	87 5	237
Nitrate	**µg/L**		10	5	36.5	<4	734	89
Phosphate, Total as P	**µg/L**		20	14	30	8	132	243
Phosphate, Ortho as P	**µg/L**		4	2	6	<2	75	247
Iron	**µg/L**	2000	19	11	44	6	104	33
Arsenic	**µg/L**	10						
Mercury	**µg/L**							

It should be noted, as with KRASR data, that throughout this 14-year period included many samples collected outside of the wet season during which the HASR treatment system was typically operated. For this reason, median color and organic carbon levels may be skewed downward. However, compared to the KRASR raw water, HASR turbidity was approximately 45% and color was 65%. DOC was comparable and nutrients were generally 25% of KRASR levels. This comparatively better water quality is in large part a function of pretreatment through WCA 1/2 before treatment by mechanical strainer and UV disinfection at the HASR.

3.1.2.3 **Disinfection Challenges**

Total and fecal coliforms were detected at a similar frequency at HASR compared to KRASR, as would be expected with the two-unit Aquionics UV disinfection system failing to meet performance requirements for coliform inactivation.

3.2 REGIONAL ASR SYSTEMS

Stantec conducted a survey of ASR system owners throughout South Florida to understand water quality issues faced by these systems and ASR treatment technologies utilized to overcome the issues. This survey included Peace River Manasota Regional Water Supply Authority, City of West Palm Beach, City of Marco Island, City of Naples, City of North Port, and the City of Bradenton.

The survey included source water quality, treatment process effectiveness, operational characteristics, system complexity, chemical usage, solids handling, capital costs, and operations and maintenance (O&M) costs, which are included as in Section 3. A description for each ASR system, treatment technology, and operational challenges is summarized below.

3.2.1 Peace River ASR

The Peace River Manasota Regional Water Supply Authority owns and operates an ASR System located at the Peace River Regional Water Supply Facility (PRF) site. The Peace River ASR system is used for storage and recovery of the potable water produced at the PRF. Each ASR well is permitted up to one (1) MGD with typical operation between 0.5 and 1 MGD for storage and recovery of potable water. Construction of the total of 21 ASR wells was completed incrementally between 1984 and 2002 at a capital cost of approximately $25 million. This cost, in addition to the production and monitoring wells, includes yard piping system for recharging the wells and sending the recovery water from the wells to the reservoirs. It does not include any other treatment system components. The construction depth of the 21 ASR wells range between 482 ft -955 ft. They utilize the Suwannee Zone for storage. Only one of the wells uses the Lower Producing Zone (LPZ or Tampa Zone) of the Intermediate Aquifer System.

Raw water quality in the Peace River Reservoir was obtained from the Peace River Regional Water Supply Authority. Total suspended solids (TSS) in the reservoir water ranges between 3.25 to 8.33 mg/L (Mean: 6.41 mg/L) and Turbidity levels range from 1.2 to 12.2 NTU (Mean 3.6 NTU). Iron levels in the Reservoir water has a wide range reported between 29 to 307 µg/L (Mean: 119 µg/L). From 2016-2018 the Total dissolved solids (TDS) ranged between approximately 180 -340 mg/L and Color ranged between 50-175 Color Units as provided in the Authority’s 2019 Water Quality Master Plan. Total Carbon in the Reservoir water was reported between 11.4 -14 mg/L (Average:12.7 mg/L) in the Authority’s 2019 Consumer Confidence Report.

3.2.1.1 Treatment

The PRF is a conventional surface water treatment facility permitted to withdraw and treat water from the Peace River Reservoir where water from Peace River is stored. The treatment facility consists of Alum coagulation / open flocculation basins, open gravity multimedia filtration (anthracite sand filter), and disinfection with chloramines. The potable water from the PRF is sent to the ASR wells by the high service pumps during the wet season. During the dry season, water is recovered and sent to two on site raw water reservoirs (6.5 billion gallons storage capacity) where it is blended with Peace River raw water then sent for potable water production at the PRF.

3.2.1.2 Operational Challenges

Peace River ASR system has faced two water quality challenges: 1) Increase in TDS levels in recovered water above the 500 mg/L Secondary Drinking Water Standard. At 700 mg/L TDS the ASR system is programmed to stop recovering water to comply with the regulations. This has been challenging for operation of the ASR system. 2) arsenic liberation in recovered water was observed at the 100 to 200-foot depth interval; however, this liberation has naturally attenuated over time.

3.2.2 City of West Palm Beach ASR

The City of West Palm Beach ASR system consists of a single well located on the eastern bank of East Clear Lake at the City’s Water Treatment Plant (WTP). The well was originally designed for a capacity of

2.5 MGD but has been upgraded to store 8 MGD from East Clear Lake in the UFA during the wet season and recover water to the water plant for treatment during the dry season. Construction was completed in 1997 at a cost of approximately $6.1 million.

3.2.2.1 **Treatment**

Surface water is conveyed by vertical turbine pumps through a mechanical strainer. This single 80-mesh strainer prevents large solids from entering the well. Coarse strained is no longer disinfected using sodium hypochlorite. Recovered water is blended with raw water from East Clear Lake prior to coagulation, sedimentation, and filtration.

3.2.2.2 **Operational Challenges**

Following a 2009 evaluation, the City did not believe ASR was cost-effective if full treatment was required up front. Therefore, the city applied for and was granted a permit to store untreated water in their ASR well. Rather than a WQCE, the City of WPB ASR operates under a Limited Aquifer Exemption (LAE).

West Palm Beach has experienced increased storage pumping head and formation plugging, potentially due to the limited treatment by coarse straining alone. However, following acidization and redevelopment, ASR capacity was restored. In order to minimize the chance for formation plugging in the future, the City has developed operational protocols to direct the first flush of water to sewer prior to storage, and limiting operation of the ASR wells to times when raw water turbidity is less than two (2) NTU.

3.2.3 Marco Island ASR

The City of Marco ASR system consists of seven (7) wells constructed at the Marco Island Source Water Facility (SWF). The intake of the SWF is constructed on two lakes (Marco Lakes) that receive approximately 90% of their water through bank infiltration from Henderson Creek. During the wet season, peak stormwater flows in Henderson Creek ensure sufficient scouring velocity to avoid excessive buildup of particulates along the bank. During these periods, water is treated and stored using the ASR wells. Recovered water from ASR Wells is sent to a storage tank at the SWF site, from which it can be pumped to the NWTP.

3.2.3.1 **Treatment**

The treatment process at the SWF removes solids and turbidity from the surface water using pressure media filters (using rock, sand and anthracite). Treated water is disinfected with monochloramine before storage. While each well is permitted for a maximum storage rate of 2.5 MGD, the aggregate system is capable of storing a maximum of 13.5 MGD. The ASR system was constructed in 1997 at a cost of approximately $20 million.

3.2.3.2 **Operational Challenges**

The City of Marco Island did not report any challenges with their ASR system and reported the level of system complexity as moderate.

3.2.4 City of Naples ASR

The City of Naples ASR system consists of four (4) ASR wells constructed at the City of Naples Water Reclamation Facility (WRF) which store reclaimed water and some surface water from the Golden Gate Canal.

3.2.4.1 Treatment

Wastewater from the City of Naples is treated by conventional methods, followed high level disinfection with sand and anthracite gravity filters free chlorine. Free chlorine combines with ammonia in the filter effluent to form chloramines for disinfection. In addition to raw wastewater, surface water from the Golden Gate Canal (up to 10 MGD) can be used periodically to augment WRF influent flows. This blended and reclaimed water is distributed for irrigation or stored using the ASR system. Reclaimed water is stored in three (3) ASR wells in the Suwannee Limestone portion of the UFA between the depths of 1080 and 1150 feet below land surface (bls). These wells are rated for (1) MGD each. This storage rate for each ASR well may be increased to 1.5 MGD with approval by FDEP during extended or extreme wet weather conditions. The first flush volume of recovered water from the ASR is sent back to the filters and disinfection. After the first flush, the recovered water is sent directly to the reclaimed water users. Construction of the ASR system was completed at 2011 at a cost of approximately $5.2 M.

3.2.4.2 Lower Hawthorne ASR

The fourth ASR well for the City of Naples is currently in cycle testing. This well is permitted for limited cycle testing to determine the feasibility of using the Lower Hawthorn aquifer for long term ASR operations. The first round of cycle testing for this ASR system was completed in January 2018. Additional testing of the ASR is under discussion.

3.2.4.3 Operational Challenges

The volume of water that can be injected is limited by the permitted maximum injection pressure of 32 psi. To keep the injection pressure below 32 psi, the volume that can be injected is limited to one (1) MGD per well. The ASR system was described as complex by operators due to recovery constraints requiring manual monitoring.

3.2.5 City of North Port ASR

The City of North Port ASR system consists of a single well located at Myakkahatchee Creek Water Treatment Plant permitted for storage of 1.5 MGD. The ASR well was constructed to store water in the upper part of the Suwannee Limestone of the UFA between the depths of 583 and 650 feet bls. Testing of the ASR well is complete, and the City has submitted an operation permit to FDEP with anticipated approval in 2020. The City of North Port invested $1.6 million for the construction of its ASR system.

3.2.5.1 Treatment

Surface water from Myakkahatchee Creek is partially treated using 50-micron cartridge filters. Treated water is dosed with sodium hydrosulfide to reduce DO to prevent the liberation of arsenic during storage and inhibit coliform bacteria formation.

3.2.5.2 Operational Challenges

The TDS of the treated water is monitored during storage and if the level exceeds 500 mg/L, storage is automatically stopped. This approach helps the City to maintain the TDS levels in the recovery water below the secondary drinking water standard of 500 mg/L.

3.2.6 City of Bradenton ASR

The City of Bradenton has two ASR systems: ASR-1 and ASR-2. The first system, ASR-1, was constructed to store potable water from the City of Bradenton's Water Treatment Plant. Treated water is stored in the Suwannee Limestone of the Floridan Aquifer System between the depths of 415 and 505 feet bls. The ASR-2 well system is located at the City of Bradenton Wastewater Treatment Facility and is currently in cycle testing.

3.2.6.1 ASR-1 Treatment

The City's Water Treatment Plant is supplied by surface water from the Braden River. The treatment process consists of coarse screening, filtration with dual-media (anthracite/sand) filters, 3.18pprox.3.18nationtion for disinfection. Potable water is dechlorinated with sodium bisulfite prior to membrane degasification to also extend the life of the membranes. These processes reduce residual chloramine levels to less than 0.5 ppb (>1-log reduction) and dissolved oxygen levels at less than 4 ppb (99.9% removal) for water being stored. These processes help prevent the mobilization of arsenic from the rock formation.

The ASR-1 system is partially automated. The first flush is conveyed to the sanitary sewer, while water recovered afterward is disinfected with chlorine and mixed with chloraminated water from the treatment process. Blended water is stored on site prior distribution. ASR-1 recovery is not to exceed 240 million gallons annually with a maximum flow rate of 1.4 MGD.

3.2.6.2 ASR-2 Treatment

Reclaimed water from the City of Bradenton WWTP is combined with excess local storm water and used for irrigation or stored using ASR-2. With ASR-2, the City is utilizing a gas stripping tower in lieu of degasification membranes used for ASR-1 to more cost-effectively reduce oxygen levels in water prior to storage.

ASR-2 operates under a construction/testing UIC permit granted by the FDEP and is currently in an extended storage duration phase of Cycle Testing event No.2. The City of Bradenton indicated a total project budget of $4.7 million, which includes design, construction, startup and operation. The ASR-2 intended to be capable of storing up to 150 MG of water annually.

3.2.6.3 **Operational Issues**

The City of Bradenton has experienced operational issues with Arsenic mobilization within the aquifer matrix due to the presence of dissolved oxygen or incompletely neutralized oxidizing disinfectants. These issues led to the installation of degasifying membranes for ASR-1 and the gas-stripping vacuum tower at ASR-2.

Table 3-5 Regional ASR Summary

Utility/ASR System	**Source Water**		**Raw Water Characteristics (median)**						**Treatment Process**			**OPEX**
		TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)	Color (PCU)	TOC (mg/L)	DOC (mg/L)	Iron (mg/L)	Filtration/ Strainer	Disinfectant (Dose)	Quench	$
Peace River (15 mgd)	Peace River Reservoir (Treated surface water)	3.25-8.33 (Ave. 6.41 mg/L) [1]	180 – 340 [2]	1.2 – 12.2 (Mean 3.6) [1]	50 –175[2]	11.4 – 14 (Ave.12.7) [3]	N/A	0.029 – 0.307 (Mean: 0.119)	PRF Coagulation/Flocculation, Multimedia Filtration	Chloramine (3.5-4 ppm Total Cl)	N/A	$1.49 / 1,000 gal (ASR recharge and recovery combined) [1]
City of WPB (8 mgd)	East Clear Lake (Untreated surface water)		276	0.71	38	13		0.01	80 mesh	None (previously dosed free Cl)	N/A	$0.25 / 1,000 gal (partially treated)
Marco Island (13.5 mgd)	Marco Lakes (Partially treated surface water)								¼" mesh coarse screening / Multimedia Filtration (Rock, Sand, Anthracite)	Chloramine	N/A	N/A
City of Naples (4.5 mgd)	Reclaimed Water and Stormwater from Golden Gates Canal (WQ available only for Canal water)	-	270 – 500 (Ave. 394.2)	-	48.8	16.9	-	0.6	–RF - Screening, Biological, Clarification, Filtration	Free Chlorine	N/A (Injecting Sub-USDW)	O&M cost is negligible for the ASR system.
City of North Port (1.5 mgd)	Myakkahatchee Creek (sent to ASR well. Recovered water treated at the WTP)								50-micron screens	N/A	Sodium Hydrosulfide used to remove DO	Chemicals: $18 K Energy: $22 K Consumables: $ 30 K Labor: Min expected
City of Bradenton (1.5 mgd)	Braden River (Treated surface water)								Coarse Screening, Filtration (Anthracite Sand Filters)	Chloramination	Sodium bisulfite (followed by degasification membranes, or gas-stripping tower)	N/A

[1] Provided by the Peace River Manasota Regional Water Authority
[2] Peace River Water Quality Master Plan, 2020 (2016-2018 data)
[3] Arithmetic average from Annual Water Quality Data for the Consumer Confidence Report Calendar Year 2019
[4] Golden Gates Canal RWQ (average for 2013) – Received from City of Naples on May 2020

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4.0 TREATMENT TECHNOLOGIES

Various treatment technologies are presented and described in this section summarizing strengths and drawbacks. In general, technologies were considered which would remove solids, turbidity, dissolved organics, and coliform bacteria from source water for storage meeting the regulatory requirements described in Section 3. Combinations of various technologies to achieve treatment objectives are provided in Section 5.

4.1 PRETREATMENT

Pretreatment is needed to remove particulates and reduce turbidity to allow for effective disinfection downstream. The high levels of color and DOC in raw water likely contribution to the suppression of UV Transmittance (UVT), leading to ineffective inactivation of coliform bacteria without barriers such as membranes. Pretreatment can improve UVT by removing interfering particulates and DOC. To minimize the UV reactor footprint and ensure effective disinfection, UVT should be increased from approximately 15% (raw water quality) to 20%, 40% or more.

4.1.1 Pressure Filtration

Rapid sand filtration is a type of granular media filtration which removes particles by depth filtration where small particles accumulate by colliding and adhering to the media through the depth of the filter bed. Typically, water will flow down through the media vertically and may be enclosed in a pressurized vessel (pressure filters). Over time, the solids will build up in the sand filter bed leading to increased headloss through the media which should trigger backwash. Backwash can also be triggered when the solids in the effluent increase beyond an acceptable level. This makes the selection of the sand media size important; media that is too small will waste the driving force in overcoming the frictional resistance of the sand and lead to headloss that may trigger frequent backwash. Media that is too large will allow more small particles to pass through that could have been captured with a smaller media size. The uniformity of media is also an important aspect that influences filter performance. Coagulant (such as aluminum sulfate or ferric chloride) may be added to the water prior to filtration to react with dissolved organic material, and to neutralize suspended particle charges and create larger particle sizes that will more readily filter out of through the sand media. Without coagulant addition, media filtration will not remove DOC. If the coagulant dose required to meet particle removal goals becomes too high, a polymer may be added to a lower dose of coagulant.

Sand and anthracite filters with a gravel support bed have been constructed and operated for the KRASR pilot project. While these filters effectively remove suspended solids and some turbidity, this technology does not remove dissolved organic carbon (DOC) and did not make a noticeable change to UV absorbance as noted in the CERP ASR Pilot Report (USACE and South Florida Water Management District, 2013)￼. Treatment with sand filters without coagulation provided limited benefit in terms of UV transmittance, although pilot scale coagulant testing achieved an average of 27% UVT compared to 17% UVT with mechanical filters and strainers was observed (discussed in Section 4.3.3). This made granular media filtration the preference for the 2002 study. Since the completion of the 2002 study, sand filters were installed at the existing five (5) MGD Kissimmee River ASR site (without coagulant addition). Operators have experienced difficulty with backwash cycles, air release valves, and pressure and flow regulation.

4.1.2 Mechanical Filters and Strainers (Disk and Basket)

Mechanical filters and strainers operate via size exclusion. Disk filters are composed of multiple stacked disks which are compressed to restrict the size of openings between the disk layers. As water passes through the disks, larger particulates become entrained for removal during backwash. During backwash, the stacked disks will physically separate and expand, aiding removal of particles. Basket strainers use a hollow drum or basket composed of metal screens with small openings. Water is pushed through the basket openings, leaving larger particles on the basket surface for removal during backwash. During backwash, a mechanical arm will typically rotate to make contact with every part of the basket, removing solids via suction. This allows backwash to occur while the unit continues to operate. These units are maintenance friendly options that will self-clean automatically in one of three ways: 1) based on a pre-set time interval, 2) when a pressure differential between the influent and effluent sides of the disks is exceeded, or 3) on a manual cycle.

One key drawback of mechanical filters and strainers for these applications is the minimum screen size which is five (5) µm. Since most particles are anticipated to be one (1) µm or less in diameter, solids and DOC will pass through the disk filter unimpeded and continue to contribute to the low level of UVT. Another drawback is that mechanical filter performance cannot be further improved with coagulation.

4.1.3 Bag Filter and Cartridge Filters

Cartridge filters and bag filters also operate by very simple size exclusion as mechanical filters. These units include a cartridge or bag placed in a housing which will capture solids too large to pass through the selected pore size. This method uses no moving parts and will not self-clean. Instead, when solids build up, water will not flow to the rest of the system until it is replaced. This makes regular maintenance important, but these units lend themselves to minimal troubleshooting due to their simplicity. This technology also allows for flexibility in pore size selection by changing out the cartridge or bag within the housing. Popular for pre-treatment and post-treatment, these units can exclude particles down to 0.2 µm in size. The concern with using cartridges or bags with such a small pore size is that they likely would clog frequently, requiring excessive maintenance and cost for replacement of consumables. Furthermore, this pretreatment option will not remove DOC.

4.1.4 Membranes

Membrane filtration removes particles by a pressure or vacuum driven physical size exclusion process where particles larger than the membrane pore size cannot pass through the hollow fibers and are rejected to a waste stream. Advantages of membranes over conventional media filtration include a small footprint, low labor cost, and process flexibility. Membranes can be split into low pressure membranes which remove particular matter and consist of microfiltration and ultrafiltration and high pressure membranes which focus on removal of dissolved compounds and consist of nanofiltration and reverse osmosis.

Low pressure membranes can be used following 0.5 mm to 1 mm screening to prevent damage to the membranes. Low pressure membranes by themselves will not remove DOC. Similarly to media filtration, coagulation would need to be used for DOC removal. If coagulant is not used, submerged membrane cassettes are preferred to assist in the accumulation of solids. In the last ten years, low pressure membrane technology has become increasingly affordable making it an effective alternative to conventional granular filtration.

High pressure membranes require significantly more protection which for surface water sources typically takes the form of pretreatment with either media filtration or low pressure membranes and then a secondary barrier or cartridge filters. High pressure membranes pore sizes can be as small as 0.001 µm and can remove DOC and should be able to exceed the 75% UVT goal without coagulation addition.

Both low and high pressure membranes can be made of several different materials and typically require ancillary equipment for cleaning, flushing or backwashing (such as pumps, tanks, piping, valves, etc.), and a control system for operation. Individual membrane units are connected via common headers for feed and filtrate flow as well as for backwash. For most low pressure systems a compressed air system is necessary for pneumatic actuators used for all unit processes. All these components add to the expense of membrane solutions.

With all membrane systems the fouling potential of the water needs to be considered. Pretreatment in various forms can be used to extend the operating duration before a cleaning cycle is needed, but pilot tests are the only way to estimate the overall fouling potential and even they cannot always predict full-scale performance. Small amounts of chemicals are required for cleaning membranes. Cleaning cycles typically will result in wasting approximately 2-5% of influent flow.

For the ASRs which require the removal of color and DOC, here are three main classifications of membranes which may meet the treatment goals. The classifications are based on the size of the membrane pores: 1) microfiltration, 2) ultrafiltration, and 3) nanofiltration. Considerations for implementing each of the membrane types is detailed in the following subsections.

4.1.4.1 **Microfiltration**

Microfiltration (MF) membranes are on the order of 0.1 µm in size and the least expensive of the types of membranes. MF can be used in place of depth filtration to reduce turbidity, total suspended solids, protozoa and some bacteria, but will not remove viruses. This level of membrane filtration was able to remove 73% of color in a pilot study completed in 2002. It must therefore be assumed that the dissolved organics that were not removed are smaller than 0.1 µm. It is important to consider that these results are nearly two decades old and water quality and membrane filtration technology have both changed since then. Therefore, further levels of filtration should be considered.

Depending on the membrane pore size, type of membrane selected, and regulatory approval given some of the SFWMD disinfection standards could be met using this technology, specifically for protozoa and possibly for bacteria. Requirements for the membrane pore size would require a tight enough membrane to size exclude total coliform / e. Coli, which would require pore size to be less than 0.1 µm. Membranes with pore sizes at 0.1 µm would also remove Cryptosporidium and Giardia. Virus would not be removed by ultrafiltration at this size, but viruses could be removed if a tandem UF/NF system was employed with nominal pore size less than 0.005 µm. In all cases regulatory approval of disinfection credit for membranes would have to be pursued.

4.1.4.2 **Ultrafiltration**

Ultrafiltration (UF) membranes are on the order of 0.01 µm and are very similar to MF membranes in operation, cost, and removal potential. In academia, UF is typically associated with better removal of viruses, but this is not widely accepted by regulators. Although the UF openings are smaller than MF, lower molecular weight dissolved organic carbon would not be removed by ultrafiltration without coagulation, which is likely to represent a reasonable fraction of the color and DOC. It is unclear without further testing (e.g., pilot testing) whether this type of filtration would provide the ability to meet primary and secondary standards without a tandem nanofiltration membrane.

4.1.4.3 **Nanofiltration**

Nanofiltration (NF) membranes are on the order of 0.001 µm in size and are a lower pressure form of reverse osmosis. Nanofiltration can remove protozoa, bacteria, viruses, and is favored for removal of dissolved organics of all sizes. This is done by the same size exclusion sieving action used in MF and UF but the small pore size is able to separate dissolved organics, and some salts, and ions. Using NF will require more extensive upstream pretreatment, typically in the form of a MF or UF membrane.

NF comes with the major drawback of treating membrane concentrate which will contain the majority of the hardness, heavy metals, high molecular weight organics, microorganisms, and often hydrogen sulfide gas that is present in the raw water. Approximately 15% of the feed flow becomes a concentrate waste stream. Concentrate often has a high pH which can trigger metal precipitation if deep well injection is used. In cases where disposal to the ocean or to a wastewater treatment plant are not feasible, disposal to a surface water or through controlled evaporation may be an option, although it has high associated operating and maintenance costs.

4.1.4.4 **Membrane Comparison**

The objective in selecting the most suitable membrane technology for this application is to remove color and ideally exclude coliform bacteria for disinfection credit. As mentioned in Section 2.2.2.2, most of the color associated with surface water comes from natural organic matter, which often takes the form of humic acid. As shown in Figure 4-1, humic acids range substantially in size. It is most conservative to assume that the humic acid particle sizes are so small that only nanofiltration will consistently remove them. If coagulant is added, UF and MF may become viable options for color removal as well. Besides the differences in color removal ability, other membrane features are compared in **Table 4-1 Comparison of Membrane Features**

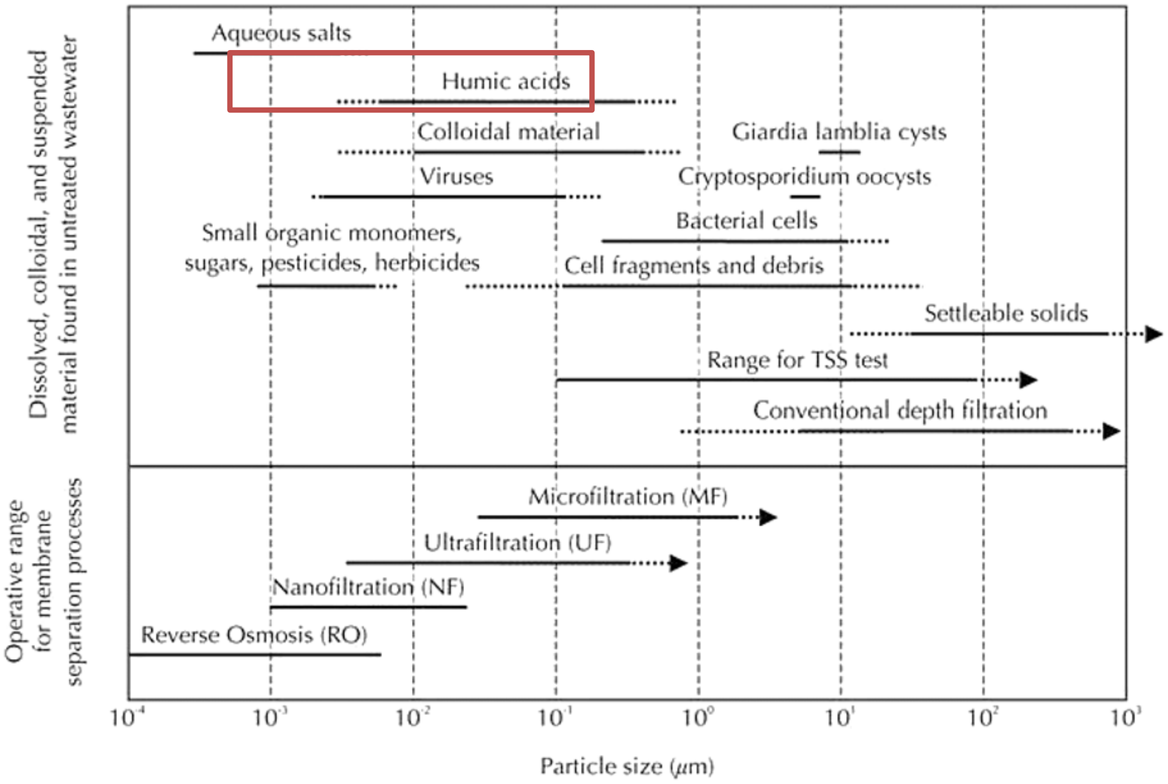

Figure 4-1 Particle Sizes and Membranes Compared (Metcalf and Eddy, 2003)

Table 4-1 Comparison of Membrane Features

Design Feature	MF	UF	NF
Removal Driving Force	Size Exclusion	Size Exclusion	Size Exclusion and Diffusion
Major Removal Differences	Removes bacteria and protozoa	Removes bacteria, protozoa, and some viruses	Removes bacteria, protozoa, viruses, and dissolved constituents (including color)
Size Exclusion	0.1 µm	0.01 µm	0.001 µm
Color Reduction (without coagulant)	May remove some color dependent on NOM particle sizes	Likely removes more color than MF	Should remove 90-96% of color
Driving Pressure[1]	Submerged vacuum: -3 to -14 psi Pressurized: 5 to 30 psi	10-35 psi	100-200 psi
Energy consumption (kwh/1000 gallons)[1]	Submerged vacuum or pressurized: 0.75-1.1	0.75-1.1	1.5-1.9
Disinfection Credit	Some removal credit for protozoa	4 log removal of protozoa,	Removes viruses; disinfection credit given
Pretreatment Required	0.5mm to 1mm screen	0.5mm to 1mm screen	MF or UF
Backwash Volume	~3-5% of influent flow	~3-5% of influent flow	~20-30% of influent flow

[1] Assumed raw water TDS range from 800 to 1200 mg/L.

For the purposes of this study, MF and UF are considered similar enough that they will be considered together in subsequent sections with an intent to test different vendors MF and UF products against one another if the technology is selected for further evaluation.

4.1.5 Ion Exchange (MIEX)

Magnetic Ion Exchange (MIEX) uses proprietary acrylic resin beads impregnated with iron oxide which has selective sites for anions like DOC. Raw water is fed to the base of the reactor where it is mixed with a blend of fresh resin and regenerated resin. DOC agglomeration onto the surface of the resin occurs in the fluidized bed. Slow speed agitators keep the resin in suspension. A stream of spent resin is withdrawn from the reactor vessel, regenerated, and returned to the vessel. A series of tube settlers of plates at the top of the reactor separate the resin from treated water. Treated water flows to the effluent launders and downstream from the process. Virgin resin is periodically added to the regeneration vessel. A stream of resin is withdrawn from the regeneration vessel for waste, or further regeneration. The overall MIEX treatment process is illustrated **Figure 4-2 MIEX Process Flow Diagram.**

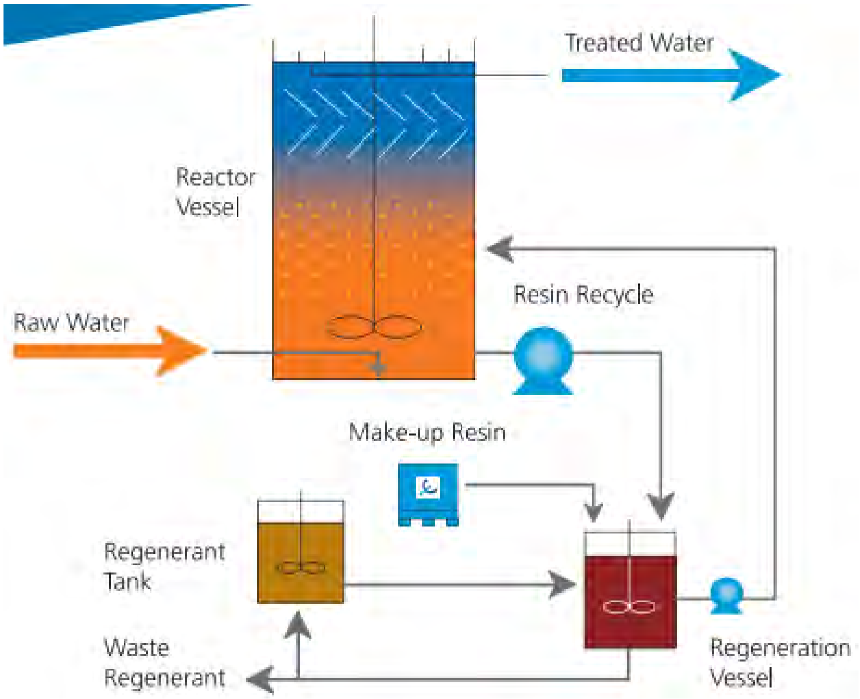

Figure 4-2 MIEX Process Flow Diagram

The resin beads range between 80 and 400µm in size and settle rapidly when agglomerated. Although MIEX will reduce solids and dissolved organics loading, it may not significantly improve turbidity and thus would require clarification and filtration downstream. MIEX can be used with minimal coagulant dosage, or possibly without any coagulant at all.

The resin regeneration process requires a high concentration salt solution (110-130 g/L) which exchanges the negatively charged DOC ions which attached to the resin particles with chloride ions. This then goes back into the treatment cycle to repeat the process of exchanging DOC with chloride ions. Regeneration consumes 300-600 lbs of salt for every million gallons of water treated and leads to a waste brine which typically ranges between 250-600 gallons in quantity for every million gallons of treated water. The brine may include 25-45 g/L of chloride, 6-16 g/L chemical oxygen demand (COD), and 5-10 g/L of DOC. Residual volumes from MIEX Treatment Systems typically range from 0.02 to 0.06% of the plant capacity. Process reactor vessels, resin regeneration vessels, fresh resin makeup tanks, and brine tanks for a 15 mgd system are illustrated in **Figure 4-3 Ion Exchange (MIEX) Structural/Mechanical Rendering**.

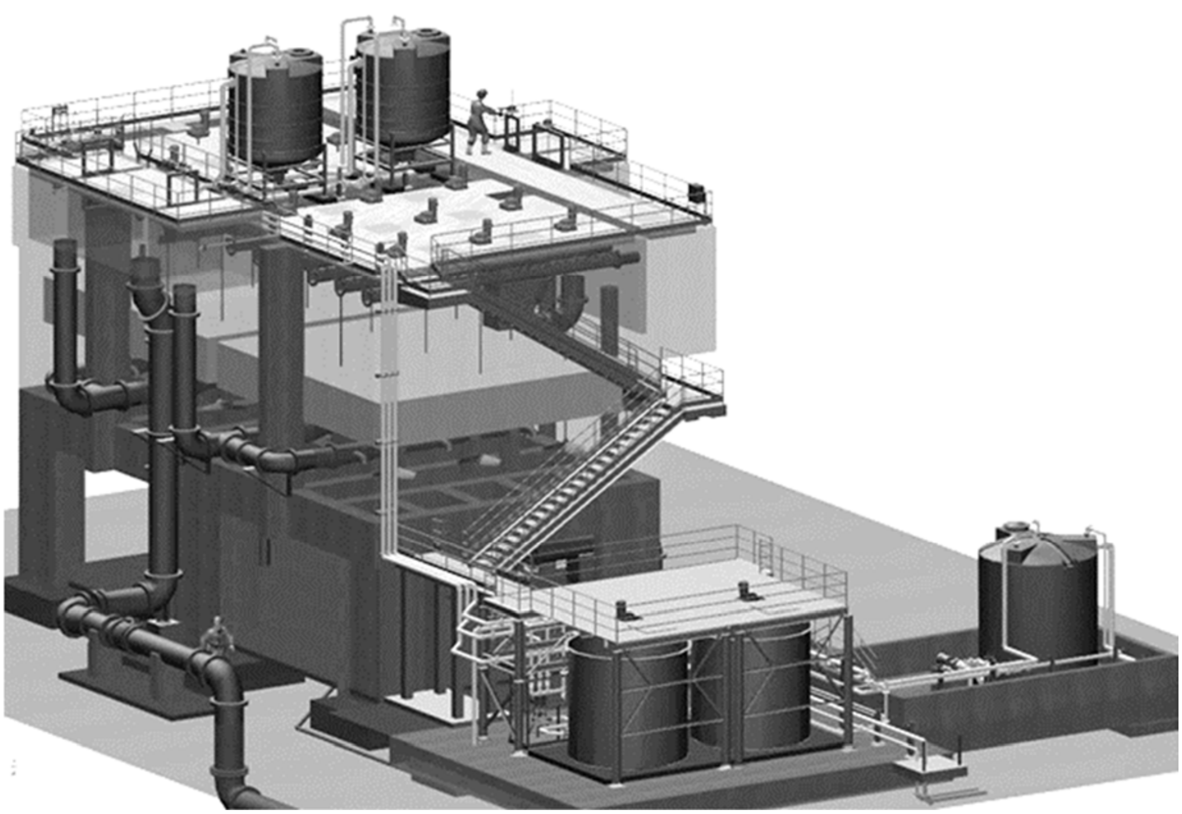

Figure 4-3 Ion Exchange (MIEX) Structural/Mechanical Rendering

MIEX can be used upstream of microfiltration and ultrafiltration membranes to reduce transmembrane pressure caused by high flux and fouling rates associated with high DOC levels. This will reduce the frequency of membrane cleaning cycles thereby extending membrane life.

4.1.6 Coagulant Addition

Although it may be possible for particles to flocculate and increase in size without chemical addition, the process is made much more effective with the addition of a coagulant. Furthermore, coagulation can turn dissolved species which cause color into particles which can be settled or filtered. Dissolved organics typically have a net negative surface charge with strong repelling forces that keep them in suspension. A coagulant works by adsorption of negatively charged dissolved organics in the water to the positively charged coagulant. This binds the particles together making them larger and more likely to be removed through filtration thereby reducing turbidity, total suspended solids, DOC, and color. Popular coagulants include aluminum sulfate, ferric chloride, prehydrolyzed metal salts, and synthetic organic coagulants.

The addition of a coagulant will improve the DOC and color removal of depth filtration and low pressure membrane methods discussed in previous sections. Of particular note, coagulant addition may make granular media filtration, microfiltration or ultrafiltration effective enough at removing DOC that NF would no longer be necessary. Generally, the use of coagulation has a lower total cost that the use of high-pressure membrane filtration but adds metal salts to the residuals associated with the treatment process.

4.1.6.1 Mixing Requirements

All coagulants must be rapidly mixed into the water to trigger the chemical reaction that will make dissolved colloids into removable particulates. This can be done in a tank with an impeller or with large diameter pipe with smaller impellers or jets enclosed. The rapid mix alone should allow the DOC charges to be neutralized for removal with media filters or membranes downstream. Traditionally, coagulant is dosed with a rapid mix followed by a slow mix period for flocculation. This will create even larger particles but will not necessarily lead to improved DOC removal beyond the level accomplished via rapid mix alone. If flocculation is of interest, it can be done with a tank or through a large diameter pipe with many bends. It is popular to also dose a polymer to improve flocculation and decrease the dose of coagulant required to meet treatment goals. This was tested in the 2009 jar tests (see Section 4.1.6.3) and seemed to lead to improved UVT levels.

4.1.6.2 Residual Disposal

Adding coagulant chemicals will result in sludge from chemical precipitation. The quantity of residuals is quite considerable and can be as much as 0.5% of the influent flow by volume. will need to be dewatered or otherwise treated. Assuming each 50MGD plant requires 40 mg/L of ACH and will also receive a polymer dose, nearly 12,000 pounds of sludge would be generated each day (5.9 tons per day). This waste can be handled by immediate wet hauling, backwash to settling ponds, or mechanical dewatering. The most cost effective option that minimizes operation complexity would be settling ponds which would require approximately 40 ft by 400 ft of space to accommodate the waste generated from treating 50 MGD of flow.

4.1.6.3 2009 Jar Test Study Results

In 2009 field testing was completed at the ASR site along the Kissimmee River to consider different coagulant treatment options (R2T, Inc., 2009). The Aquionics UV reactors were designed for disinfection at 25% UVT but were inconsistent in meeting permit requirements for coliform inactivation, particularly when UVT fell below the 25% design point (this was correlated with pumping from the Kissimmee River during high flow conditions). Ferric chloride was ruled out due to concerns with maintaining compliant residual metal levels and potential interference of iron with downstream UV disinfection. It was determined in that report that Aluminum chlorohydrate (ACH) was the favored option.

Two options for chemical addition yielded 30 to 40% transmittance: 40 mg/L (active) of ACH or 20 mg/L of ACH in conjunction with 1 mg/L of AS100 polymer. At 40 mg/L of ACH, the filtered water exceeded the secondary drinking water standard of 0.2 mg/L of aluminum, making this dose unacceptable. The option which significantly reduced the coagulant dose necessary, and the associated aluminum levels, required polymer which is an additional chemical stream to monitor and maintain. A dose of 40 mg/L is also believed to be high on the high end, and would taper down as organic loading declined during the operating season.

Also noted during field testing was that the KRASR tested rapid mixing, in-pipe. This treatment process did not have the flexibility to provide a second phase of reduced speed mixing to facilitate flocculation prior to filtration. In future, alternative coagulants and mixing methods should be considered.

4.1.7 Pretreatment Summary

A summary comparison of pretreatment alternative technology vendor quotes are provided in the table below:

Table 4-2 Comparison of Pretreatment Vendor Quotes

Scope Item	Pressure Filter (Tonka/Kurita)	Ion Exchange (MIEX)	UF+NF (Suez)	Coagulant+MF/UF (Aqua Aerobic)
Dewatering/ Waste Handling Requirement	2-5% of flow will be backwashed and need dewatering	670 lbsalt per MG treated; 40% recovery possible with EcoRegen System. EcoRegen waste brine treatment and resin regeneration is included	Brine disposal from NF required	3% of concentrate flow will be backwashed, thickened and dewatered
Chemical Addition	Not included in quote but could add coagulant	Not included in quote	Hydrochloric acid for cleaning; not included in quote.	Coagulant dose: 10ppm ACH; Sodium hypochlorite, sodium hydroxide, and sulfuric acid for TMP Rinse once each week
Configuration	22 pressure vessels (each 12ft dia. 48ft long)	4 contactor basins (each 30ft x 30ft x 25ft H) 5 to 8 regeneration tanks (depends on color removal goal)(each 12ft dia. 10ft H) 1 or 2 recycle brine tanks (depends on color removal goal) (each 12ft dia. 14.5ft H) 2 or 3 salt tanks (depends on color removal goal)(each 12ft dia. 19ft H)	12 trains for UF,13 trains for NF	5 trains of 5 high capacity ceramic MF/UF vessels, 90 membranes per vessel ~69ft long by 32ft wide, each
Startup/Training/Testing	Field services: installation inspection, media installation supervision, start-up and operator training	Not mentioned	Not mentioned	Onsite at start-up and commissioning, also offer in-service training
Warranty	Not mentioned	Not mentioned	Not mentioned	25 year warranty, 25-year life cycle used for OPEX cost calculations, not pro-rated; 1 year mechanical warranty
Disinfection	None; UV necessary	None; UV necessary	4+ log removal for protozoa and disinfection credits	4+ log removal of fecal coliform/bacteria
Equipment Cost, 60 PCU color goal, 50 MGD Capacity	System may not remove color unless coagulant is added $22,623,000	$12,193,000	Can remove down to 5 PCU Submerged UF: $12,500,000 Pressurized UF: $9,800,000 NF: $14,000,000	Can remove down to 10 PCU MF/UF System: $40,000,000

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4.2 DISINFECTION

Disinfection of treated surface water is required to reduce coliform bacteria to 4 cfu/100mL as described in Section 2.1.1. Reduction of turbidity and total organic carbon can help optimize effectiveness of disinfection technologies. Disinfection system(s) for the LOWRP ASR sites would conceptually be located after pretreatment.

System redundancy for the disinfection system will require implementation of an N+1 configuration for all potential technologies (duty + standby). Configuration of each site is expected to be developed in approximately five (5) MGD per well increments, with an initial start-up capacity of 10 MGD and expansion to buildout at 50 MGD. This type of a system will require modularity of the selected disinfection treatment technique to provide redundancy and reliability with the expectation of future expansion and addition of future parallel treatment trains. Disinfection standards per the Surface Water Treatment Rule and Florida guidelines for total coliform in UIC applications are summarized in Table 2-2 Disinfection Requirements: Log Removal.

Regulations for microorganisms are managed through selective use of treatment techniques under the National Primary Drinking Water Standards (NPDWS). Microorganism contaminants do not have specific log-removal criteria per the NPDWS. Total coliforms, which would be regulated for the ASR facilities, are required to be less than 4CFU/mL per the Florida Statutes on Class V Underground Storage. Recommended treatment techniques for ASR are described in detail below and would be recognized under EPA standards for performance.

Several alternative disinfection technologies are presented below, with the top three alternatives carried forward into potential treatment trains in Section 5. Consideration toward the equipment and footprint required for each treatment technique, as well as the cost-benefit of implementing the technologies are discussed. While this portion of the alternatives' assessment is focused on technology feasibility for disinfection, complicating issues include maintaining adequately reducing conditions within the aquifer to limit arsenic mobilization, minimizing chemical addition into the aquifer, and mitigating temperature shifts of the recharged water.

4.2.1 Chemical Disinfection: Chlorine and Chloramines

Chemical disinfection using chlorine or chloramines requires management of chlorine contact time (C·T) to provide adequate retention time and chemical dosing for pathogen inactivation after initial chlorine demand is satisfied. It is readily recognized by NPDWS as a treatment technique for disinfection and would not require extensive efforts for startup validation for total coliform removal.

The use of chlorine for disinfection of surface water is both effective and proven to meet primary drinking water standards, but using a chemical disinfectant carries significant drawbacks in waters containing high concentrations of dissolved organic carbon. With adequate pre-treatment to reduce turbidity via the filtration process, oxidant concentrations can be managed to reasonable dosing while meeting C·T requirements as shown in Table 4-3 Chlorine CT Values for Disinfection. However, the disinfection by-product formation potential (DBPFP) is expected to be very high due to the high level of organic compounds in the source water, even with low disinfectant dosing. For chlorine disinfection alone, DBPFP be a significant barrier to implementation. Chlorine C·T values are presented in **Table 4-3 Chlorine CT Values for Disinfection** for disinfection of E. Coli.

Table 4-3 Chlorine CT Values for Disinfection

Disinfection Target	Log-Removal Required	C·T value
E. Coli	2-Log (4-Log would be required in wet season)	0.034-0.05 mg*min/L for 5°C /2

Note: CT values taken from EPA and assume disinfection pH of between 6-9. [EPA Disinfection Profiling REF].

Maximum Total Coliform for Kissimmee River was 3800CFU/100mL; standard is 4CFU/100mL [CERP ASR Pilot Report (USACE and South Florida Water Management District, 2013)]. Values have been observed for TC as high as 15,000CFU/100mL during wet weather events.

2. https://www.who.int/water_sanitation_health/water-quality/guidelines/en/watreatpath3.pdf?ua=1

Chloramination can be used as an alternative to chlorination. Chloramines are a group of compounds containing chlorine and ammonia. Monochloramine is a less-volatile but longer-lasting disinfectant, favored for drinking water distribution systems. Chloramine C·T values are higher than those for chlorine to achieve similar inactivation levels. Chloramination would require a longer C·T to allow for chlorination, breakpoint chlorination. As such, greater storage volumes would need to be provided for disinfection prior to re-pumping and storage. Additionally, while DPBFP for chloramines may not be as high for regulated compounds such as THMs and HAA5s, chloramines are a precursor to unregulated DBPs such as nitrosodimethylamine (NDMA).

Residual oxidizers such as chlorine/chloramine have the ability to mobilize arsenic in the aquifer. To avoid arsenic mobilization, it would be necessary to quench the residual chlorine/chloramine to shift the oxidation-reduction potential (ORP) of the water prior to storage. Typically, oxidant quenching is achieved by chemical addition (e.g., peroxide, sodium bisulfate/thiosulfate), which would require additional chemical dosing by operators.

Injection of chlorine/chloramines in advance of the recharge well system will require chemical delivery infrastructure including chemical storage, chemical feed pumps, piping with instrumentation and controls, disinfectant, and disinfectant quench chemicals. A clearwell reservoir or tank would be required to provide adequate retention time of the water to meet the required chlorine contact time. Chemical disinfection would not be favored because of

1. the need for large onsite storage or generation of chlorine and/or ammonia; and
2. increased contact time required for breakpoint chlorination or chloramine disinfection, as well as increased disinfection byproduct formation potential, and
3. need for chemical quenching of disinfectant to mitigate risk of arsenic mobilization in the aquifer.

For these reasons, chlorine/chloramine chemical disinfection was removed from further consideration.

4.2.2 Pasteurization

Pasteurization is a proven disinfection method involving raising the temperature of the water to sub-boiling (minimum 60°C to 65°C) for pathogen inactivation. Similar to a chemical disinfectant system, pasteurization requires the liquid to be held with the correct temperature for a set retention time to be effective. This time has been documented from 5 minutes to 30 minutes in scientific literature based on the raw water quality conditions (Andreatta, 2007). The majority of pasteurization processes used for water treatment are implemented for low-cost disinfection in developing countries. These processes are typically land intensive, relying on solar-thermal disinfection to provide low throughput water production (Lundgren, 2014). This method of disinfection is not recognized by the EPA as an approved treatment technique and may require demonstration testing for validation. This treatment technique is not recommended for the LOWRP sites for the following reasons:

1. Production of between five (5) MGD to 50 MGD of disinfected water at each site would require an immense heat input.
2. The estimated required heat input for pasteurization at one 10 MGD site would require over one (1) million kWh of electricity per day. This calculation assumes a 100% efficiency of heat transfer with starting temperature of 25°C (median) and no reduction of the temperature from 60°C prior to aquifer injection.
3. Pasteurization is best implemented in a low-demand batch system, where adequate time exists to raise the water temperature and allow retention time for pathogen inactivation.
4. While a solar-driven system could be far more sustainable, the land-intensiveness of such a process would make it prohibitive at this scale of implementation (i.e., tens of acres).
5. Reliability and redundancy of pasteurization as a disinfection alternative are significantly less than all of the other proposed options.

For these reasons, pasteurization was removed from further consideration.

4.2.3 Membrane Techniques: Ultrafiltration and Nanofiltration

Membranes can be used to exclude pathogens from the treatment process based on size. Most bacteria are very small (~ 1 μm long). A single E. coli is around 2 μm long and about 0.5 μm in diameter, while ultrafiltration (UF) membrane openings are on the order of 0.01 μm. As such, coliform bacteria can be rejected by these membranes openings which are 50 times smaller than the organism. Details on membrane sizes required for disinfection were previously described in **Section 4.1.4**.

As discussed in Section 4.1.4, membranes can also provide a tandem benefit of pretreatment for turbidity (UF or NF) and color removal (UF + coagulation or NF). Membranes are recognized as a treatment technique under the SWTR and NPDWS for disinfection credits.

4.2.4 Ultraviolet (UV)

Ultraviolet disinfection requires a similar approach to chlorine in that the UV dose and reactor retention time are key factors in achieving adequate inactivation of pathogens. However, the required contact time for UV disinfection is much shorter than for chlorine or chloramine disinfection and is in the order of a few seconds. For UV treatment, the UV dose (mJ/cm^2) is considered an **I**·T value, which represents the UV intensity (mJ/cm^2-s) multiplied by the time spent in the reactor (seconds), divided by the ultraviolet transmittance (UVT, %). These values have been benchmarked for the levels of inactivation required for virus, Giardia, and Cryptosporidium, but key parameters that can increase dose requirements include low ultraviolet transmittance and high DOC/TOC (e.g., color). For this source water, both of these parameters are risk factors for not meeting disinfection requirements, which must be carefully managed in detailed design. Ultraviolet light is a non-selective treatment approach, in that it does not only target pathogens, but targets all constituents that can absorb UV light within the water matrix which will increase dose requirements for low-quality source waters. DNA absorbs ultraviolet light wavelengths between 200-300nm, which is called the ‘germicidal range’ and represents the effective wavelengths to deliver for pathogen inactivation and disinfection. Virus inactivation is significantly more energy intensive for UV-disinfection than inactivation of other pathogens.

Table 4-4 Ultraviolet Disinfection Requirements shows total log removal requirements for disinfection throughout the treatment process. Pre-treatment filters may provide some disinfection credits depending on the quality of filtration they provide (e.g., NF covers all requirements but 1-log virus) and unit process effluent turbidity. Hence, with effective filtration upstream, lower ultraviolet doses may be needed to provide disinfection credits. For the case of the Kissimmee River and Taylor Creek ASR sites, the limiting factor for UV disinfection will not be turbidity, or particulate matter, but the colloidal and dissolved color and organic carbon that remains after the filtration process.

Table 4-4 Ultraviolet Disinfection Requirements

Disinfection Target	Log-Removal Required	Delivered UV Dose Required
Giardia	3-Log	11 mJ/cm^2
Cryptosporidium	2-Log	5.8 mJ/cm^2
E. Coli	4-Log	20 mJ/cm^2 /1
Minimum Recommended Dose for Pathogen Inactivation in Drinking Water (assumes post-filtered, low turbidity; does not assume 4-log virus inactivation is achieved)		50 mJ/cm^2 /2

Note: Dose values taken from EPA Ultraviolet Disinfection Guidance Manual. Reactors may be applied in series to meet these doses based on their validation criteria.

/1 https://www.who.int/water_sanitation_health/water-quality/guidelines/en/watreatpath3.pdf?ua=1

/2 USEPA Ultraviolet Disinfection Guidance Manual, NWRI Validation Standards

As noted above, the previous installation at the KRASR site was designed to achieve a dose of 40mJ/cm^2 once upgrade to three-reactors in series and has proven to be seasonally inadequate to provide total coliform reductions below 4CFU/100mL. Hence, this value is recommended as the minimum recommended dose, and detailed design should review all water quality parameters that may lessen effectiveness of UV disinfection prior to implementation to properly account for low UVT and high DOC.

4.2.4.1 UV System Design Considerations

Effective implementation of ultraviolet irradiation for disinfection relies on management of a few key parameters:

- Ultraviolet Transmittance (UVT) – defined as the transmittance of light through the a one centimeter sample (opposite of the light absorbed by the sample, represented as $UVT_{254} = 10^{-UVA_{254}}$) at 254nm. This parameter is influenced by the water's color, turbidity, particle loading, and concentration of dissolved organic/inorganic compounds.
- Ultraviolet Dose, UV Dose – defined as the amount of energy flux required by the water quality and contaminant loading to meet disinfection standards or alternatively as the amount of UV energy that the system can deliver per square cm of surface area (units are in mJ/cm^2)

Table 4-4 provides UV dose values required to meet inactivation requirements for pathogens under pristine conditions with no upstream treatment. However, in full scale applications, the lower the UVT, the higher the UV dose that is required to achieve the same amount of disinfection due to competing constituents that absorb/block UV light transmittance to pathogens. The CERP ASR Pilot Report (USACE and South Florida Water Management District, 2013) showed that low UVT for the Kissimmee River prevented adequate UV disinfection of total coliforms, which has the lowest UV-dose requirement. True color and UVT data from cycle testing at the Kissimmee River ASR site is shown in Figure 4-4 Relationship of True Color and %UVT in Kissimmee River ASR Cycle Testing, which demonstrates higher UVT is achieved with lower true color of the source water. Without increasing the UVT, pathogen inactivation would require a substantial UV-dose (increasing reactor quantity, power consumption, etc.). Inactivation of total coliform should be feasible with an adequately sized reactor, even with the low UVT and high DOC. UV manufacturers supply systems for wastewater treatment that are validated down to 6% UVT, but the disinfection requirements for potable water are different than those of wastewater, and implementation of such a system would require preliminary or pilot testing to verify efficacy.

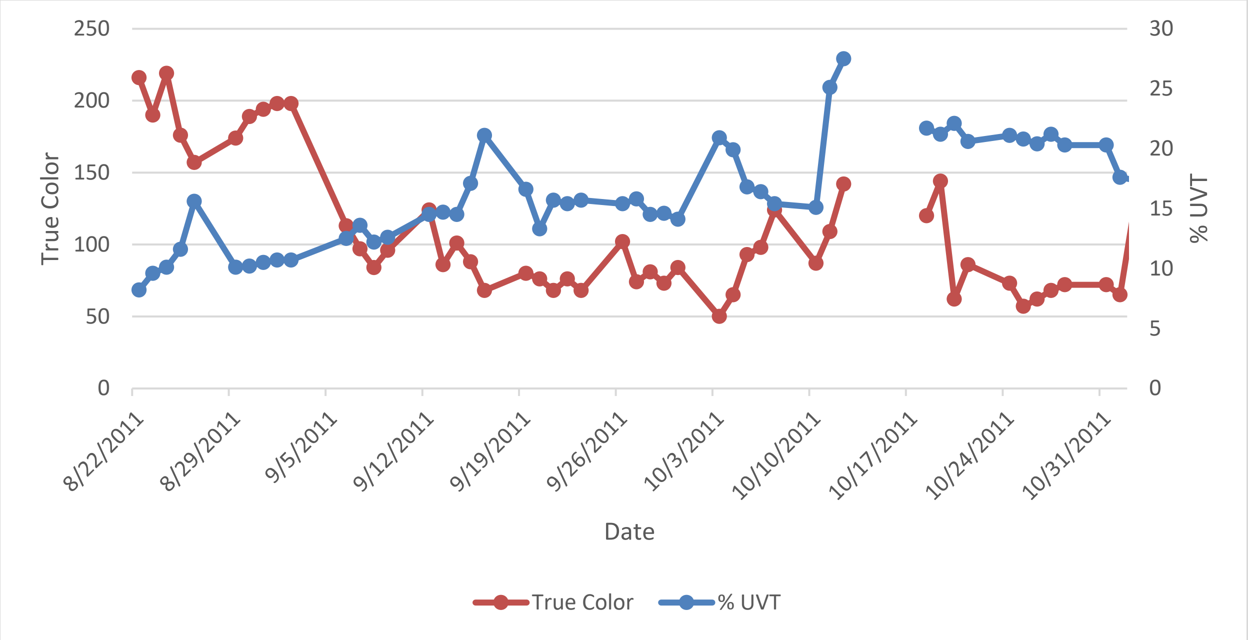

Figure 4-4 Relationship of True Color and %UVT in Kissimmee River ASR Cycle Testing

Figure 4-4 generally illustrates an inverse relation between UVT and Color. As color of water decreases during the rainy season, UVT increases. While not highly correlated, a scatterplot of UVT and Color for Kissimmee River water is illustrated in **Figure 3-1 KRASR Cycle 4 UVT vs True Color.**

Table 4-5 Ultraviolet Disinfection Constraints

Water Quality Parameter	Estimated Value	Implementation Constraints
Ultraviolet Transmittance (% UVT)	20%	From the Regional Aquifer Storage And Recovery Technical Data Report (USACE and South Florida Water Management District, 2015), the UVT could be maintained at 20% using coarse screening and bank filtration methods as previously documented in the SFWMD pilot study. *Not all UV vendors are capable of meeting validation requirements for water with UVT of 20%. An open-channel system would be most likely implemented to manage the low UVT using a reactor originally designed for wastewater treatment but validated to NWRI standards; this solution would require re-pumping prior to aquifer injection.*
	40%	Addition of a more sophisticated pre-filtration system such as sand filters (without any coagulation) was shown to increase UVT to between 35-45% during parts of the wet season without major water quality disturbances. To consistently meet >40% UVT a more robust system would be recommended for pre-treatment. *UVT is adequately high to allow all vendors to provide a recommended, validated reactor for this water quality, with reduced costs for treatment compared to 20% UVT. Both open channel and pressure reactors are available for this solution, and selection would be based on pre-treatment head and need for re-pumping.*
	60%	Reaching a UVT at or above 60% would require substantial pre-treatment including for example: coagulant-assisted filtration or low-pressure membrane filtration; nanofiltration or the use of ozone pre-treatment for filtration. *The cost-benefit of pre-treatment required for increasing the UVT of the raw water to over 60% would have to be weighed against the reduction in ultraviolet technology required to meet pathogen inactivation requirements. UVT at 60% allows for the lowest number of UV reactors and lowest capital and O&M costs for UV treatment (e.g., fewer lamps, reduced power consumption).*
Color (PCU)	≤ 130	True color typically consists of dissolved organic carbon and is not highly responsive to conventional, low-cost pre-treatment methods, particularly those without chemical addition. Color-causing compounds serve as a blinder throughout the UV treatment system, absorbing light and blocking UV transmittance to pathogens. This greatly limits efficacy of UV treatment and would require increased number of lamps and reactors to provide sufficient UV dose. *UV systems that are used for wastewater treatment are more often regulated to low UVT / high color conditions but should be able meet total coliform inactivation requirements for this application, even with very high TC counts in the raw water. If color cannot be cost-effectively managed by filtration, an open channel system is recommended for low-UVT/high-color to meet pathogen inactivation goals.*
DOC/TOC (mg/L)	≤ 25	LOWRP source water has little difference between measured TOC and DOC, indicating that most of the organic material is dissolved, making pre-treatment more intensive if required.

Water Quality Parameter	Estimated Value	Implementation Constraints
		UV can mitigate DBP formation compared to chemical disinfection for high DOC waters, but DOC will absorb UV light, limiting effectiveness of the UV treatment process and requiring a higher UV dose.

Note:

1. One vendor indicated that they would not be able to provide 4-log virus removal without pre-treatment to ≥ 80% UVT, for which they recommended GAC or ozone with biologically active carbon, which would increase operational complexity and treatment cost per gallon significantly.

2. Most water treatment facilities operate significantly above 90% UVT, resulting in limited number of reactors available that are validated for such low UVT.

3. Operation of the system under the range of water quality parameters as listed under the "Estimated Value" would require delaying annual start-up of the ASR system until the water quality was stabilized (after first seasonal flush) and may require shut down during periods of severe weather.

As UVT of the pre-treated water increases, the cost of UV treatment decreases, along with number of reactors required, lamps and UV dose which will impact both capital investment and long-term operations and maintenance costs.

4.2.4.2 **Low Pressure High Output**

Low pressure high output (LPHO) mercury lamps emit light at 254nm and are used primarily in disinfection applications. Benefits of this system is targeted delivery of disinfection wavelengths for pathogen inactivation. LPHO systems can achieve very high disinfection doses of ultraviolet light without production of excess heat or expenditure of energy on production of non-UV wavelengths and are thus more energy efficient. However, the maximum output per UV lamp in a LPHO arrangement is limited so large systems using LPHO have very high numbers of lamps and other supporting components. The diversity of selection of vendors providing large scale low pressure ultraviolet disinfection systems is less than that of medium pressure lamps.

4.2.4.3 **Medium Pressure High Output Lamps**

Medium pressure mercury lamps provide a broad spectrum of ultraviolet irradiation (and visible light) from 200-400nm. Inactivation of pathogens is known to occur with 254nm UV irradiation, but some studies indicate enhanced DNA inactivation at 265nm or 285nm, which are delivered using medium pressure lamps. These lamps are validated to inactivate pathogens due to the production of wavelengths beyond 254nm in the germicidal range.

While effective at delivering a range of disinfection wavelengths, there are some drawbacks to medium pressure lamps. Heat generation from wavelengths emitted in the visible and infrared spectrum makes them less energy efficient. Nitrate photolysis (wavelengths < 250nm) can produce nitrite and N-DBPs (with subsequent chemical oxidant addition) as by-products. Due to issues associated with the broad spectrum of light emitted and complications associated with the validation process it may be harder to find a validated

MP system for very low UVT water sources. For these reasons, Medium pressure lamps is not recommended for this evaluation.

4.2.4.4 UV-LEDs

Ultraviolet light-emitting diodes have been demonstrated at bench and point of use/point of entry scale to be effective for disinfection (flow ranging up to 12gpd). UV-LEDs provide a mercury-free irradiation solution for disinfection, and the scale of the LEDs allows for significant reactor design flexibility, high energy efficiency and compact footprint. UV-LEDs produce discrete wavelength emission, allowing for selection of one or more wavelengths for use in reactor design. However, this technology has not been implemented for municipal-scale applications and is not recommended for the SFWMD ASR as a test-case.

4.2.4.5 Reactor Design Considerations

Reactors may be designed to meet UV dose goals through combining reactors in series or in parallel depending on the manufacturer. Reactors may be closed pipe, or open channel, use crossflow or parallel flow configurations, and the marketplace variability allows for adjustment of footprints, reduction or increase in quantity of reactors required, and availability of reactors to treat low UVT source waters.

UV can be quite maintenance intensive, requiring monthly sensor calibrations, wipers replacement every two (2) years, UVT analyzers maintenance, in addition to routine lamp and ballast replacement. Design should consider the parameters presented in **Table 4-6 UV Reactor Design Parameters** to ensure adequate provision of UV light into the reactor to meet the required disinfection dose with de-rating based on the UVT able to be provided in the source water.

Table 4-6 UV Reactor Design Parameters

Federal, Local and State Standards	Treatment Objectives	Bench Scale / Pilot Testing Requirements and Needs
Lamp Technology Selection	UV Dose Requirements	Chemical Oxidants (AOP)
Process Design	Hydraulics and Flow Balancing	Power Requirements
Off-Spec Discharge Procedures	Equipment Layout and Site Footprint	System Redundancy (N+1)
Operation and Maintenance Requirements	System Optimization under Field Conditions	Start-up and Commissioning Requirements

As noted above, key water quality parameters for successful implementation of ultraviolet disinfection include management of: UVT, DOC/TOC, and photochemistry of aqueous compounds (scavengers to disinfection outcomes). Pre-treatment technology should provide a consistent, minimum UVT for which the UV system can be designed and operated to meet disinfection log-removal targets.

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Table 4-7 Comparison of UV Vendor Quotes

Scope Item	Wedeco	Trojan	Calgon	Aquionics”(20")	Aquionics”(30")
Reactor Vessel	LBX1–00 ” 20" ANSI flange closed vessel for W/WW applications	Trojan UV Signa	C3500D – not validated below 35% UVT	Inline 18000+; 20” ANSI flanges	Inline 36000+; 30” ANSI flanges
Lamp Type	Low-pressure Hg Eco–ay - life of 14,000 hours 60 lamps per vessel	Low-pressure Hg 1000W Solo Lamps 20% UVT: 324 Lamps (108 standby) 40% UVT: 180 Lamps (60 standby) 60% UVT: 90 Lamps (30 Standby)	Low-pressure Hg Lamp Life 16,000 hours 20% UVT: 512 Lamps (35%: 384 lamps) 40% UVT: 256 Lamps 60% UVT: 128 Lamps	B6050E+ Medium Pressure 18 lamps per unit Lamp power adjustable 35%-100%	B8080E+ Medium Pressure 18 lamps per unit Lamp power adjustable 35%-100%
UV Sensor	Included	Not described, likely included	Not described, likely included	Included	Included
Wiping / Fouling Prevention	Included	AntiClean WW chemical/mechanical wiping system	Not described	Included	Included
UVT monitor	Included	Included	20 UVT Sensors Included	Not described	Not described
I&C	PLC interface + Modem that has WEDECO Remote Service Support	Lamp drivers and control system provided in outdoor-rated panel	Includes PLC/HMI	PLC with NEMA-12 (indoor installation); Master Control Panel included	PLC with NEMA-12 (indoor installation); Master Control Panel included
Electrical Requirement	480V, 3-phase, 60Hz, 4 wire+ground	20% UVT 6 PDCs, HSC, SCC 40%/60% UVT: 3 PDCs, HSC, SCC PDCs (480V/277V, 60Hz, 63kVA), HSC (480V, 60Hz, 2.5kVA), SCC (120V, 60Hz, 1.8kVA)	20% UVT: 20 PDCs, 5 SCCs 480/277V, 3-phase 4-wire	480V, 3-phase, 60Hz	480V, 3-phase, 60Hz
Power Consumption	21.25 kW per vessel	67.4kW (60% UVT) to 227.4kW (20% UVT)	378.6kW (20% UVT)	Not described	Not described
Level Controller	Integrated Baffle Plate	3 Fixed Weir	Weirs	Not described	Not described
UVT Limits	Case #1: 40% (15+1 configuration) Case #2: 60% (7+1 configuration) 20%UVT was ~56 reactors; validated int’ 20's but not economical.	20% UVT: 41 ft channel; (2+1 configuration) 40% UVT: 35 ft channel; (2+1 configuration) 60% UVT: 31 ft channel; (2+1 configuration)	20% UVT: 4 banks per channel (4+1 channels); channel is 56.5 ft (L) x 2 ft (W) x 6 ft (H) 40% UVT: 2 banks per channel (x+1 channels) 60% UVT: 1 bank per channel (x+1 channels)	20% UVT: 5 Trains of 5IL in series (no +1) 40% UVT: 4 Trains of 5IL in series (no +1) 60% UVT: 3 Trains of 2IL in series (no +1)	20% UVT: 5 Trains of 5IL in series (no +1) 40% UVT: 4 Trains of 5IL in series (no +1) 60% UVT: 3 Trains of 2IL in series (no +1)
UV-Dose	80mJ/cm^2 (MS2 RED)	50mJ/cm^2 (MS2 RED)	70mJ/cm^2 (MS2 RED); Reaction time of 36.4sec	Not described	Not described
Startup/Training/Testing	Included	Not described, likely included	Not described, likely included	Not described	Not described
Warranty	Lamps 14,000 hours; Prorated after 9,000 System Warranty: 18 Mo. from delivery or 12 Mo. from substantial completion	Lamps 15,000 hours; Prorated after 9,000 System Warranty: 18 Mo. from delivery or 12 Mo. from substantial completion	System Warranty: 18 Mo. from delivery or 12 Mo. from substantial completion	Not described	Not described
Submittals Timeline	8 weeks after approved PO	Not described	Not described	Not described	Not described
Delivery Timeline	16 weeks after approved submittals	Not described	28-32 weeks after approved shop drawings	10-14 weeks ARAD	10-14 weeks ARAD
20% UVT Price, 10 MGD	Not Provided due to Validation Ratings	$1,853,775	$1,946,000	$3,994, 644	$2,198,559
40% UVT Price, 10 MGD	$2,550,000	$1,063,883	Not Provided	$3,200,996	$1,331,868
60% UVT Price, 10 MGD	$1,420,000	$681,440	Not Provided	$995,682	$703,419
Footprint, 10 MGD					

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4.2.5 Oxidation and Advanced Oxidation

Oxidation is a process such as ozone which is used to assist in the removal of color which increases the UV transmittance of water being disinfected. Advanced oxidation processes (AOP) use hydroxyl (OH-) radicals to oxidize pollutants and that have been employed at full scale for drinking water treatment. AOP processes include ultraviolet with hydrogen peroxide and ultraviolet with a photocatalyst. AOP systems are implemented to achieve specific outcomes that merit the comparatively increased complexity of operations and maintenance of these systems.

4.2.5.1 Ozonation

Ozone is among the most powerful oxidants and disinfectants available. Similar to ultraviolet light, ozone is a non-selective oxidant. For the SFWMD ASR raw water sources, this non-selectivity means that higher doses will be required to meet disinfection goals because of the high DOC and color in the water matrix. While pre-filtration steps can remove any particulate matter that would adsorb pathogens and limit disinfection effectiveness, both dissolved organic carbon and color (fulvic and humic acids) would be strong scavengers of the ozone. Alkalinity, pH, and temperature will contribute to the rate of reaction for ozone and its mass transfer into the water. A key constituent to monitor for ozone technology implementation is bromide, which is readily oxidized to bromate through ozonation processes. The MCL for bromate is 10 µg/L, which can be exceeded with excess ozone dosing (> 10mg/L, source water dependent) or raw water concentrations of bromide greater than 0.5 mg/L to 1 mg/L. This issue is typically a concern in coastal areas due to the higher natural occurrence of bromide.

Ozone generation would be accomplished onsite from oxygen which in turn can either be delivered as liquid oxygen (most common) or through a process such as vapor swing absorption which purifies oxygen from the air. All ozone systems have significant operational complexity but provide a potential means to manage multiple contaminant issues to meet both primary and secondary drinking water standards. Ozonation can provide oxidation of DOC and color-causing compounds in water with sufficient doses and contact times, though higher organic compounds will present higher ozone decay rates and larger initial doses required. This has been documented in previous SFWMD/USACE pilot studies for ASR treatment alternatives.

Sizing for typical drinking water applications of ozone will dose excess ozone to provide an ozone residual after satisfying the ozone demand, which would dissipate in a period of approximately ten minutes or less. For this application, it would be important not to have an ozone residual enter the aquifer due to potential issues with arsenic mobilization potential and despite the rapid natural decay would necessitate an ozone quenching process prior to injection. Ozone treatment processes can be implemented in pressure pipe or in an ozone contact basin depending on the desired footprint, contact time, and other design parameters.

Ozone C·T values are presented in **Table 4-8** Ozonation Requirements to Meet Disinfection Standards for disinfection of the target contaminants. Up to 4-Log reduction of E. coli would be required during the wet season based on historical water quality data, which would increase the dose of ozone required, though it would remain lower than the dose required to inactivate Cryptosporidium.

Table 4-8 Ozonation Requirements to Meet Disinfection Standards

Disinfection Target	Log-Removal Required	Ozone CT Value
E. Coli	2-Log (4-Log would be required in wet season)	0.02 mg*min/L at 5°C

Note: Dose values taken from EPA Ultraviolet Disinfection Guidance Manual. Reactors may be applied in series to meet these doses based on their validation criteria.

(WHO, 2004)

4.2.5.2 **Ultraviolet Advanced Oxidation Process**

UV/Chemical Oxidant

Ultraviolet advanced oxidation processes with added chemical oxidants such as hydrogen peroxide have been shown to improve water quality beyond disinfection. However, these processes rely on the radicalization of compounds using the UV light, such as $H_2O_2 + h\nu \rightarrow 2HO^{\cdot}$. To achieve radical production, a reasonably high UVT must be provided in the source water. Otherwise, chemical reactants will not be adequately consumed, reducing functionality of the UV/AOP process.

While UV/AOP solutions with chemical oxidants can induce oxidation of dissolved organic compounds, the UV dose demand is much higher for UV/AOP systems. A well-designed system could reduce color to meet secondary standards, but there are a few drawbacks which make this system unlikely for recommendation in the LOWRP ASR application:

- UV/H_2O_2 or other chemical oxidant (e.g., para-acetic acid) would require a post-treatment quench prior to injection in the aquifer. This can be achieved chemically or using GAC.
- Limited UVT would dramatically reduce the effectiveness of the UV/AOP process and would require significant upsizing to achieve disinfection and color reduction goals.

UV/Photocatalyst

Advanced oxidation systems using ultraviolet light and a photocatalyst can eliminate need for chemical addition upstream of the UV process by using a recirculating semiconductor photocatalyst that can produce radical species and induce oxidation/reduction reactions on the surface of the material. UV/photocatalyst systems have used for remediation of organic and inorganic contaminants, with significant research and efforts toward synthetic dye wastewaters, which correlate to the Kissimmee River/Taylor Creek surface waters with high color/DOC. Full scale installations have focused largely on Superfund site remediations or stormwater to date.

UV/photocatalyst processes can provide a no-chemical addition solution for oxidation of color and disinfection, but these processes are faced with a few drawbacks that may limit efficacy for application in the ASR system including:

- Higher electrical energy per order required when compared to UV/H_2O_2 (this comes as a tradeoff to not needing a consumable chemical reagent and auxiliary systems, such as would be required for UV/H_2O_2)
- Limitations of mass-transfer of the photocatalyst and light delivery, which would be increased by low-UVT or high DOC/color source water if pre-treatment was not consistent and/or sufficient.
- Efficacy of light delivery and adequate UV dose to induce photocatalytic reactions through a high throughput, single-pass reactor is likely to be limited, or require a very large footprint system.

4.3 RESIDUALS MANAGEMENT

Separation of solids from liquids during the treatment process requires management of residuals. The nature and efficiency of the treatment process determines the quality and quantity of the waste stream produced.

4.3.1 Backwash Pond

A backwash pond or settling basin is a simple technology for solids separation, which relies on settling of solids in an open basin. A decant pump draws water from the surface of the pond via a floating skimmer as water level fluctuates. This supernatant liquid can then be re-treated through the process, while solids are periodically removed from the basins with equipment and trucked off-site for disposal. Multiple basins allow for alternating operating cycles between filling from backwash operations and settling. Daily hauling of sludge would be required from one pond or the other.

With a hydraulic load rate of approximately 0.5 gpm/sf, conceptual backwash ponds would provide 1.67 hours of detention time. Pond design criteria are summarized for applicable alternatives in **Appendix B**. Operating Costs for Sludge management, including sludge production rates, and trucks per day required for disposal are summarized in **Appendix F**: **2022 OPEX Sludge**.

While dimensions may vary slightly for different alternatives 1A, 1B and 2B, a conceptual sketch of this technology is illustrated in **Figure 4-5 Backwash Pond**

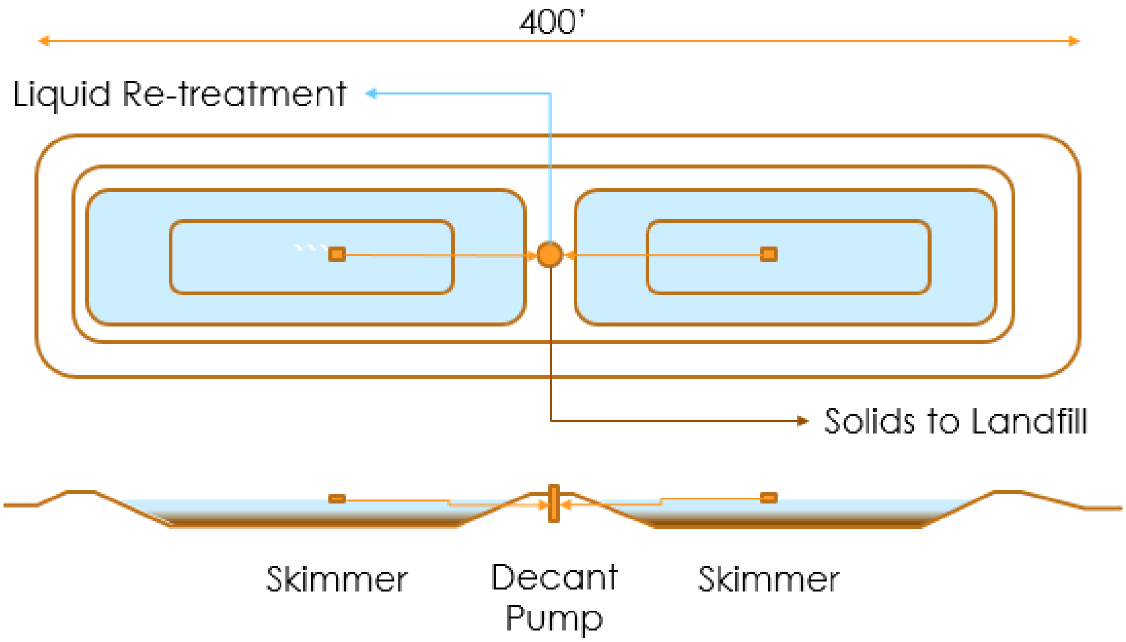


Figure 4-5 Backwash Pond

4.3.2 Thickening and Dewatering

A gravity thickener is a conical bottom tank which separates separates solids from clarifies liquid (decant). As solids settle by gravity, a rotating scraper mechanism concentrates toward the center underdrain where they can be pumped out. This process can increase coagulated backwash solids from the MF/UF process from 0.25% to almost 4% with a significantly smaller footprint than a backwash pond. Thickened solids can be pumped to a centrifuge for dewatering using a dewatering centrifuge.

A decanter centrifuge consists of cylindrical and conical bowl assemblies, a motor and a gearbox to create a differential rotational speed between the bowl assemblies. Centrifugal force created by the rotation of the bowl forces solids particles to separate from the liquid and move toward the bowl wall. Solids compact on the cylindrical of the bowl wall. The scroll conveyor located inside the bowl, rotates at a slightly faster speed than the bowl, carrying solids to the discharge. A conceptual sketch of this technology is illustrated in **Figure 4-6 Decanter Centrifuge.**

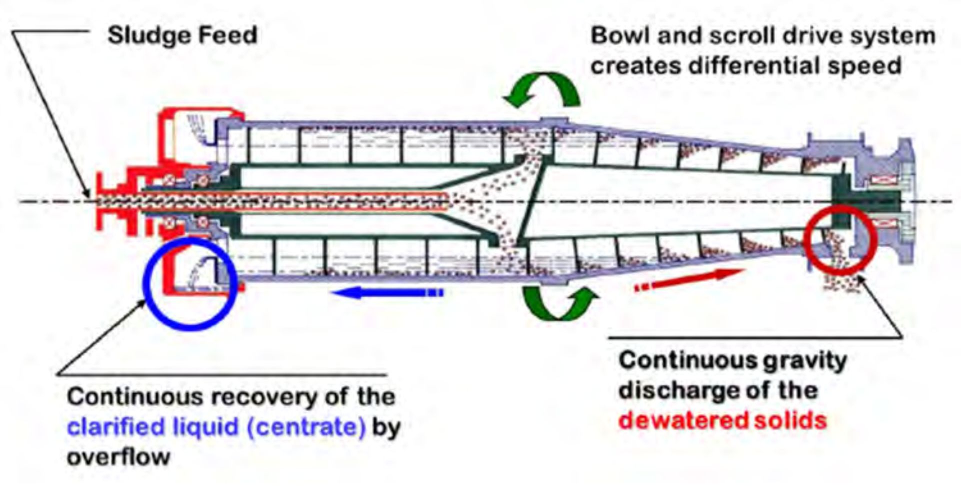


Figure 4-6 Decanter Centrifuge

4.4 TECHNOLOGY EVALUATION CRITERIA

4.4.1 Fatal Flow Criteria

Evaluation of treatment technologies were excluded from further consideration or inclusion in potential treatment trains on the basis of the following fatal flaws:

1. Any process that is complex in nature compared to other processes and require a high level of manned staffing, operator and maintenance attention
2. Any treatment process that produces levels of DBPs in excess of standards for Maximum Contaminant Levels (MCLs), and Maximum Residual Disinfectant Levels (MRDLs).
3. Technology or system is not scalable to 50 MGD.
4. Any process not suitable for high organic loads, algae, and high turbidity that are common characteristics of Lake Okeechobee tributary surface water.

Treatment technologies described in this section are summarized in terms of treatment function and fatal flaws which eliminate each from further consideration as part of a treatment train. Treatment methods that are not able to reliably remove organics were not shortlisted, which ruled out bank filtration, radial collector wells, and bag filters & cartridge filters. These technologies are presented in **Table 4-9 Treatment Technology Summary.**

Table 4-9 Treatment Technology Summary

Treatment Technology	Solids Removal	Turbidity Removal	DOC Removal	Pathogen Removal	Fatal Flaw
Media Filtration	X	X			
Mech Filters and Strainers (Basket/Disk)	X				Yes, 4
Bag Filters and Cartridge Filters					Yes, 3
Ion Exchange (IX)		X	X		Yes, 1
MF/UF Membranes	X	X		X	
NF Membranes		X	X	X	
Coagulation		X	X		
Chlorination				X	Yes, 2
Pasteurization				X	Yes, 3
UV				X	
Ozonation			X	X	Yes, 1
Advanced Oxidation				X	Yes, 2

Treatment criteria which were not eliminated on the basis of fatal flaws were carried forward for consideration as part of potential treatment trains in Section 5, with the exception of Ion Exchange (IX). Despite being considered complex in nature, this technology was carried forward for comparison purposes.

5.0 TREATMENT ALTERNATIVES

Shortlisted treatment technologies from Section 4 were arranged into treatment trains for consideration of treatment potential and evaluation in terms of economic and non-economic criteria.

5.1 POTENTIAL TREATMENT TRAINS

The most significant difference in treatment trains lies in the pretreatment of water prior to disinfection. These pretreatment technologies include Media Filters, Two-stage Media filters with coagulant, Ion Exchange (MIEX), Ceramic MF membranes with coagulant, and UF and NF membranes without coagulant. These treatment technologies were grouped conceptually with the goal of reducing organics and color and increasing UVT to optimize disinfection system sizing as indicated by the goals presented below. Alternatives 1A, 1B and 1C meet primary drinking water standards, while alternatives 2A and 2B meets secondary drinking water standards. These treatment trains are summarized in **Table 5-1 Potential Treatment Trains**, and described & illustrated based on a 50 MGD buildout in the following paragraphs.

Table 5-1 Potential Treatment Trains

Process/Treatment Alternative	Alt 1A	Alt 1B	Alt 1C	Alt 2A	Alt 2B
	Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, MF/UF	UF, NF
Color Goal (PCU, approx)	150	70	60	15	15
UVT Goal (%, approx)	20	40	40	-	-
Treatment Standard Met	Primary			Secondary	
Filtration/Color Removal					
Strainers					X
Media Filters	X	X			
Coagulation		X		X	
Ion Exchange (IX)			X		
MF/UF Membrane Filtration				X	X
NF Membrane Filtration					X
Disinfection					
UV (channel)	X		X		
UV (reactor)		X			
Residuals					
Backwash Pond	X	X			
Dewatering (Centrifuge)				X	
Deep Injection Well			X		X

The potential treatment trains considered herein are based upon a centralized approach, with a single raw water station, electrical room, and control room to power,

It should be noted that during alternative treatment train development exercises, ultrafiltration w/o coagulation (previously alternative 1E) was not believed to produce significantly better water quality than alternative 2A. Since the costs would be on the same order of magnitude, this alternative was removed from further consideration. The remaining treatment trains are described herein.

Assumed recovery for treatment processes used to develop a mass balance for each potential treatment train are summarized in **Table 5-2 Treatment Process Recovery.** Design criteria including a mass balance for each process is provided in **Appendix B**. Vendor proposals and equipment data sheets are provided in **Appendix C**.

Table 5-2 Treatment Process Recovery

Loss No.	Description	Recovery
I	PRESSURE MEDIA FILTERS	95.00%
II	PRESSURE MEDIA FILTERS W/ COAG	95.00%
III	MIEX	99.95%
IV	MF/UF CERAMIC MEMBRANES	97.00%
V	POND OR SLUDGE THICKENER	90.00%
VI	STRAINER	99.50%
VII	POLY UF MEMBRANES	95.00%
VIII	POLY NF MEMBRANES	85.00%
IX	MECHANICAL DEWATERING	50.00%

5.1.1 Alternative–1A - Media Filtration, UV Channel Disinfection

Alternative 1A is intended to be representative of the existing KRASR Treatment system, with an appropriately designed UV system. This system consists of intake screening, raw water pumping, and media filtration (22, pressure vessel type). However, because color and organics removal are negligible with this pretreatment technology, UVT would likely remain low. As has been experienced by SFWMD and R2T O&M staff, UVT values of 20% at best could be expected. While 3 vendors quoted UV systems for this UVT, not all may be valid. Previous SFWMD experience with Aquionics casts doubt as to the efficacy of their claims. Calgon, while providing a quote for 20% UVT, is only validated down to a minimum 35% UVT. Wedeco declined to quote equipment for a system of this low UVT. Thus, Trojan channel type reactors were considered for this treatment train.

While Trojan reactors are validated for such low UVT water, breaking pressure from closed pipes after the filters to an open channel for UV would necessitate construction of a wet well and re-pumping from the treatment process to ASR wells. Raw and intermediate pumps are addressed in Section 5.2.2. At 50 MGD buildout capacity, open channel UV disinfection would require 11 (10+1) channels with 324 lamps each for a total of 1188 UV lamps. A shade structure over the channels and covers over the channels are recommended to minimize nuisance wildlife issues and minimize sunlight deterioration of equipment. Based on experiences with the KRASR site pressure filter vessel, district staff requested a cover be considered as part of this alternative.

Alternative 1A is operationally simple, and because it does not remove significant turbidity and dissolved solids, residuals management would be less than other alternatives. A backwash pond with decant pump could economically manage sludge. However, as indicated above, there is no Color/DOC Removal with this alternative and it carries the highest potential for aquifer plugging. This process would yield the lowest UVT for disinfection, be highly unreliable, and would not meet secondary drinking water standards. The forward treatment process for Alternative 1A is illustrated in **Figure 5-1 Alternative 1A - Media Filtration, UV Channel Disinfection.**

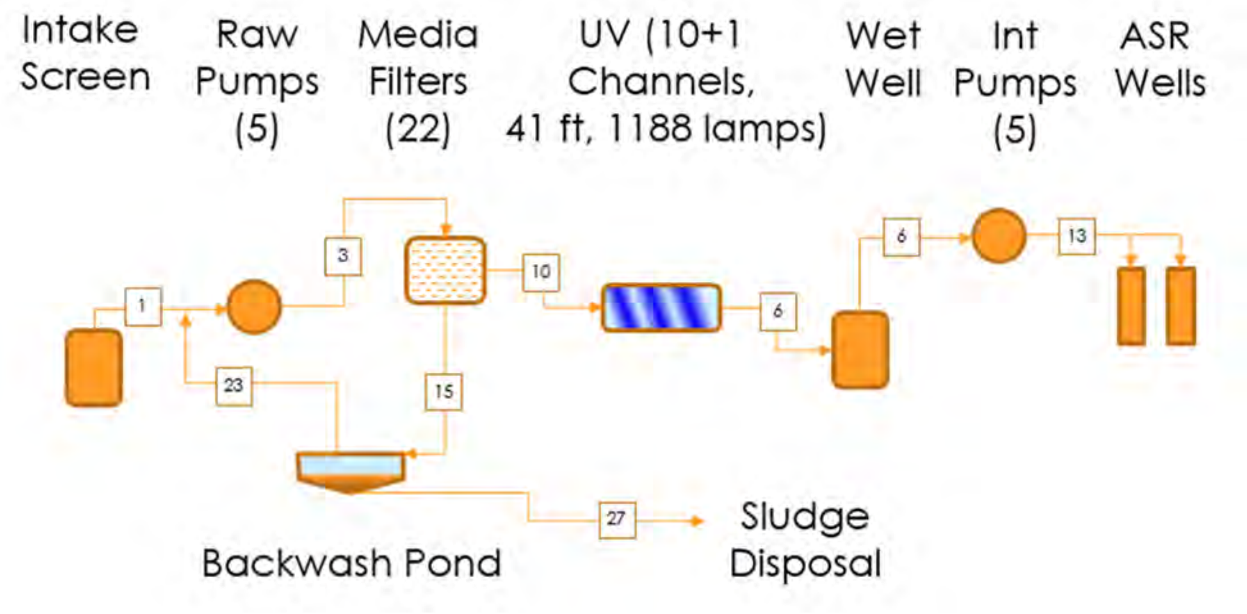


Figure 5-1 Alternative–1A - Media Filtration, UV Channel Disinfection

5.1.2 Alternative 1B – 2 Stage Media Filtration, Coagulation, UV Disinfection

Alternative 1B is similar to Alternative 1A with intake screening, raw water pumping, and media filtration (pressure vessel type). However, Alternative 2 separates filtration into two (2) stages. The first stage serves as roughing filters (16 vessels) while the second stage (18 vessels) provide fine (sand) media filtration. By separating these filters in series, coagulant addition prior to the second stage can more effectively remove DOC with fine media filtration.

This alternative would require a coagulant storage and feed system, capable of dosing approximately 40 mg/L to treat high DOC raw water, and tapering down as DOC levels recede through the season to reduce color and DOC conceptually to 70 PCU, or 10 mg/L. This alternative would require pilot testing to optimize coagulant dosing, and could require a polymer or acid storage and feed system. However, by reducing the filter loading rate from 6 gpm per square foot (gpm/sf) as seen at the KRASR site to approximately 4 gpm/sf for the roughing filter, and to 3 gpm/sf for the fine media filter, shearing of floc particles could be minimized. Substantial Color/DOC removal could be achieved with this alternative, and therefore has a lower potential for aquifer plugging, and could achieve a moderately higher UVT for disinfection. Since this process remains under pressure throughout the train, an intermediate pumping station is not necessary for storage.

One advantage of this alternative is the ability to reach the 40% minimum UVT necessary to open up competition to pressure vessel type UV manufacturers including Trojan, Wedeco, Calgon and AquaIonics. These will be more smaller lamps, with a greater total number of lamps required. For example, at 50 MGD buildout, 51 (50+1) Wedeco LBX1500 pressure vessels would be required with 60 lamps each to provide the required dose. This would require a total of 3,060 lamps with a total power draw of 1,062kW (over 2.5 times as many lamps as needed for Alternative 1A). Based on experiences with the KRASR site, district staff requested a cover be considered over the filter vessels and UV reactors as part of this alternative.

Advantages of alternative 1B are similar to alternative 1A in that it is operationally simple. When color levels are low, the chemical feed systems will remain in standby. However, during periods of marginal water quality, if color levels have not fallen to sufficient levels for direct filtration alone, the coagulant will provide O&M staff with the ability to treat and begin storing water earlier in the season than without. Also, as this process is capable of removing significant turbidity and dissolved solids, residuals management would be higher than other Alternative 1A. However, a backwash pond with decant pump could economically manage sludge dewatering. Alternative 1B would not meet secondary drinking water standards. The forward treatment process for Alternative 1B is illustrated in **Figure 5-2 Alternative 1B – 2 Stage Media Filtration, Coagulation, UV Disinfection.**

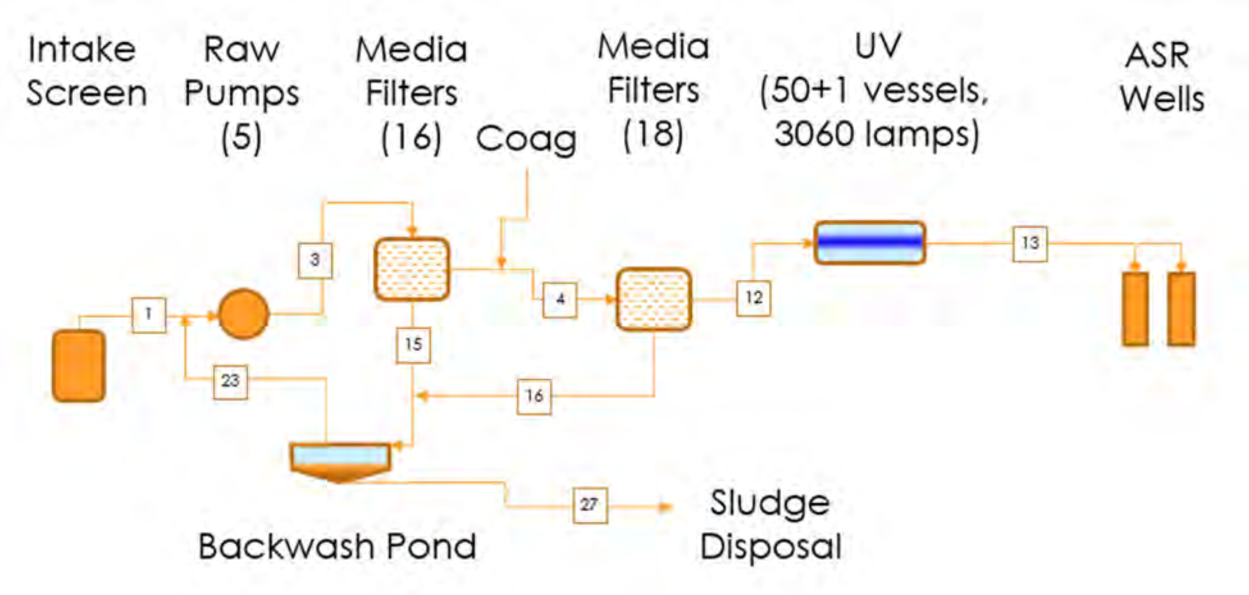


Figure 5-2 Alternative 1B – 2 Stage Media Filtration, Coagulation, UV Disinfection

5.1.3 Alternative 1C – Ion Exchange (MIEX), UV Disinfection

Alternative 1C consists of intake screening and raw water pumping, followed by Ion Exchange (MIEX). This alternative provides good color/DOC removal and therefore has a moderate potential for aquifer plugging compared to alternatives 1A and 1B. With improved color/DOC removal, alternative 1C could reliably achieve 40% UVT for disinfection. The importance of reaching this 40% minimum UVT with broken pressure (open basin) pretreatment is the ability to optimize channel UV disinfection which could meet disinfection requirements with a total of 660 lamps. This represents a reduction in the number of lamps required by alternative 1A by 45%. A shade structure over the channels and covers over the channels are recommended to minimize nuisance wildlife issues and minimize sunlight deterioration of equipment as observed at the KRASR site. However, the MIEX process involves a multi-story concrete deck structure which could become a home to wildlife if not enclosed.

Similarly, to alternative 1A, breaking pressure from closed pipes from the raw water pumps to an open basin for MIEX would necessitate construction of a wet well and intermediate pumping from the treatment process to ASR wells. Since this intermediate pumping station would be necessary, it would allow for either UV channel or UV pressure vessel technology.

Advantages of alternative 1C include reliable color/DOC removal, and only one chemical (salt) required for resin regeneration. However, the MIEX resin is a proprietary consumable which cannot be competitively sourced. Additionally, MIEX is considered by some operators to be a mechanically intensive process requiring maintenance of multiple subsystems, including resin regeneration, virgin resin feed, brine makeup and submersible mixers. The concentrated organic waste stream from this process would require disposal by deep injection well. Alternative 1C also would not meet secondary drinking water standards. The forward treatment process for Alternative 1C is illustrated in **Figure 5-3 Alternative 1C – Ion Exchange (MIEX), UV Disinfection**

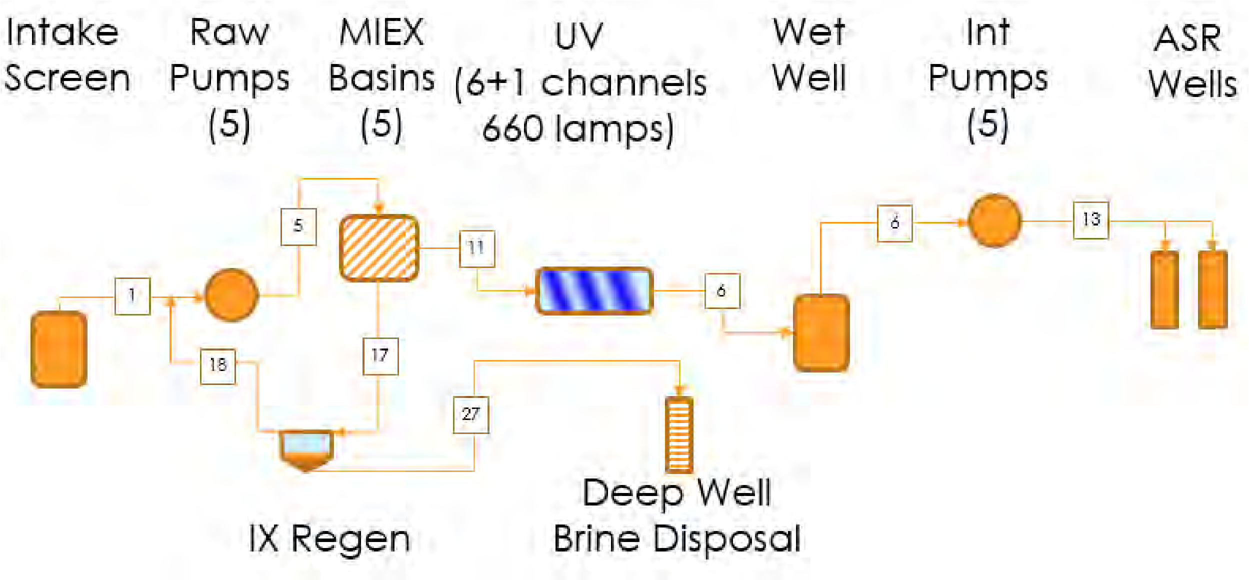


Figure 5-3 Alternative 1C – Ion Exchange (MIEX), UV Disinfection

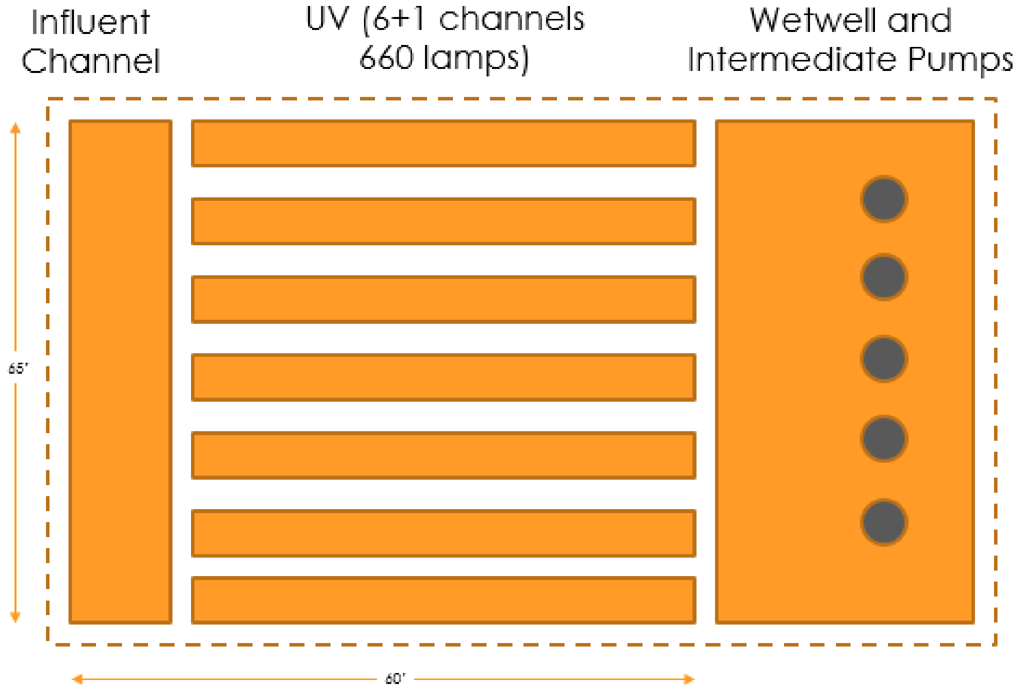


Figure 5-4 Alt–1C - UV Channel and Wetwell

5.1.4 Alternative 2A – Coagulation, Microfiltration/Ultrafiltration (MF/UF)

Alternative 2A consists of intake screening and raw water pumping to treatment. The MF/UF process excludes coliform size bacteria, so permeate and would not require additional disinfection (UV or chemical) to meet regulatory requirements. Similarly, to alternative 1B, this alternative would require a coagulant storage and feed system, capable of dosing approximately 30 mg/L to treat high DOC raw water, and tapering down as DOC levels recede through the season to reduce color and DOC conceptually to 70 PCU, or 10 mg/L. This alternative would require pilot testing to optimize coagulant dosing,

Since membrane permeate remains pressurized throughout the treatment process, alternative 2A does not require a wet well or intermediate pumping prior to storage. Additionally, with a 97% recovery rate, concentrate flows are significantly lower compared to filter backwash flows associated with alternative 1A and 1B.

Membrane backwash would be thickened prior to mechanical dewatering. Decant from the gravity thickener would be re-treated with membranes, while thickened sludge would be pumped to centrifuges. Centrate from this process would be similarly re-treated with membranes. Residuals management would be comparable or slightly less than alternative 1B based on overall efficiencies. With one of the smaller overall footprints, this process could also be enclosed in a building to protect it from nuisance wildlife issues.

Advantages of alternative 2A are that Ceramic MF/UF membranes are a reliable and proven process which can provide comparable Color/DOC removal to Alternative 1B. During periods of marginal water quality, if color levels have not fallen to sufficient levels for direct filtration alone, coagulant will provide O&M staff with the ability to treat and begin storing water earlier in the season than without. However, when color levels decrease through the rainy season, chemical feed systems can be turned off. This process provides a lower potential for potential aquifer plugging. Ceramic membranes are also not subject to the same type of manufacturing irregularities as polymer membranes and are warranted for a longer period. Ceramics may also be more resilient to re-starting after seasonal periods of standby. However polymer membranes are well proven at large scale and the two materials should be evaluated against one another to determine actual comparative benefits.

Membrane treatment process are considered by some operators to be mechanically intensive processes requiring maintenance of systems with significant instrumentation and controls and chemical cleaning systems. Alternative 2A would also meet secondary drinking water standards. The forward treatment process for Alternative 2A is illustrated in **Figure 5-5 Alternative 2A – Coagulation, Microfiltration/Ultrafiltration (MF/UF).**

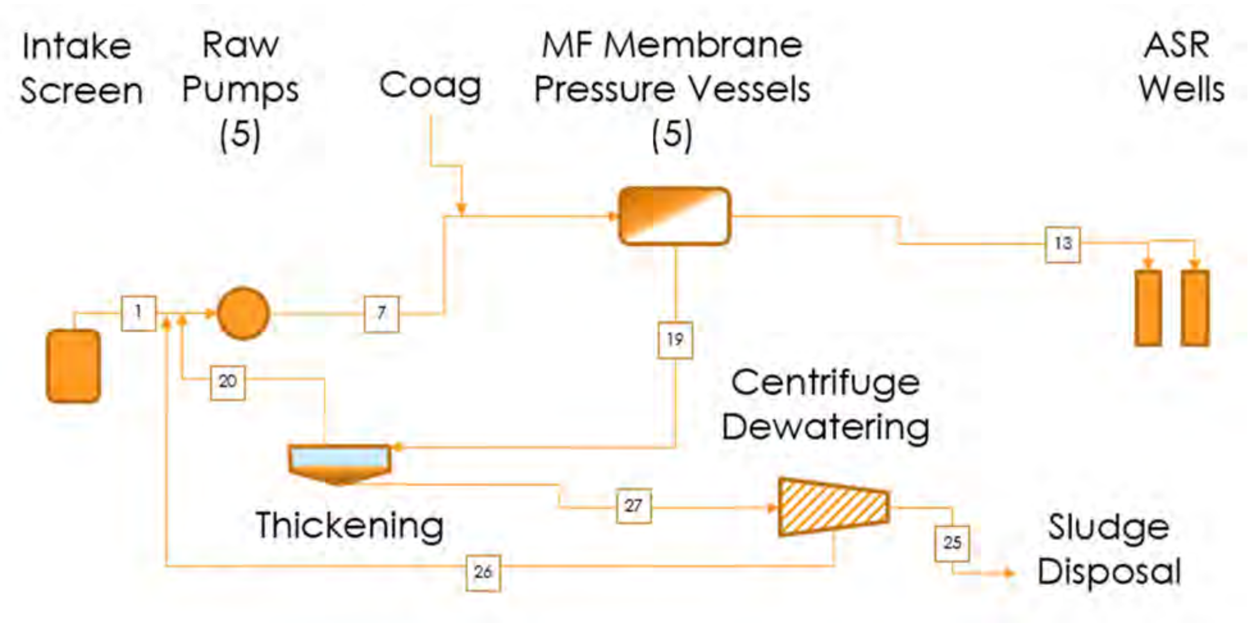


Figure 5-5 Alternative 2A – Coagulation, Microfiltration/Ultrafiltration (MF/UF)

5.1.5 Alternative 2B – Ultrafiltration, Nanofiltration

Alternative 2B consists of intake screening and raw water pumping, followed by straining, ultrafiltration and nanofiltration. This alternative considers submerged ultrafiltration membranes. Breaking pressure from closed pipes after the strainers to open basins for submerged membranes would necessitate intermediate pumping to pull through UF membranes, push through NF membranes and convey water to ASR wells. Similar to alternative 2A, the ultrafiltration process excludes coliform size bacteria, so permeate and would not require additional disinfection (UV or chemical). Strainer backwash and concentrate from the UF process would be directed to a backwash pond for dewatering, while high TDS concentrate from the NF process would require construction of a deep injection well.

Advantages of this reliable and proven process include excellent Color/DOC removal, lowest potential for aquifer plugging, and no coagulant. Residuals management for alternative 2B would be comparable to alternative 1B. Unfortunately, due to the lower recovery of polymer UF and NF membranes than ceramic MF membranes in Alternative 2A, sizing of upstream processes flows is nearly 64 MGD. Furthermore, this process has the highest capital cost and energy costs with pumping for alternative 2B are the highest of all considered.

The forward treatment process for Alternative 2B is illustrated in **Figure 5-6 Alternative 2B – Ultrafiltration, Nanofiltration.** Equipment proposals, including UF and NF membranes from Suez are included in **Appendix C**.

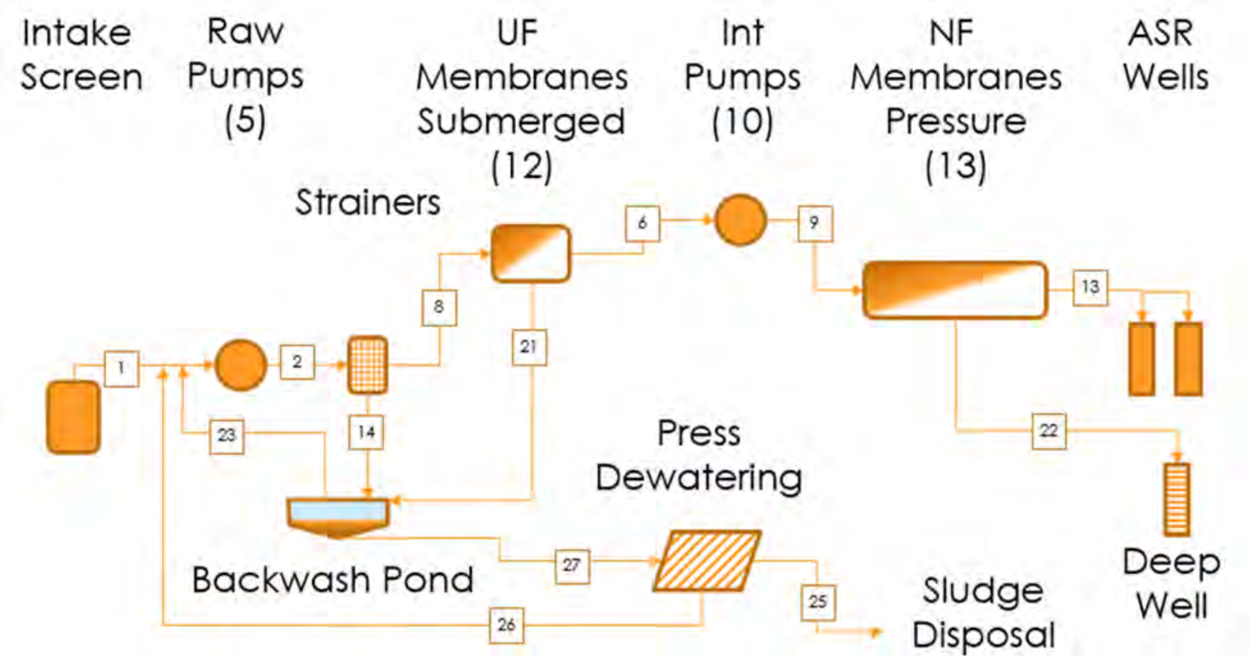


Figure 5-6 Alternative 2B – Ultrafiltration, Nanofiltration

5.2 ANCILLARY PROCESSES

All treatment technologies will require similar ancillary processes including raw water screening and pumping.

5.2.1 Screening

Raw Water screening technologies including intake and exclusion of wildlife, and ecological impact are discussed in Section 6. A conceptual approach raw water pumping is partially illustrated below and more fully detailed in **Figure 6-5 Intake DesignTM-SK-S01A.**

5.2.2 Pumping

5.2.2.1 Raw Water Pumps

Raw water pumps at each site will draw water through the intake screen and convey it to the treatment process downstream. Vertical turbine pumps are recommended over axial flow pumps for higher efficiencies. The pump station could be isolatable with a slide gate for dewatering and maintenance access. Sizing of these pumps would be dependent on the downstream treatment process head requirement. A conceptual raw water pump station is illustrated below as **Figure 5-7 Raw Water Pump Station.**

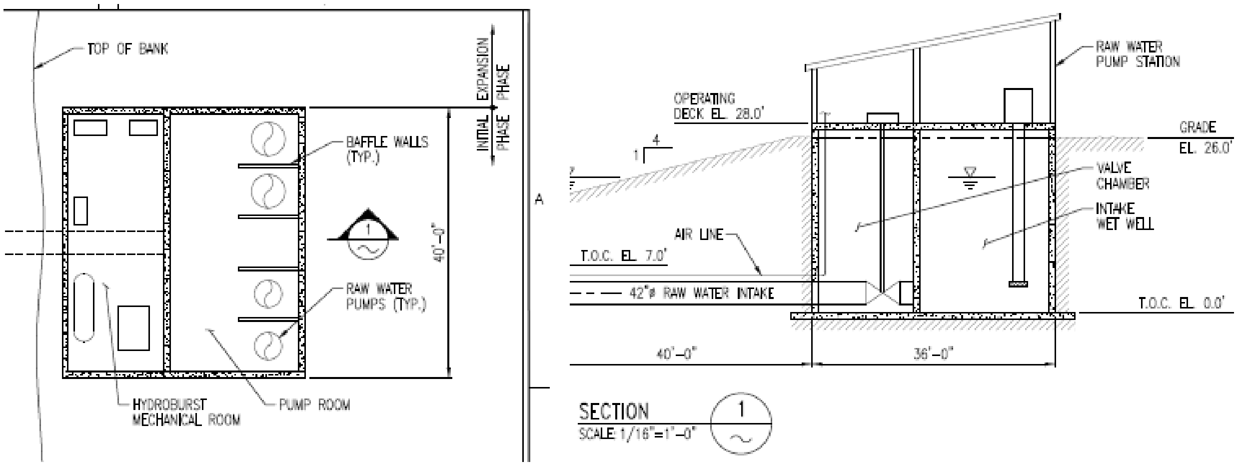


Figure 5-7 Raw Water Pump Station

5.2.2.2 Intermediate Pumps

For treatment process which involve open basins, including channel UV disinfection, MIEX, or submerged membranes, intermediate pumps would be needed to convey water downstream to treatment processes, through pipelines and to overcome artesian well pressure for storage. From the preliminary Phase I design for C-38S Kissimmee River site, a length of 2800 feet was estimated from a centralized treatment system site (orange) to the farthest well pair. For head loss calculations, 36, 30 and 24-inch pipe sizes were assumed. Potential routing of this piping is illustrated in **Figure 5-8 C-38S Conceptual Piping from Treatment to ASR Wells.**

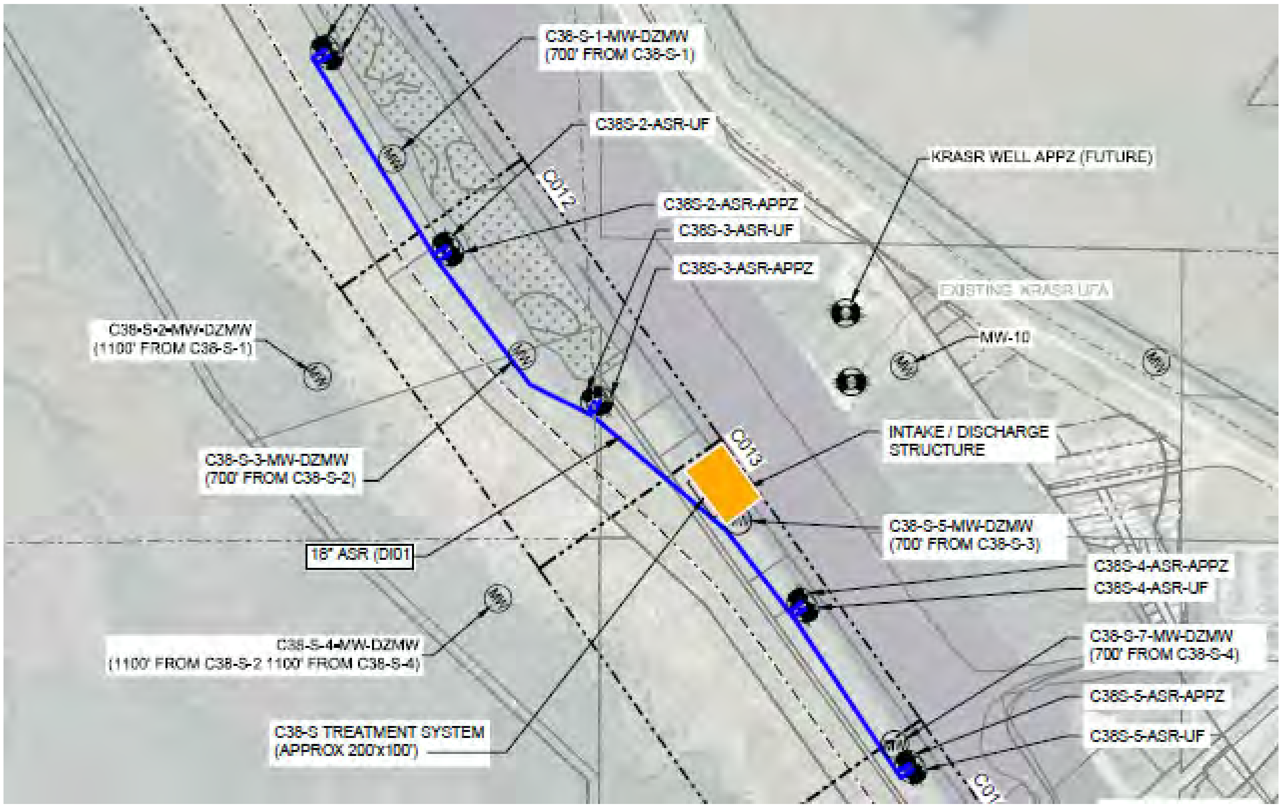


Figure 5-8 C-38S Conceptual Piping from Treatment to ASR Wells

Intake, piping and other major head losses estimated through alternative treatment processes are summarized in terms of TDH, flow and motor horsepower in **Table 5-3 Raw and Intermediate Pumps by Treatment Train.** Pump curves and manufacturer pump data sheets are included in **Appendix C**.

Table 5-3 Raw and Intermediate Pumps by Treatment Train

Process/Treatment Alternative	**Approximate Head (ft)**				
	Alt 1A	**Alt 1B**	**Alt 1C**	**Alt 2A**	**Alt 2B**
	Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, Ceramic MF	UF, NF
Intake/Screen to CL pretreatment	3	3	3	3	23
Media Filtration (single stage)	15	15			
Media Filtration (second stage)		15			
UV Disinfection (pressure vessel)		20			
Tank Head (MIEX or membrane)	10		30		10
Ceramic MF Membranes				80	
Poly UF Membranes					40
Poly NF Membranes					230
Piping to Farthest ASR Well Pair	22	22	22	22	22
Artesian Well Pressure	20	20	20	20	20
Subtotals					
Raw Pumps Head	**28**	**95**	**33**	**125**	**33**
Raw Pumps Flow (MGD)	53.95	59.41	50.04	51.94	71.40
Motor Horsepower	75	300	100	300	125
Intermediate Pumps Head	**42**		**42**		**313**
Intermediate Pumps Flow (MGD)	50		50		58.12
Motor Horsepower	100		100		500

5.2.2.3 Recovery Pumps

Artesian pressure at the wellhead was assumed to be 20 ft. Head losses from the farthest well pair to the discharge structure were estimated as 20 ft. While artesian pressure alone may be enough for recovery of 5 MGD per well initially, diminishing artesian pressure over time may limit flow. Therefore, recovery pumps were sized for 5 MGD assuming no artesian pressure. Design criteria for recovery pumps are summarized below in **Table 5-4 Recovery Pump Design Criteria**.

Table 5-4 Recovery Pump Design Criteria

Criteria	Rating
Recovery Pump Head (ft)	23
Recovery Pump Flow (MGD)	50
Motor Horsepower (HP)	100

5.2.2.4 Pump Drives

Discussions with field staff have indicated a district preference for constant speed motors over VFDs. It is also understood FPL requires reduced voltage soft starters for motors and would be provided for raw and most intermediate pumps. However, for Alternative 2B, intermediate pumps will be needed to compensate for diminishing flux through UF and NF membranes. For this reason, these intermediate pumps would require VFDs. Recovery pump motors could also be outfitted with VFDs to match pumping capacity to the diminishing specific capacity of each ASR well. However, this is not a project requirement, and flow could be trimmed with throttling valves.

5.3 TREATMENT PROCESS FOOTPRINT

The area required by treatment process for each alternative considered is summarized in **Table 5-5 Treatment Process Footprint.** Lower total footprint areas (green) were considered more favorable than process requiring greater area.

Table 5-5 Treatment Process Footprint

Process/Building Description	Treatment Process Alternative Area (sq ft)				
	Alt 1A	**Alt 1B**	**Alt 1C**	**Alt 2A**	**Alt 2B**
	Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, Ceramic MF	UF, NF
Filtration/Color Removal					
Strainers					1,280
Media Filters	26,400	40,800			
Coagulation		900		900	
Ion Exchange (IX)			20,400		
MF/UF Membrane Filtration				15,200	9,600
NF Membrane Filtration					5,400
CIP System				1,500	1,500
Disinfection					
UV (channel)	5,750		3,750		
UV (reactor)		6,000			
Ancillary Processes					
Raw Water Pumps	1,800	1,800	1,800	1,800	1,800
Intermediate Pumps	4,000		4,000		4,000
Electrical Room	2,500	2,500	2,500	2,500	2,500
Control Room	625	625	625	625	625
Waste					
Backwash Pond	17,600	16,000			20,800
Dewatering			1,800	1,800	
Subtotal of Process Buildings	59,000	69,000	33,000	24,000	48,000
Roads, Parking, Access (10%)	5,900	6,900	3,300	2,400	4,800
Total Footprint	**64,900**	**75,900**	**36,300**	**26,400**	**53,900**

As can be seen in Table 5-5, Alternative 1B required the greatest amount of land to construct. This is not particularly surprising as the Alternative 1B requires approximately 50% more filters than alternative 1A.

Alternative 2A required the least amount of land to construct. Alternative 2B, UF-NF requires approximately 100% more land than alternative 2A. Footprint areas were scored inversely in relation the smallest alternative (2A), which was scored as 10/10 in section 5.4.

5.4 STAFFING

Staffing requirements vary by alternative with more complex processes require greater staffing levels for administrative tasks, operations, maintenance of equipment, and supervision. It is assumed that when in operation, these facilities will be operated 24-hrs/day, requiring shift work. Lower staffing requirements (green) were considered more favorable than process requiring greater staffing.

Table 5-6 Staffing Requirements by Alternative

Labor Rates and Positions	**Staffing Requirement (FTEs) and Approximate Rates**				
	Alt 1A	**Alt 1B**	**Alt 1C**	**Alt 2A**	**Alt 2B**
	Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, Ceramic MF	UF, NF
Administrative, Janitorial, Direct Rate	$40,000	$40,000	$40,000	$40,000	$40,000
No. of Administrative Assistants	1	1	1	1	2
Technician Direct Rate	$55,000	$55,000	$55,000	$55,000	$55,000
No. of Technicians (Maint, Elec, I&C)	4	5	5	4	6
Operator Direct Rate	$65,000	$65,000	$65,000	$65,000	$65,000
No. of Operators (Field, Central)	3	3	4	4	6
Supervisors Direct Rate	$95,000	$95,000	$95,000	$95,000	$95,000
No. of Supervisors	2	2	2	2	2
No Total Staff	**10**	**11**	**12**	**11**	**16**

These requirements were developed as a guideline in considering operating water treatment processes, and may slightly vary by classification of employee, rate and number. Some staffing requirements may be able to be spread across multiple facilities as additional LOWRP ASR sites are developed.

5.5 NON-ECONOMIC EVALUATION

Evaluation treatment technologies were also evaluated on the basis of non-economic criteria developed with participation of SFWMD staff using a weighting criterion. Criteria were adapted from the Screening of ASR Surface Facility Treatment Process (CH2M Hill, 2003) and additional criteria added.

Table 5-7 Non-Economic Criteria Weighting

Criteria	Description	Weighting
Color/Organics Removal	For UV disinfection to work well, UVT must be as high as possible. Color, associated with DOC, is a primary factor in causing low UVT levels. Filtration options which remove DOC will make downstream UV disinfection more effective. Furthermore, secondary drinking water standards require a maximum 15 PCU of color. Options that can meet this standard will have a higher rating.	15
Simplicity of Residuals Management	Due to the rural surroundings of Lake Okeechobee, it is not possible to dispose of waste stream residuals through a sewer for wastewater treatment. Therefore, the selection of methods which minimize chemical additions and reduce the quantity of waste produced is a significant consideration.	10
Operational Considerations	Treatment methods that require more regular maintenance are less favorable. This may be associated with more moving parts, chemical additions, and general lack of automation.	25
Staffing Requirements	Processes which require less operator and technician supervision are more favorable and score more highly than those which require more.	5
Minimal Risk for Aquifer Plugging	Processes which do not significantly remove suspended solids and turbidity and allow biogrowth to be passed downstream will, over time, begin to plug the formation and require well rehabilitation. These processes are less favorable than those which remove these constituents.	10
Process Reliability	Processes that are less likely to meet primary and secondary water treatment goals will have a lower rating in this category. The uncertainty primarily stems from lack of recent water quality information. Some filtration methods have better reputations at removing color than others. Additionally, some methods are newer, leading to more uncertainty about performance.	20
Environmental, Health and Safety	Processes which require significant chemical feed systems which would potentially impact the health and safety of workers, or the environment would score lower by this criterion. Processes which require deep well injection in addition to ASR wells also scored lower.	10
Constructability	Pretreatment processes which are modular, constructed without elevated structures and tanks can be constructed more quickly and would score higher by this criterion.	10
Footprint	Processes were compared against the treatment process with the smallest land area requirement for construction and scored in an inversely proportional manner.	10

Alternatives were scored based on these non-economic criteria and summarized in **Table 5-8 Treatment Alternative Non-Economic Scoring.** Higher scoring alternatives (green) are considered more favorable than lower scoring.

Table 5-8 Treatment Alternative Non-Economic Scoring

Non-Economic Criteria		**Process/Treatment Alternative**				
	Weighting	**Alt 1A**	**Alt 1B**	**Alt 1C**	**Alt 2A**	**Alt 2B**
Criteria		Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, Ceramic MF	UF, NF
Color/Organics Removal	15	0	8	9	8	10
Simplicity of Residuals Management	5	8	6	7	7	3
Operational Considerations	25	20	16	10	18	5
Staffing Requirements	5	5	5	4	5	3
Minimal Risk of Aquifer Plugging	10	0	8	6	8	10
Process Reliability	20	6	16	12	16	16
Environmental, Health and Safety	10	10	8	6	8	4
Constructability	10	8	7	5	9	4
Footprint	10	4	3	7	10	5
Subtotal	110	**61**	**77**	**66**	**89**	**60**

5.6 ADVANTAGES AND DISADVANTAGES

Advantages and disadvantages with treatment alternatives considered in Section 5 are summarized in **Table 5-9 Potential Treatment Train Advantages and Disadvantages.**

Table 5-9 Potential Treatment Train Advantages and Disadvantages

Process Train	Advantages	Disadvantages
ALT 1A Media Filtration, UV Disinfection	• Simple operation Environmental Health & Safety (no chemicals) • Lowest treatment efficiency means lowest residuals management required • Constructability • Lowest OPEX Cost • Second lowest CAPEX cost	• No Color/DOC Removal • Significant Potential for Aquifer Plugging • Lowest UVT for disinfection • Low process reliability and inconsistent disinfection at KRASR • Does not meet secondary standards
ALT 1B 2 Stage Media Filtration, Coagulation, UV Disinfection	• Relatively simple operation • Provides Color/DOC Removal to increase UVT for disinfection • Flexibility to treat marginal water quality earlier in the season • Environmental Health & Safety (only requires 1 chemical, coagulant)	• Requires 50% more filters than Alt 1A to operate in series. • Residual coagulant sludge significant • Highest Potential for Aquifer Plugging • Lower UVT for disinfection • Operationally challenging at KRASR (potentially due to filter loading rate) • Does not meet secondary standards • Highest CAPEX cost • Second highest OPEX cost

Process Train	Advantages	Disadvantages
ALT 1C Ion Exchange, UV Disinfection	• Good Color/DOC Removal • Environmental Health & Safety (only requires 1 chem, salt) • Better UVT makes optimized channel UV disinfection feasible • Lower Potential for Aquifer Plugging • Lowest CAPEX cost	• Complex in nature • Resin beads are consumable and proprietary • O&M intensive for recycle, recharge subsystems • Constructability • Requires deep injection well for organic brine waste disposal • Does not meet secondary standards • 3rd highest OPEX cost
ALT 2A Coagulation, Microfiltration/ Ultrafiltration (MF/UF Pressure Vessels),	• Better Color/DOC Removal • Low Potential for Aquifer Plugging • Ceramic membrane elements have higher life expectancy • Meets secondary standards • Smallest footprint • Treatment equipment could be easily enclosed with building • Minimal sludge handling • 2nd lowest OPEX cost	• Perceived as operationally complex • Environmental Health & Safety (requires 3 cleaning chem) • I&C intensive for O&M • Highest CAPEX cost • 3rd highest CAPEX cost
ALT 2B Ultrafiltration (Submerged Membranes), Nanofiltration (Pressure Vessel Membranes)	• Excellent Color/DOC Removal • Meets secondary standards • Lowest Potential for Aquifer Plugging • Reliable and proven process • No coagulant required • Disinfection credit (UV disinfection not required)	• Requires deep injection well for NF waste disposal • Environmental Health & Safety (requires 3 cleaning chem) • Operationally complex • Greatest energy demand • Highest CAPEX • Highest OPEX cost

6.0 ECOLOGICAL CONSIDERATIONS FOR INTAKE AND DISCHARGE

6.1 REGULATORY FRAMEWORK FOR INTAKE DESIGN

There are no codified regulatory requirements related to intake screening for ASR facilities other than comment and recommendation letters provided by FWC and FDEP on a project specific basis. In lieu of regulations specific to ASR's, industry practice is currently guided by Section 316(b) of the US Clean Water Act (CWA) which regulates the withdrawal of cooling water for many power generation and industrial facilities which utilize intake water for cooling purposes. For a facility to be subject to Section 316(b) rules, the source waterbody must be "waters of the US" and at least 25 percent of the water being withdrawn must be designated use exclusively for cooling. The proposed ASR well systems do not meet the criteria for regulation under Section 316(b); however, the objective of the Section 316(b) regulations is to ensure large water users are utilizing the best technology available (BTA) for minimizing impingement mortality and entrainment impacts from the water withdrawals and as such, the Section 316(b) standards have been used by water managers as guidelines for the selection of water intake BTA for other facilities that may not be regulated under the federal Section 316(b) rules.

The Section 316(b) rules are prescriptive in their assessment of BTA for the reduction of impingement mortality. Of the seven (7) technologies and operational measures listed as BTA for impingement, only two are directly applicable for the proposed ASR systems. These BTA options include operating an intake structure with a maximum through-screen velocity of 0.5 ft/sec. or the operation of a modified traveling water screen (MTWS) which includes a fish handling and return system.

Under Section 316(b), if a facility chooses to comply with the impingement standards by installing MTWS, an optimization study must be conducted to ensure the MTWS are installed and operated in a manner to achieve the greatest reduction in impingement mortality for non-fragile species. Fragile species are defined as those species that have an impingement survival rate of less than 30 percent based on prior impingement studies (40 CFR §125.92(m)). These fragile species, including gizzard shad and other clupeid species, are generally expected to exhibit high mortality rates from the process of being impinged on an intake screen and transported within an organism return system, regardless of the efficiency of the system operation. This is notable for the proposed ASR systems due to the relative abundance of gizzard and threadfin shad in the ASR system source waterbodies.

Entrainment reduction BTA is not as explicitly defined in the Section 316(b) regulations; instead, the appropriate regulatory permit issuers (i.e. FDEP) are required to evaluate entrainment BTA on a site-specific basis. However, there are certain criteria and alternatives that must be evaluated, including the use of fine mesh screens with a mesh size of 0.08 inches (2.0 mm) or smaller.

Since the proposed ASR well systems do not meet the criteria for regulation under the Section 316(b) rules, and there are no explicit regulations or ecological standards for minimizing impingement mortality and entrainment impacts for non-cooling water withdrawals such as ASR systems. In the absence of codified regulation, it is anticipated that regulators will use BTA guidance under Section 316(b) as a “benchmark” when evaluating the ASR system. With this understanding, and consistent with the Kissimmee ASR Pilot Project, intake screen options presented in this evaluation are based on through-screen velocity of 0.25 fps and mesh size of 0.04 in (1.0 mm) in which exceed the standards presented in the Section 316(b) rules.

6.1.1 Source Water Species Evaluation

Surface water withdrawals may have ecological impacts when aquatic organisms are drawn into the water intake (entrainment) or trapped against a screen or other exclusionary device (impingement). To assess the effectiveness of various intake design alternatives in reducing impingement mortality and entrainment impacts, it is important to evaluate the species present in the source water.

During a 2007 baseline study to determine the fish community structure at four (4) pilot ASR sites (Caloosahatchee River, Kissimmee River, Moore Haven, and Port Mayaca within the St. Lucie canal), the FWC identified a total of 47 fish species at these sites. The majority of fish sampled (approximately 81 percent) were from families important to the recreational and commercial fisheries in Lake Okeechobee (Tetra Tech, 2007). To help inform intake coarse screen design criteria and equipment selection, the information below provides some species-specific morphological, life history and spawning habitat information of select recreational, commercial, and baitfish species at the proposed ASR sites that may be impacted by intake structures.

Black crappie (Pomoxis nigromaculatus) is an important recreational species in the Lake Okeechobee watershed and was noted by the FWC as a vulnerable species during the previous, limited entrainment studies at the Kissimmee River Aquifer Storage and Recovery (KRASR) well system. Black crappie can spawn year around in Florida due to the warm waters but have been found to primarily spawn from January to May in Lake Okeechobee (FWC, 2017). Spawning occurs in shallow waters protected by dense vegetation where nests are established in colonies over clay, sand, or muddy bottom that support rooted vegetation. The eggs sometimes attached to the root bases of the vegetation (FWC, 2019) (FWC, 2017). The FWC has found that after the channelization of the Kissimmee river, a favorite spawning location for Lake Okeechobee black crappie is within C-38 south of S-65E (FWC, 2017). Black crappie eggs are approximately 0.04 in (1.0 mm) in diameter or less and are heavy and adhesive; eggs are deposited in benthic nests or attached to submergent vegetation, as noted above (Currier, 2018) (FWC, 2019). Approximately 2 to 3 days after fertilization, the eggs hatch and the larval black crappie remain in the nest for several days until they can swim and hunt successfully, at which point they move to deeper waters in the middle of channels (FWC, 2017). Black crappie larvae range from 0.08 to 0.2 in (2.0 to 5.1 mm) in length and are poor swimmers; not known to swim faster than 0.5 ft/sec (USACE, 2004). Fry move vertically throughout the water column primarily to forage on other planktonic species and secondarily to avoid predation while following the currents downstream into Lake Okeechobee (FWC, 2017).

Bluegill (Lepomis macrochirus) and redear sunfish (Lepomis microlophus) are also important recreational species in the Lake Okeechobee watershed. Bluegill spawn once lake waters warm to between 70 to 75

°F, which is usually from March to September. Male Bluegills create nests in colonies in shallow waters (1 to 5 ft deep) in sand or fine gravel similar to black crappie (Murdy, Baker, & Musick, 1997). Bluegill eggs range in size from 0.05 to 0.06 in (1.3 to 1.5 mm) and are adhesive in nature (Oplinger & Wahl, 2014). When the eggs develop into larvae, they range from 0.20 to 0.22 in (5.1 to 5.6 mm) in length (Meyer, 2011) and are not known to swim faster than 0.5 ft/sec (USACE, 2004). Redear sunfish are similar, having egg diameters that range from 0.05 to 0.06 in, which develop into larvae ranging in length from 0.20 to 0.23 in (5.1 to 5.8 mm) (Meyer, 2011).

Largemouth bass (Micropterus salmoides) is another important recreational species in the Lake Okeechobee watershed and the largemouth fishery has historically supported economically important tournaments on the lake. Largemouth bass spawn in late winter to early spring in a similar manner as both black crappie and bluegill. Males fan a nest to protect the egg, however, largemouth bass prefer hard packed sand and gravel for nesting in water depths of 2.0 to 6.6 ft (Steed, 2018). Largemouth bass have an egg diameter of 0.06 to 0.07 in (1.5 to 1.8 mm) that that adhere to plant material (Meyer, 2011). The fry, at hatching, are 0.16 to 0.24 in (4.1 to 6.1 mm) in length and stay in the nest for 7 to 10 days where they will then absorb their yolk sac and begin to swim and feed on their own (Steed, 2018) (Davis & Lock, 1997). Swimming speed of largemouth bass has not been well studied and available information is concentrated on larger fish (for purposed of targeting fishing methods). General guidance provided in a 1997 study indicates that largemouth bass are able swim at speeds up to 2.5 times their body length per second (Davis & Lock, 1997), though it is assumed that this guidance was applicable to fully developed individuals.

Sunshine bass is a hybrid between a white bass (Morone chrysops) and striped bass (Morone saxatilis) and is the only stock enhanced fisheries species that is introduced to the Lake Okeechobee watershed via the Lower Kissimmee River by the FWC (Personal communication with FWC, 2020). Studies have shown that swimming speeds of larval striped bass can range from 0.02 to 0.09 ft/s for critical burst speed for pre-feeding (1 to 5 days post-hatch) larvae to 0.06 to 0.10 ft/s for sustained swimming (i.e. during 1-hour tests) for striped bass larvae sized 0.24 to 0.35 in total length (Meng, 1993) (Peterson & Harmon, 2001). However, as sunshine bass are stocked by FWC, the size at which these fish would be introduced to Lake Okeechobee waters is expected to be much larger, and therefore their swimming ability is much more developed. Similarly, because they are a socked species, the susceptibility of sunshine bass eggs may not be a concern, as primary spawning occurs outside of the watershed.

Catfish, including channel catfish (Ictalurus punctatus) are part of the “catfish” complex that makes up the only commercial fishery in Lake Okeechobee. Channel catfish spawn in spring and early summer, where males will choose to nest in weedy vegetation near the lake’s shores under rocks or an undercut bank. Channel catfish eggs are very adhesive and range from 0.09 to 0.12 in (2.3 to 3.0 mm) in diameter (Chapman, 2018).

The **brown bullhead** (Ameiurus nebulosus) is another catfish species that is commercially fished in Lake Okeechobee. This species nests in late spring to early summer in shallow mud or sand near abundant aquatic vegetation with 0.09 to 0.11 in (2.3 to2.8 mm) diameter eggs and hatched larvae approximately

0.16 to 0.31 in (4.0 to 7.9 mm) long (Scott & Crossman, 1973). Brown bullhead has similar life history attributes to the other catfish species (Ictaluridae) that are commercially fished in the lake.

Threadfin shad (Dorosoma petenense) are an abundant species in the Lake Okeechobee Watershed and the primary forage food for many predators including adult black crappie (FWC, 2017). Threadfin shad broadcast spawn primarily from April through September in open water over vegetation so that their adhesive eggs, which range in size from 0.03 to 0.05 in (0.8 to 1.3 mm) diameter, can adhere to plant material (Wallus, Yeager, & Simon, 1990). Larval threadfin shad range from 0.12 to 0.20 in (3.0 to 5.0 mm) (Tomljanovich & Heuer, 1986) and are generally known as pelagic midwater dwellers and move in large schools (Wallus, Yeager, & Simon, 1990).

Gizzard shad (Dorosoma cepedianum), like threadfin shad, are an abundant species in the Lake Okeechobee watershed; however, have varying morphological characteristics and spawning habitats. Gizzard shad are upstream open water spawners that prefer sandy and rocky substrate that their eggs can adhere to. Gizzard shad egg size ranges from 0.007 to 0.03 in (0.2 to 0.8 mm) diameter (Michaletz, 1998). Gizzard shad larvae are most abundant in surface waters as they are herbivorous filter-feeders (Jones, Martin, & Hardy, 1978) with a larval size similar to that of threadfin shad at approximately 0.13 in (Cooper, 1978). Both threadfin and gizzard shad are assumed to swim at a speed of 0.03 to 0.26 ft/sec, similar to that of other clupeids, including Alosa spp. (Klumb, Rudstam, & Mills, 2003).

6.1.1.1 Fish Species Relative Abundance

The FWC has conducted fisheries surveys in Lake Okeechobee for many years. These sampling efforts help define the community structure and can provide insight into the relative abundance trends for the species sampled. Primary sampling methods used include electrofishing and otter trawl surveys, as well as creel surveys of anglers on the lake. Data presented below was provided by the FWC and includes the fall community electrofishing and fall trawl surveys for the eleven-year period from 2009 to 2019. Fall community electrofishing sampling was conducted at three (3) randomly selected sites within 22 fixed polygons. The fall trawl surveys consisted of 27 fixed site samples with two (2), 10-minute tows at each site as well as directed trawl surveys near the mouth of the Kissimmee River targeting black crappie. The graph below presents the fall community electrofishing data for the period from 2009 to 2019 (**Figure 6-1**). Threadfin shad had the highest catch per unit effort (CPUE) in eight (8) out of the 11 years from these samples. The shad abundances were boosted by very high catch rates in 2016 and 2017. Bluegill had the highest CPUE in the years that threadfin shad did not dominate and their abundance remained fairly consistent otherwise.

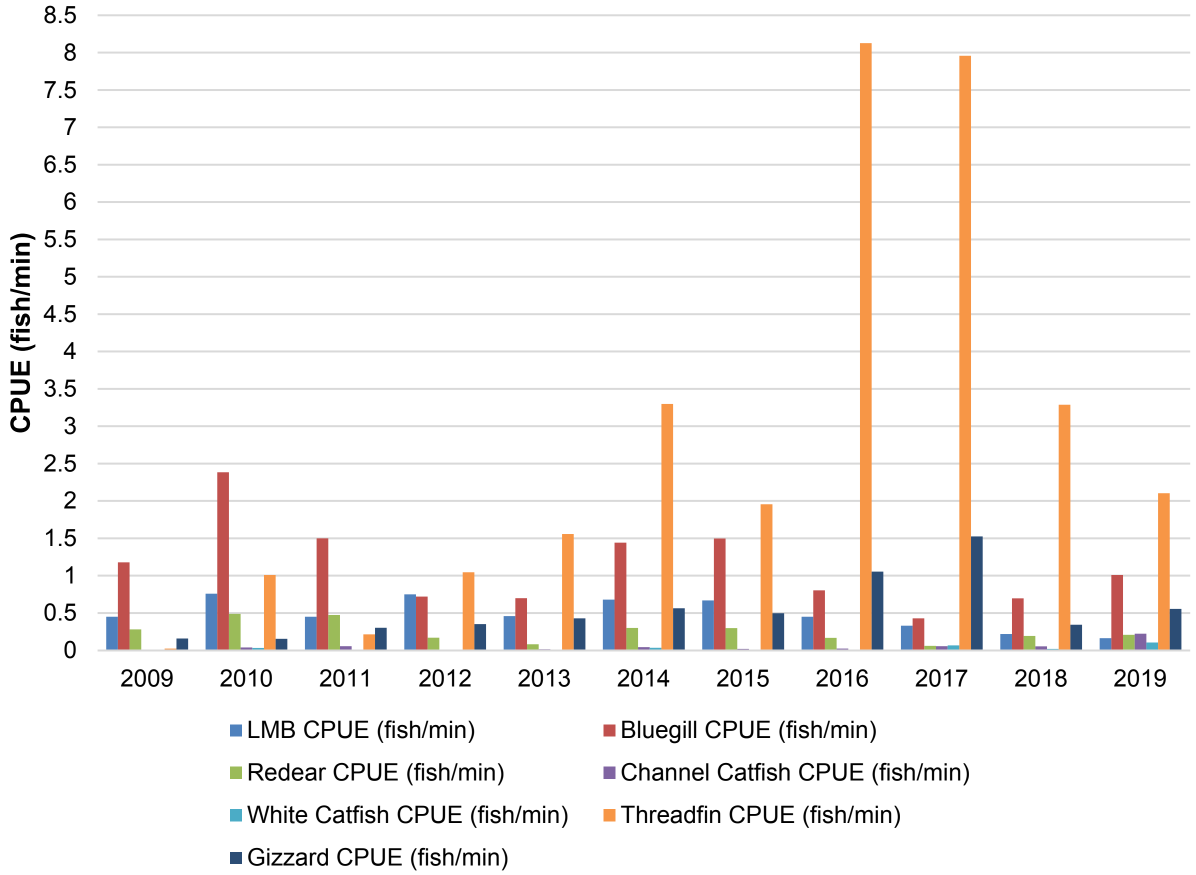


Figure 6-1 FWC Fall Community Electrofishing

Threadfin shad again had the highest CPUE in more than half of the fall trawl surveys, with both threadfin and gizzard shad having very high catches in 2010. The trawl data in the graph below (**Figure 6-2**) includes the black crappie surveys and shows that the CPUE for black crappie was comparable to threadfin shad populations for most years except for 2009, when crappie catch was the lowest in the dataset, and 2010 when threadfin shad CPUE was disproportionally high, as described above.

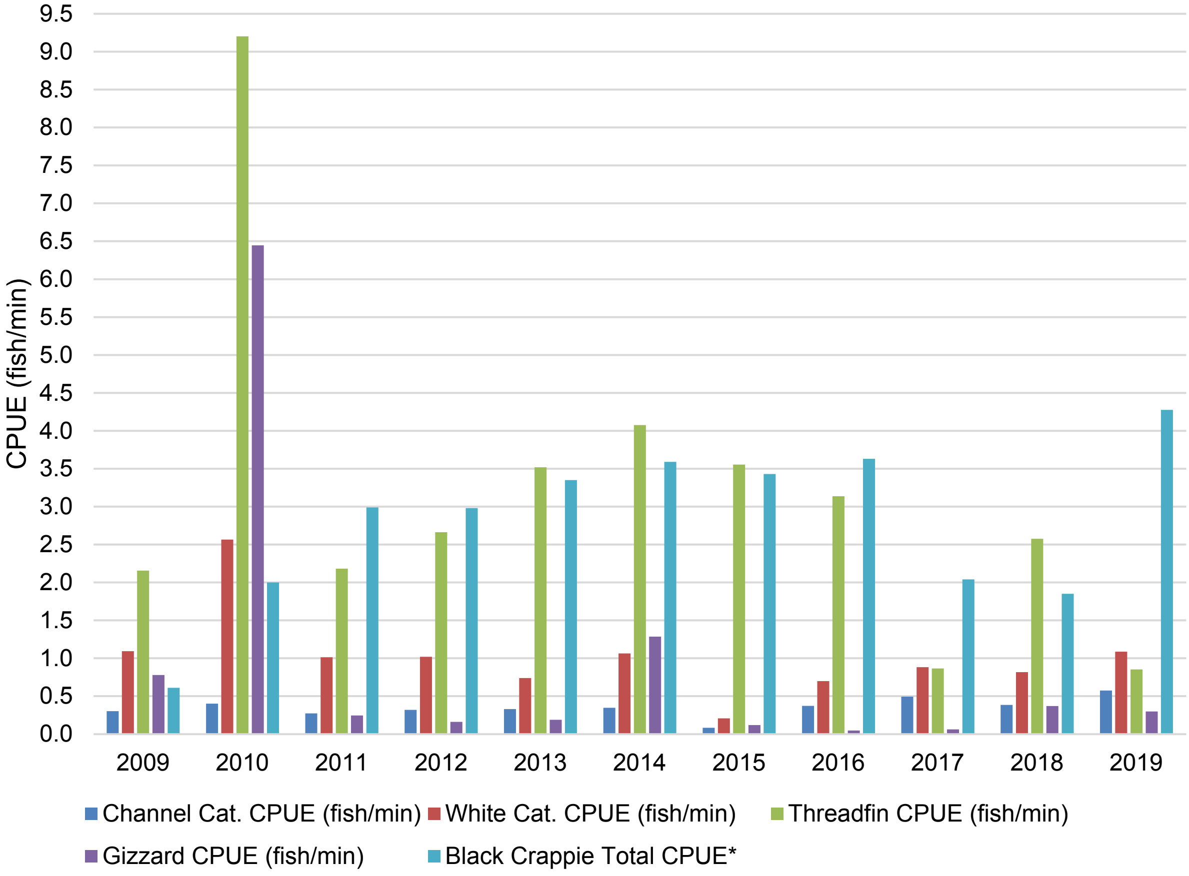


Figure 6-2 FWC Community Trawl CPUE

6.2 INTAKE DESIGN

6.2.1 Intake Exclusion Technologies

The intake structure is the point at which water is withdrawn from the source waterbody and conveyed to the suction side of the raw water intake pumps. In addition to water conveyance, the intake structure provides the initial course screening to reduce the quantity of solids, organic matter, and aquatic life entering the facility trough the raw water intake. There are several types of coarse screen technologies that can be considered, each developed to address specific site conditions and operating constraints. The purpose of this evaluation is to identify course screen technologies potentially suitable for the ASR system, identify screen technology characteristics that are compatible with site constraints, and identify screen technologies that have been short-listed for further evaluation and refinement based on project selection criteria.

The five sites identified as part of this technical memorandum (C-38N, C-38S, L-63N, S-191,and L-63S) present slightly different site characteristics with respect to available water depth, channel width, and crossing flow, but generally fall into the category of freshwater “stream”, with crossing flow across the intake, moderate water depth, minor water level fluctuation, and gently sloping channel banks. The primary site characteristics and design criteria for each of the five sites is provided in **Table 6-1 Key Site Features and Water Levels Pertinent to Intake Screen Evaluation** in later sections of this document.

For the purposes of evaluating possible coarse screen technology options, the intake structure for each site is considered to function as a gravity flow system. This system includes construction of a new open wet well located adjacent to the top of bank to serve as the pump suction reservoir (wet well), and inlet structure projecting into the channel as needed to provide adequate water depth for the operating constraints of the selected coarse screen technology, and means of conveying water from the intake screen to the wet well. To determine whether a screen technology should be short-listed for further evaluation, the following project selection criteria (as identified in the statement of work) was utilized:

- Simplicity of system operation and maintenance
- Compliance with UIC, NPDES, and 404 permit standards
- Capital cost of construction and operation
- Power and electrical requirements
- Prevention of entrainment and entrapment [impingement] of sensitive species
- Compliance with narrow logistical siting configurations
- Scalability and modularity

Based on our experience, four course screen technologies were identified as potentially suitable for the proposed ASR well raw water intakes as listed below. Note that MTWS were not included in this list of options for initial consideration due to SFWMD familiarity with such equipment and MTWS inability to meet project specific selection criteria due to increased level of operations, maintenance, power demands, and ongoing effectiveness studies required to implement MTWS.

- Infiltration Galleries and/or Radial Collector Wells
- Stream Bed Filtration
- Aquatic Filter Barriers
- Fine Mesh Static Screens

In the subsections below, each of these coarse screening technologies is described in general terms to include primary features, known limitations, prior experience, and evaluation against project selection criteria to identify which are suitable for consideration as short-list options for further evaluation. More detailed information about each technology can be found in **Appendix C**.

6.2.1.1 Infiltration Galleries and/or Radial Collector Wells

Infiltration galleries are a form of bank filtration (BF) that utilizes the natural filtration properties of the local geology to remove particulates from surface water as its pulled through sediments to a horizontal screen system. The pressure differential caused by pumping through the horizontal screen will induce flow from a nearby surface water source through an embankment prior to entering the screen gallery. Infiltration through the embankment mechanically filters the water by retaining suspended particulates in the sediment. BF can also remove various heavy metals and trace elements by sorption. However, this method relies on the quality of the sediment of a given embankment, and in the Lake Okeechobee ASR well areas, the sediment is composed primarily of fine sand and silt. The transmissive properties of the fine and silt is relatively low and prone to plugging with fines during the operation of the BF system. As a result, BF is not a feasible option as an intake alternative.

Radial collector wells draw water through horizontal screen laterals (sometimes spaced vertically at various depths) along a single vertical shaft (caisson) that helps reduce well drawdown in comparison with traditional vertical wells. The design of the length of the laterals and the selection of screen slot sizing will vary by application. Long laterals will reduce intake velocity through the screen, which will decrease the speed of clogging and associated head losses. This helps to reduce necessary maintenance. Typically, this technology is used to draw water directly from an aquifer with good local recharge. Similar to infiltration galleries, the laterals are prone to plugging as particles are trapped in the sediment surrounding the laterals. In most areas where radial collector wells are utilized, the overlying sediment tends to be coarse grained and, in many cases, the river is prone to scouring the bottom sediments, which helps remove the buildup of fines. At the Kissimmee River and other canals in the area, the flow velocities are low with minimal scouring potential. As a result, plugging of the bottom sediments will result in significant reduction in the collector well capacity.

Currently, the geotechnical information available for the two ASR sites is insufficient to perform a site-specific evaluation for bank filtration; however, the previous “Technical Memorandum – Site Testing and Supplemental Modeling for a Bank Filtration System at the Seminole Brighton ASR Pilot Project” prepared by Entrix, Inc. for the District in June 2009 can be referenced to help assess the feasibility of the technique for the C-38N, C-38S, L-63N, L-63S, and S-191 sites. Further consideration and development of these systems would require a well field investigation to characterize the aquifer properties to determine the number, size, depth and configuration of wells needed as well as estimated costs for operation and frequency of redevelopment.

The infiltration gallery bank filtration model described in the Entrix report included a 25-ft deep canal with a compound side slope varying from 4H:1V to 2H:1V. The model assumed the slope material was excavated and replaced with sand having a horizontal hydraulic conductivity of 50 ft/day. Given these parameters, Entrix calculated a horizontal well installed in the modified bank would collect 0.002 MGD/ft, 87% from the canal and 13% from groundwater. Intake of groundwater could potentially require a consumptive use permit. Assuming this configuration is applicable to the current sites, each site bank filtration system would need to produce 57.5 MGD at a required length of 28,730 ft (5.4 miles) to meet the requirement for drawing 50

MGD from the river per site. The almost 11 mile length of bank filtration system (infiltration gallery) required for both the C-38N and C-38S sites is illustrated in Figure 6-3

Figure 6-3 Infiltration Gallery length required for C-38 Treatment Sites

6.2.1.2 **Stream Bed Filtration**

Stream bed filtration is a system which utilizes layers of permeable rock and granular material as the intake screen. This system is similar to infiltration galleries and bank filtration systems, but instead of being installed shore-side and drawing groundwater, this system is installed on the stream bed to draw water directly from the source waterbody. In general, the system requires excavation or dredging of the existing stream bed for installation of perforated intake pipes and replacement of native stream bed material with stone and granular fill material with gradation selected to allow water to seep through the fill material instead of having a concentrated intake flow. To maintain sufficient inflow with very small seepage rates, the bed filtration must have a relatively large footprint, and some maintenance may be required for long-term performance as natural sediments accumulate and intake pipe openings clog over time. Stream bed filtration systems are more common on smaller applications and appear more often in larger lake environments.

Stream bed filtration effectively meets three of the seven project criteria. Once installed this is an extremely simple system to operate, requires very little short-term maintenance, does not require significant power or electrical systems for operation, and provides effective prevention of entrainment and entrapment if designed and installed properly. The criteria which stream bed filtration does not meet include high capital cost associated with in-water stream bed modifications and imported fill; high long-term maintenance cost if the filtration bed needs to be revitalized due to sedimentation or clogging; the need for large footprint which increases in direct proportion to increased intake flow; and potential regulatory hurdles associated with disturbance of stream bed habitat.

Due to the large footprint needed for a 50 MGD system, high capital cost, and anticipated regulatory hurdles associated with stream bed modification, stream bed filtration is not considered suitable as short-list option for further evaluation.

6.2.1.3 **Aquatic Filter Barriers**

Aquatic filter barriers are a system of technologies similar to turbidity curtains that utilize fixed or floating booms, bottom weights, and anchors to hold fine mesh nets (woven fabric) in a vertical orientation to filter water entering the intake area. Utilizing existing site features and anchor techniques, aquatic filter barriers can typically be installed with minimal infrastructure to support the system. Aquatic filter barriers have an extremely fine-mesh and low permeability which keeps TSV well below the 0.25 fps regulatory threshold and prevents fine particles and life forms form passing through the barrier. However, due to the low permeability, a very large surface area is required to maintain adequate inflow. In our experience, aquatic filter barriers are better suited for still-water applications where water level fluctuation is minimal or in-stream barriers where there is a constant flow perpendicular to the barrier orientation, and do not perform well in cross-flow orientations and fluctuating water levels anticipated at the proposed ASR intake sites. Filter barriers do require some method of removing accumulated material and marine growth from the face of the barrier, and this can be achieved with an airburst or bubbler type system for routine removal with supplemental manual cleaning by divers or barrier removal on a seasonal basis. In general, these systems require significant routine maintenance in the form of regular inspection & adjustment, repair of tears, diver assisted cleaning & monitoring, and regular replacement of wear items.

This technology was specifically identified by SFWMD during the course of this project with a request to include this option as an initial consideration. Stantec has prior experience conducting ecological and environmental monitoring of an aquatic filter barrier system at a water treatment facility located on the Taunton River in Massachusetts. This facility is permitted to withdraw up to 10 MGD of water from the river and utilizes a seasonally deployed filter barrier (Gunderboom®) as the first fish screening device before water enters the intake structure. The filtering curtain is constructed of fine mesh (approximately 0.02 in) fabric and acts as the primary fish exclusion technology when it is deployed from March 1 through November 15. The effectiveness of the filter barrier as an exclusion technology at this facility was documented by a robust monitoring program that has been in place since commissioning of the facility in 2008; however, Stantec observed that the magnitude and frequency of performance issues has increased in the years following installation. In recent years, fish exclusionary performance has decreased compared to the five years following commissioning of the facility. Increases in impingement and entrainment is attributed to a reduction in the effectiveness of the system due to materials and maintenance issues, including breaches such as overtopping, fabric tears, and undermining. These breaches, regardless of the magnitude, compromised the exclusionary effectiveness of the system. As a result of the ongoing performance issues, the facility undertook a major retrofit of the filter barrier system, replacing most of the filtration panels, approximately eight (8) years after initial deployment, however, performance issues continued as the replacement filtration material aged. Due to performance issues additional permitting conditions were imposed requiring the facility to develop and implement an Operation and Maintenance program to visually inspect the integrity of the system on a routine basis during each withdrawal period, perform monthly dive inspection and maintenance of the submerged portions of the system, and perform weekly retrieval and release of fish trapped impoundment between the filter barrier and the intake structure.

Aquatic filter barriers effectively meet four of the seven project criteria. When properly installed and maintained, these barriers do prevent entrainment and entrapment of sensitive species, have a relatively low capital cost for initial installation due to the minimal infrastructure required, have minimal power and equipment demands for the airburst cleaning systems, and filter barriers can meet some of the regulatory compliance standards. However, these systems are maintenance intensive, will have adverse regulatory impacts associated with placement of a barrier over a large footprint within the waterway, and are not well suited for the proposed side bank site configurations with crossing stream flow. Due to the maintenance intensive nature and poor long-term performance of these systems when not properly maintained, aquatic filter barriers are not considered suitable as short-list option for further evaluation.

6.2.1.4 **Fine Mesh Passive Screens**

Fine mesh passive screens (commonly referred to as wedge-wire screens) are a form of fixed screen submerged in the source water body and equipped with a mesh fine enough to prevent entrainment of material and organisms sized at 0.04 in (1.0 mm) or less. Since these screens are static in nature with limited means of recovering impinged organisms, they are typically sized to achieve very low TSV. The more common arrangement of passive screens is known as a Cylindrical Wedge-Wire screen (CWW) which consists of V-shaped wire mesh formed into a cylindrical drum configuration and attached to an intake pipe. These drums are typically located slightly off-shore where there is sufficient water depth above the drum, a sweeping flow across the screen which is greater than the TSV, and positioned in the water column where flow is not obstructed by bottom sediments or adjacent structure. Based on operating criteria, multiple drums can be added to intake pipe(s) to supply intake flow required. Routine cleaning to remove material collected on the screens is typically achieved with an airburst system that forces compressed air from inside to outside of the drum (opposite water intake direction) so that accumulated material can be swept away from the intake screen. Mechanically brushed systems are also commercially available. Since the screens are submerged off-shore, they are susceptible to algae and marine growth (mussels, barnacles) and do require periodic diver assisted cleaning, maintenance, and inspection. Based on general site characteristics, all sites considered in this evaluation, with the exception of site L-63S, meet the primary water depth and crossing flow conditions for CWW drum screens. For site L-63S, the shallow water depth would require what is known as a half-drum arrangement where CWW equipment is mounted on the stream bed with provisions to minimize sedimentation adjacent to the equipment.

CWW technology has been successfully installed in numerous facilities including the Kissimmee River ASR Pilot Project and has been accepted by many regulatory authorities as Best Technology Available (BTA) for compliance with 316(b) regulations at other facilities throughout the country. Schematic CWW intake arrangements that meet the project criteria of 0.04 in (1.0 mm) screen opening and TSV less than 0.25 fps are provided in **Figures 6-4** through **Figure 6-6** for both the typical site locations as well as L-63S.

CWW screens effectively meet five of the seven project criteria. This technology is compliant with regulatory standards, can prevent entrainment of aquatic life larger than 0.04 in (1.0 mm), can minimize impingement of aquatic life on the screens with low TSV, is compatible with the proposed site configurations, is easily scalable and modular to accommodate a range of flows, and can be equipped for remote or automated operation. However, CWW screens do represent the mid-range of capital cost associated with infrastructure and equipment; do require power and instrumentation for operation; do require equipment for the airburst system; and do include mechanical components that requires routine maintenance and repair.

Since this technology is recognized by regulators as BTA for environmental compliance, meet most of the project criteria, and were successfully utilized in the Kissimmee ASR Pilot Project, CWW screens have been selected as a suitable short-list option for further evaluation as a primary screen alternative.

6.2.2 Intake Alternative Development

This discussion provides additional information related to intake coarse screen CWW technology shortlisted for consideration at the LOWRP ASR Wells locations.

The C-38N and C-38S are located along the lower reach of the Kissimmee River which is relatively deep with a wide channel with side slopes on the order of 4H:1V. These sites are very similar to conditions depicted in the Kissimmee ASR Pilot Project drawings. Although the Kissimmee River is a navigable waterway, it is assumed that there is sufficient channel width and depth to allow the intake to be located slightly offshore without significantly altering use of the waterway. The water level at these sites correlates closer to water levels in Lake Okeechobee rather than direct influence of channel flow. For this evaluation, preliminary water level for these sites was based on historical stage data from tailwater gauge at monitoring station S154-T, and it appears that sufficient water depth is present during historic “low water” conditions to accommodate installation of either Cylindrical Wedge Wire Screens (CWWS) as depicted in **Figure 6-4 Intake DesignTM-SK-S01 – Typical for C38N and C-38S.**

The second next set of sites includes C-59 and L-63N located upstream of water control structures at Nubbins Slough and along Taylor Creek. The source waterbody for this group is slightly shallower and narrower channels serving with side channel bank slopes assumed to be similar 4H:1V slopes. It appears that there is sufficient channel width to allow the intakes to be located slightly offshore without significantly altering use of the waterway. The water level in these sites is dictated primarily by gate settings at control structure C-59. For this evaluation, preliminary water level for these sites was based on historical stage data from headwater gauge at monitoring station S191_H, and there appears to be sufficient water depth during historic “low water” conditions to accommodate installation of CWWS as depicted in **Figure 6-5 Intake DesignTM-SK-S01A – Typical for L-63N and S-191.**

The last site is L-63S located within smaller canal system on Taylor Creek. The source waterbody for this site is shallow and relatively narrow channel and does not appear to be a navigable waterway. The proposed ASR well sites are adjacent to existing control structure S650 and could be located in an area with 4H:1V bank slopes, or a vertical bulkhead. The water level at this site appears to be dictated primarily by gate settings at control structure S650 as well as C-59. For this evaluation, preliminary water level for this site was based on historical stage data from headwater gauge at monitoring station S650_H. Water depth at historic “low water” conditions is quite shallow, but does appear capable of accommodating CWWS, although slight variations in equipment are necessary to achieve desired intake flow. As depicted in **Figure 6-6 Intake Design TM-SK-S02 – Typical for L-63S**, CWWS equipment will need to be half-drum models mounded directly on the intake sill and be slightly longer as compared to the deeper channel sites. Maximizing intake submergence could help reduce entrainment of fish, larva and eggs where dissolved oxygen levels are lower. Accordingly, intake depth by site will be optimized to balance depth of intake while minimizing potential intake of bottom sediment. This will be easier for C-38 and L-63N, which are deeper than others. However, anoxic conditions will quickly become oxic when pumping (mixed flow) begins. Table 6-1 summarizes key project features and pertinent intake data for each site.

Table 6-1 Key Site Features and Water Levels Pertinent to Intake Screen Evaluation

C-38N (Kissimmee River):			
Channel Depth:	~30 feet	Season of Intake Operation:	July - October
Channel Width:	~580 feet	Water Level Fluctuation:	6 ft range annual
In-Water Bank Slope:	4H:1V	Water Surface Elevation:	EL 11 to EL 17
Bottom Composition:	sediment/bedrock	Reference DBHydro Station:	S154_T (stage)
		Reference DBHydro Station:	S65E, S84 (flow)
C-38S (Kissimmee River):			
Channel Depth:	~30 feet	Season of Intake Operation:	July - October
Channel Width:	~580 feet	Water Level Fluctuation:	6 ft range annual
In-Water Bank Slope:	4H:1V	Water Surface Elevation:	EL 11 to EL 17
Bottom Composition:	sediment/bedrock	Reference DBHydro Station:	S154_T (stage)
		Reference DBHydro Station:	S65E, S84 (flow)
L-63N (Taylor Creek):			
Channel Depth:	~30 feet	Season of Intake Operation:	July - October
Channel Width:	~580 feet	Water Level Fluctuation:	3 ft range annual
In-Water Bank Slope:	4H:1V	Water Surface Elevation:	EL 17 to EL 20
Bottom Composition:	sediment/bedrock	Reference DBHydro Station:	S191_H (stage)
		Reference DBHydro Station:	flow not available
S-191 (Nubbins Slough):			
Channel Depth:	~30 feet	Season of Intake Operation:	July - October
Channel Width:	~580 feet	Water Level Fluctuation:	3 ft range annual
In-Water Bank Slope:	4H:1V	Water Surface Elevation:	EL 17 to EL 20
Bottom Composition:	sediment/bedrock	Reference DBHydro Station:	S191_H
		Reference DBHydro Station:	S191_S (flow)

L-63S (Taylor Creek):			
Channel Depth:	~8 feet	Season of Intake Operation:	July - October
Channel Width:	< 60 feet	Water Level Fluctuation:	1.5 ft range annual
In-Water Bank Slope:	4H:1V	Water Surface Elevation:	EL 18 to EL 19.5
Bottom Composition:	sediment/bedrock	Reference DBHydro Station:	S650_H (stage)
		Reference DBHydro Station:	S650_P (flow)

6.2.2.1 **Screen Design Criteria**

Based on preliminary evaluation of technologies considered for intake coarse screening and wildlife exclusion, the only one retained as a short-list option for further consideration is CWW - Fine Mesh Static Screens. The primary screen design criteria for CWW is based on characteristics of early life stage aquatic life to exclude eggs, larvae, and juveniles of the fish species identified in Subsection 6.1.1. Assessment of available biological data, comments received from FWC, and parameters selected for the Kissimmee ASR Pilot Project where used to establish the following screen performance criteria utilized in development of the intake arrangements:

1. Screen Opening: 0.04 in (1.0 mm)
2. Through Screen Velocity: 0.25 feet per second
3. Intake Design Flow: Incremental from 10 MGD to 50 MGD
4. Intake Head Loss: System Allowance for Intake < 3 feet
5. Intake Bays: (2) as minimum to allow maintenance isolation
6. Operation: Seasonally Intermittent

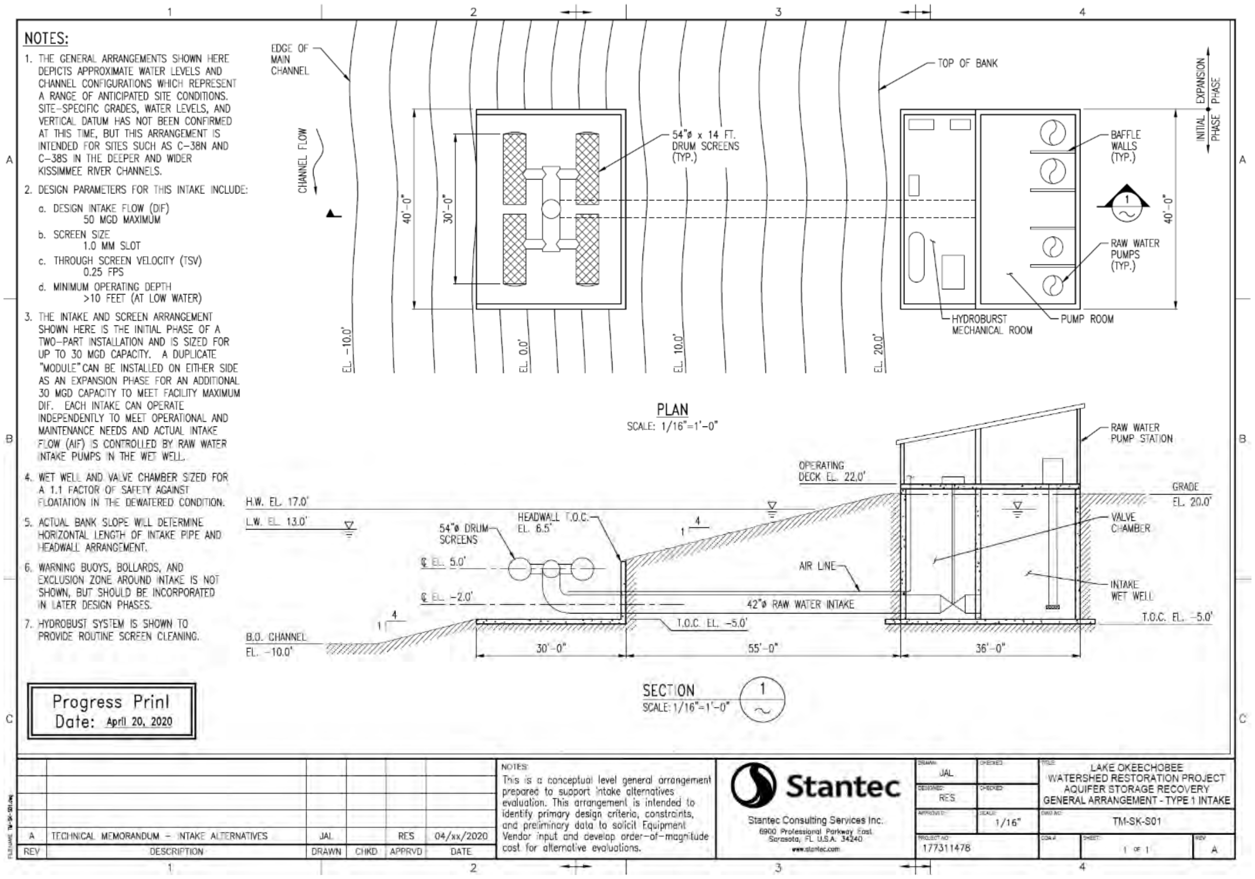
Intake design flow is noted as incremental with the understanding that intakes will be constructed in phases to provide additional intake capacity as additional ASR wells are installed at each site. The construction cost associated with intake structures is heavily skewed toward infrastructure construction including dewatering, excavation, foundations, water passages, raw water piping, and screen equipment, which is generally more economical to install in larger increments with excess capacity rather than multiple small additions. For this reason, this evaluation considered two phases of installation. Each phase is represented by identical "modules" with water passages sized to accommodate four pumps per wet well at a combined capacity of up to 30 MGD per module. This arrangement provides operational flexibility to install combinations of 5 MGD and 10 MGD pumps as needed to suite system demands, and individual intake screens can be added as the pump capacity increases. Once 30 MGD pump capacity is achieved, the second water passage module will need to be constructed as the expansion phase. Although water passages in the two-module installation is slightly oversized for the 50 MGD design flow, actual flow will be dictated by pump operation, and the two independent modules will allow for continued operation at 60% capacity if one module needs to be dewatered for routine maintenance or emergency repair.

6.2.2.2 Intake General Arrangement and CWWS Equipment Selection

The primary design considerations for general arrangement layout for CWWS are sufficient water depth above the screen to avoid vortices, clearance between drums or obstructions, clearance above bottom sediments, balancing pipe lengths from screen head to common header, and adequate pipe size to minimize headloss. Each of these factors are adjusted in an iterative process to develop a piping and header geometry that can accommodate the number and size of drums dictated by mesh size and flow requirements.

For this evaluation, a four-screen header was selected so that individual screen heads can be added as the well system expands, and individual screens can be taken out of service for maintenance or replacement without shutting down the entire intake system. Vendors were contacted to obtain screen head dimensions and models as depicted in equipment data sheets below, and raw water intake pipes were sized to keep velocities below five (5) fps. The conceptual layout developed for CWWS includes an intake sill and headwall to provide a stable foundation for pipe supports, retain channel bank slopes at the headwall, prevent bottom erosion due to airburst cleaning, simplify sediment removal near the intake, and provide anchorage for buoys or warning devices to identify the intake screens. The screen material recommended is Z-alloy to deter marine growth, and stainless steel is recommended for pipe and fittings. The raw water intake line is shown as buried pipe from inlet to the valve chamber to position the inlet in deeper water slightly offshore while minimizing built infrastructure. The valve chamber is provided to isolate the intake during maintenance dewatering and provides a convenient location for housing air burst mechanical equipment. The raw water line feeds directly into a single wet well serving as the common reservoir for suction side of all intake pump in the module.

The general arrangement for CWWS are identified as Type I, Type IA, and Type II as indicated respectively on Drawings TM-SK-S01, TM-SK-S01A, and TM-SK-S02. The primary difference between the Type I and Type IA screens is the position of header pipe in relation to intake sill needed to accommodate smaller canals. The major difference in Type II screen is the half-drum equipment needed to accommodate the very shallow water depth.



NOTES:

1. THE GENERAL ARRANGEMENTS SHOWN HERE DEPICTS APPROXIMATE WATER LEVELS AND CHANNEL CONFIGURATIONS WHICH REPRESENT A RANGE OF ANTICIPATED SITE CONDITIONS. SITE-SPECIFIC GRADES, WATER LEVELS, AND VERTICAL DATUM HAS NOT BEEN CONFIRMED AT THIS TIME, BUT THIS ARRANGEMENT IS INTENDED FOR SITES SUCH AS C-38N AND C-38S IN THE DEEPER AND WIDER KISSIMMEE RIVER CHANNELS.
2. DESIGN PARAMETERS FOR THIS INTAKE INCLUDE:
   - a. DESIGN INTAKE FLOW (DIF) 50 MGD MAXIMUM
   - b. SCREEN SIZE 1.0 MM SLOT
   - c. THROUGH SCREEN VELOCITY (TSV) 0.25 FPS
   - d. MINIMUM OPERATING DEPTH >10 FEET (AT LOW WATER)
3. THE INTAKE AND SCREEN ARRANGEMENT SHOWN HERE IS THE INITIAL PHASE OF A TWO-PART INSTALLATION AND IS SIZED FOR UP TO 30 MGD CAPACITY. A DUPLICATE "MODULE" CAN BE INSTALLED ON EITHER SIDE AS AN EXPANSION PHASE FOR AN ADDITIONAL 30 MGD CAPACITY TO MEET FACILITY MAXIMUM DIF. EACH INTAKE CAN OPERATE INDEPENDENTLY TO MEET OPERATIONAL AND MAINTENANCE NEEDS AND ACTUAL INTAKE FLOW (AIF) IS CONTROLLED BY RAW WATER INTAKE PUMPS IN THE WET WELL.
4. WET WELL AND VALVE CHAMBER SIZED FOR A 1.1 FACTOR OF SAFETY AGAINST FLOATATION IN THE DEWATERED CONDITION.
5. ACTUAL BANK SLOPE WILL DETERMINE HORIZONTAL LENGTH OF INTAKE PIPE AND HEADWALL ARRANGEMENT.
6. WARNING BUOYS, BOLLARDS, AND EXCLUSION ZONE AROUND INTAKE IS NOT SHOWN, BUT SHOULD BE INCORPORATED IN LATER DESIGN PHASES.
7. HYDROBUST SYSTEM IS SHOWN TO PROVIDE ROUTINE SCREEN CLEANING.

Progress Print
Date: April 20, 2020

NOTES:
This is a conceptual level general arrangement prepared to support intake alternatives evaluation. This arrangement is intended to identify primary design criteria, constraints, and preliminary data to solicit Equipment Vendor input and develop order-of-magnitude cost for alternative evaluations.

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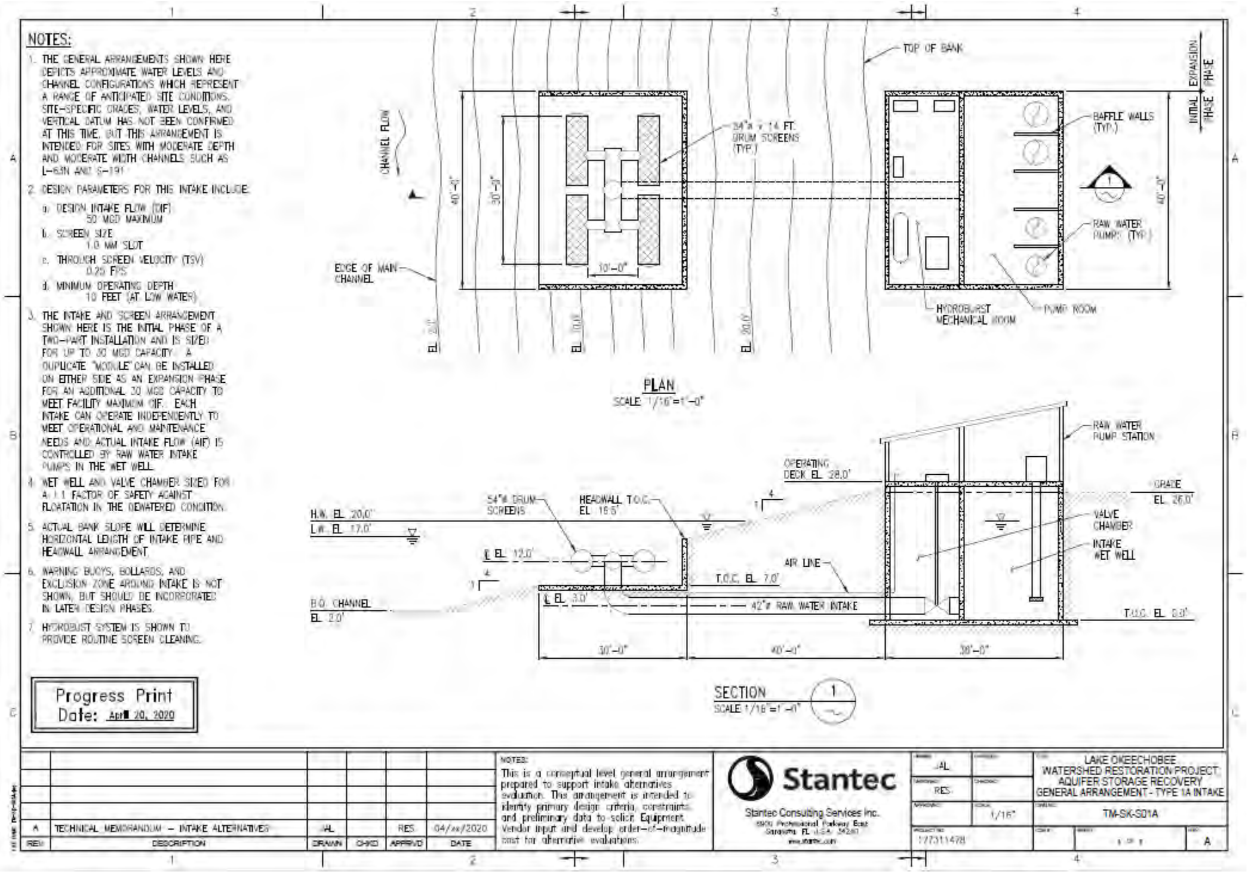
REV	DESCRIPTION	DRAWN	CHKD	APPRVD	DATE
A	TECHNICAL MEMORANDUM – INTAKE ALTERNATIVES	JAL		RES	04/xx/2020

DRAWN: JAL
DESIGNED: RES
SCALE: 1/16"
PROJECT NO: 177311478
TITLE: LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT AQUIFER STORAGE RECOVERY GENERAL ARRANGEMENT - TYPE 1 INTAKE
DWG NO: TM-SK-S01
SHEET: 1 OF 1
REV: A

Figure 6-4 Intake DesignTM-SK-S01 – Typical for C38N and C-38S



NOTES:

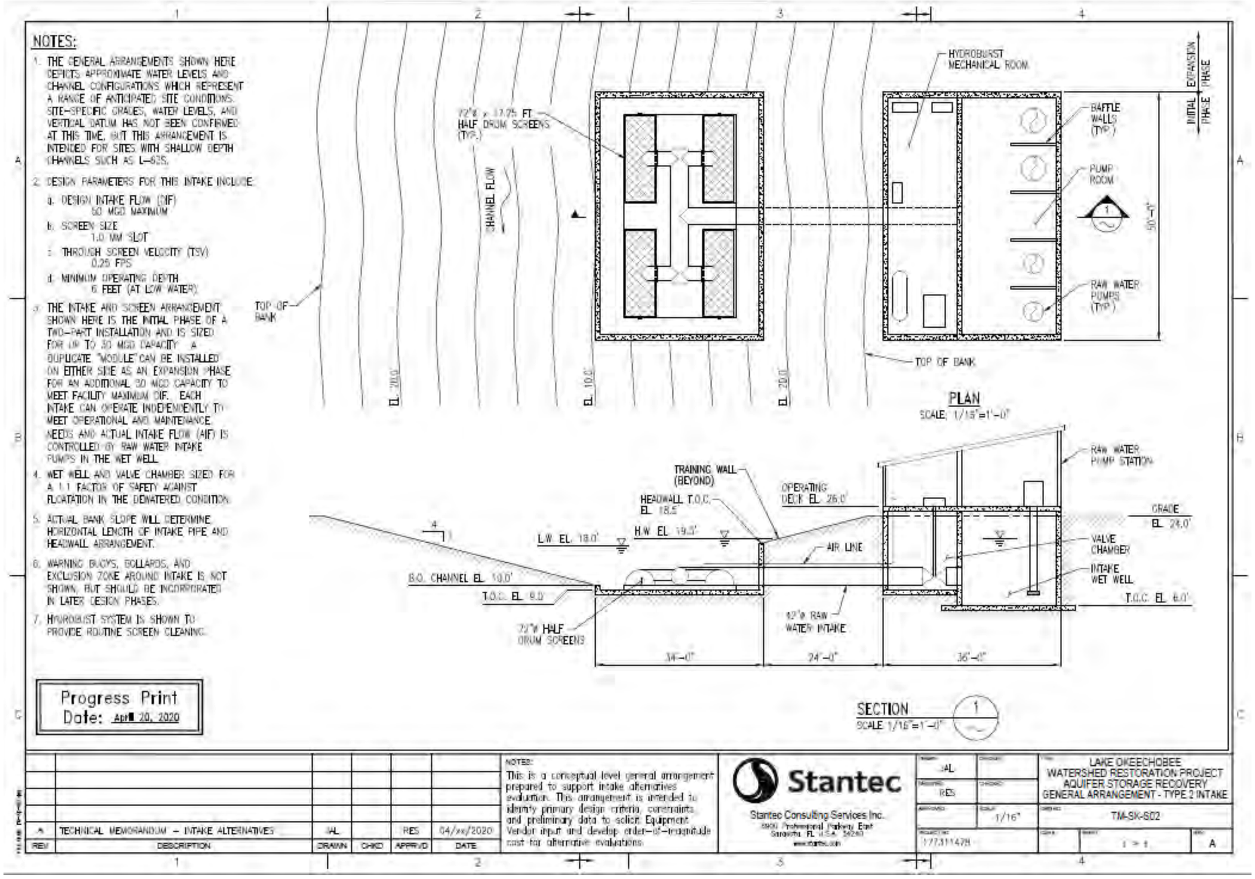
1. THE GENERAL ARRANGEMENTS SHOWN HERE DEPICTS APPROXIMATE WATER LEVELS AND CHANNEL CONFIGURATIONS WHICH REPRESENT A RANGE OF ANTICIPATED SITE CONDITIONS. SITE-SPECIFIC GRADES, WATER LEVELS, AND VERTICAL DATUM HAS NOT BEEN CONFIRMED AT THIS TIME, BUT THIS ARRANGEMENT IS INTENDED FOR SITES WITH MODERATE DEPTH AND MODERATE WIDTH CHANNELS SUCH AS L-63N AND S-191
2. DESIGN PARAMETERS FOR THIS INTAKE INCLUDE:
   - a. DESIGN INTAKE FLOW (DIF) 50 MGD MAXIMUM
   - b. SCREEN SIZE 1.0 MM SLOT
   - c. THROUGH SCREEN VELOCITY (TSV) 0.25 FPS
   - d. MINIMUM OPERATING DEPTH 10 FEET (AT LOW WATER)
3. THE INTAKE AND SCREEN ARRANGEMENT SHOWN HERE IS THE INITIAL PHASE OF A TWO-PART INSTALLATION AND IS SIZED FOR UP TO 30 MGD CAPACITY. A DUPLICATE "MODULE" CAN BE INSTALLED ON EITHER SIDE AS AN EXPANSION PHASE FOR AN ADDITIONAL 30 MGD CAPACITY TO MEET FACILITY MAXIMUM DIF. EACH INTAKE CAN OPERATE INDEPENDENTLY TO MEET OPERATIONAL AND MAINTENANCE NEEDS AND ACTUAL INTAKE FLOW (AIF) IS CONTROLLED BY RAW WATER INTAKE PUMPS IN THE WET WELL.
4. WET WELL AND VALVE CHAMBER SIZED FOR A 1.1 FACTOR OF SAFETY AGAINST FLOATATION IN THE DEWATERED CONDITION.
5. ACTUAL BANK SLOPE WILL DETERMINE HORIZONTAL LENGTH OF INTAKE PIPE AND HEADWALL ARRANGEMENT.
6. WARNING BUOYS, BOLLARDS, AND EXCLUSION ZONE AROUND INTAKE IS NOT SHOWN, BUT SHOULD BE INCORPORATED IN LATER DESIGN PHASES.
7. HYDROBUST SYSTEM IS SHOWN TO PROVIDE ROUTINE SCREEN CLEANING.

Progress Print
Date: April 20, 2020

NOTES:
This is a conceptual level general arrangement prepared to support intake alternatives evaluation. This arrangement is intended to identify primary design criteria, constraints and preliminary data to solicit Equipment Vendor input and develop order-of-magnitude cost for alternative evaluations.

REV	DESCRIPTION	DRAWN	CHKD	APPRVD	DATE
A	TECHNICAL MEMORANDUM – INTAKE ALTERNATIVES	JAL		RES	04/xx/2020

Figure 6-5 Intake DesignTM-SK-S01A – Typical for L-63N and S-191

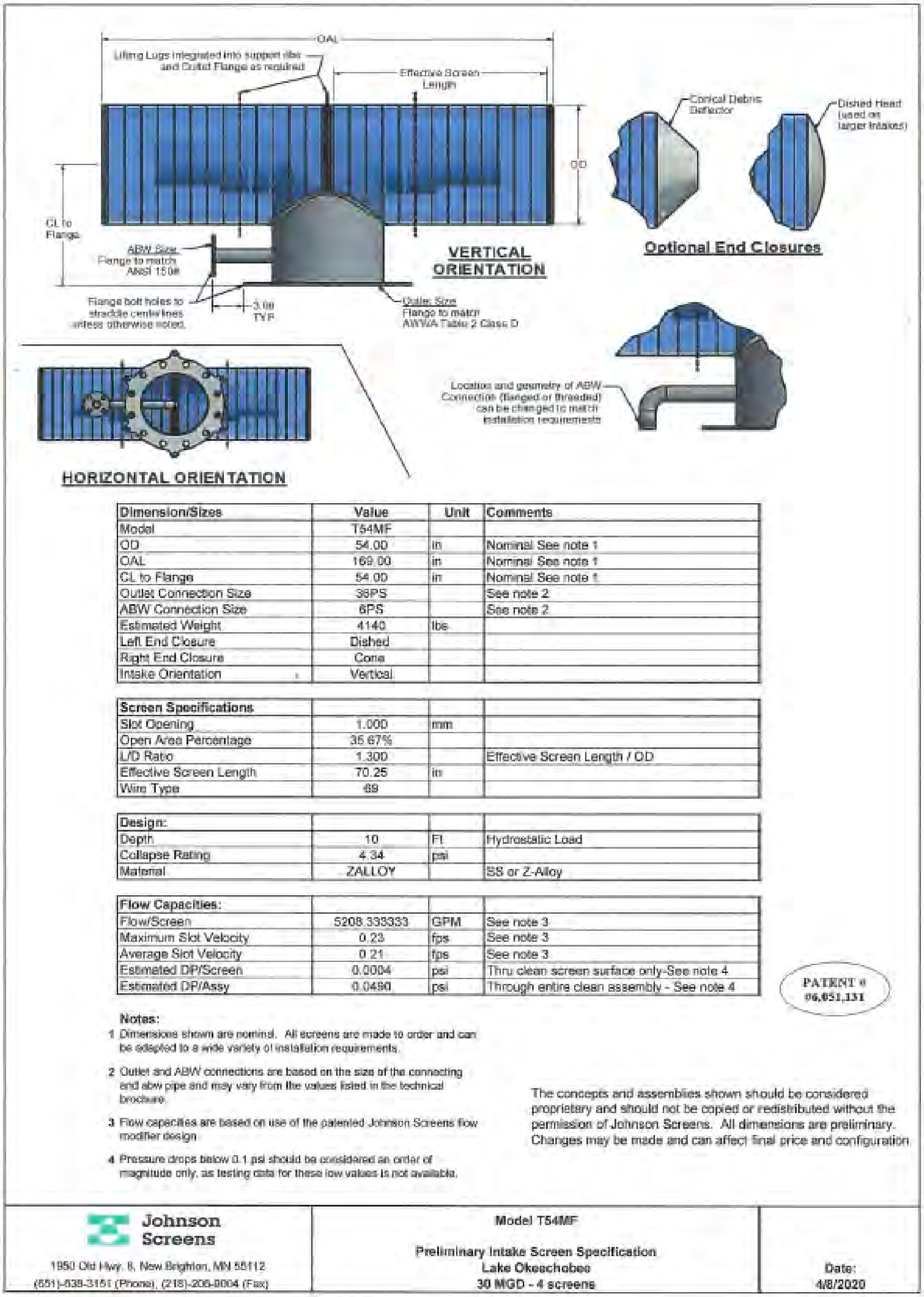


NOTES:

1. THE GENERAL ARRANGEMENTS SHOWN HERE DEPICTS APPROXIMATE WATER LEVELS AND CHANNEL CONFIGURATIONS WHICH REPRESENT A RANGE OF ANTICIPATED SITE CONDITIONS. SITE-SPECIFIC GRADES, WATER LEVELS, AND VERTICAL DATUM HAS NOT BEEN CONFIRMED AT THIS TIME, BUT THIS ARRANGEMENT IS INTENDED FOR SITES WITH SHALLOW DEPTH CHANNELS SUCH AS L-63S.
2. DESIGN PARAMETERS FOR THIS INTAKE INCLUDE:
   - a. DESIGN INTAKE FLOW (DIF) 50 MGD MAXIMUM
   - b. SCREEN SIZE 1.0 MM SLOT
   - c. THROUGH SCREEN VELOCITY (TSV) 0.25 FPS
   - d. MINIMUM OPERATING DEPTH 6 FEET (AT LOW WATER)
3. THE INTAKE AND SCREEN ARRANGEMENT SHOWN HERE IS THE INITIAL PHASE OF A TWO-PART INSTALLATION AND IS SIZED FOR UP TO 30 MGD CAPACITY. A DUPLICATE "MODULE" CAN BE INSTALLED ON EITHER SIDE AS AN EXPANSION PHASE FOR AN ADDITIONAL 30 MGD CAPACITY TO MEET FACILITY MAXIMUM DIF. EACH INTAKE CAN OPERATE INDEPENDENTLY TO MEET OPERATIONAL AND MAINTENANCE NEEDS AND ACTUAL INTAKE FLOW (AIF) IS CONTROLLED BY RAW WATER INTAKE PUMPS IN THE WET WELL.
4. WET WELL AND VALVE CHAMBER SIZED FOR A 1.1 FACTOR OF SAFETY AGAINST FLOATATION IN THE DEWATERED CONDITION.
5. ACTUAL BANK SLOPE WILL DETERMINE HORIZONTAL LENGTH OF INTAKE PIPE AND HEADWALL ARRANGEMENT.
6. WARNING BUOYS, BOLLARDS, AND EXCLUSION ZONE AROUND INTAKE IS NOT SHOWN, BUT SHOULD BE INCORPORATED IN LATER DESIGN PHASES.
7. HYDROBURST SYSTEM IS SHOWN TO PROVIDE ROUTINE SCREEN CLEANING.

NOTES:
This is a conceptual level general arrangement prepared to support intake alternatives evaluation. This arrangement is intended to identify primary design criteria, constraints and preliminary data to solicit Equipment Vendor input and develop order-of-magnitude cost for alternative evaluations.

Figure 6-6 Intake Design TM-SK-S02 – Typical for L-63S



Dimension/Sizes	Value	Unit	Comments
Model	T54MF		
OD	54.00	in	Nominal See note 1
OAL	169.00	in	Nominal See note 1
CL to Flange	54.00	in	Nominal See note 1
Outlet Connection Size	36PS		See note 2
ABW Connection Size	6PS		See note 2
Estimated Weight	4140	lbs	
Left End Closure	Dished		
Right End Closure	Cone		
Intake Orientation	Vertical		

Screen Specifications			
Slot Opening	1.000	mm	
Open Area Percentage	35.67%		
L/D Ratio	1.300		Effective Screen Length / OD
Effective Screen Length	70.25	in	
Wire Type	69		

Design:			
Depth	10	Ft	Hydrostatic Load
Collapse Rating	4.34	psi	
Material	ZALLOY		SS or Z-Alloy

Flow Capacities:			
Flow/Screen	5208.333333	GPM	See note 3
Maximum Slot Velocity	0.23	fps	See note 3
Average Slot Velocity	0.21	fps	See note 3
Estimated DP/Screen	0.0004	psi	Thru clean screen surface only-See note 4
Estimated DP/Assy	0.0490	psi	Through entire clean assembly - See note 4

PATENT #
#6,051,131

Notes:

1 Dimensions shown are nominal. All screens are made to order and can be adapted to a wide variety of installation requirements.

2 Outlet and ABW connections are based on the size of the connecting end abw pipe and may vary from the values listed in the technical brochure.

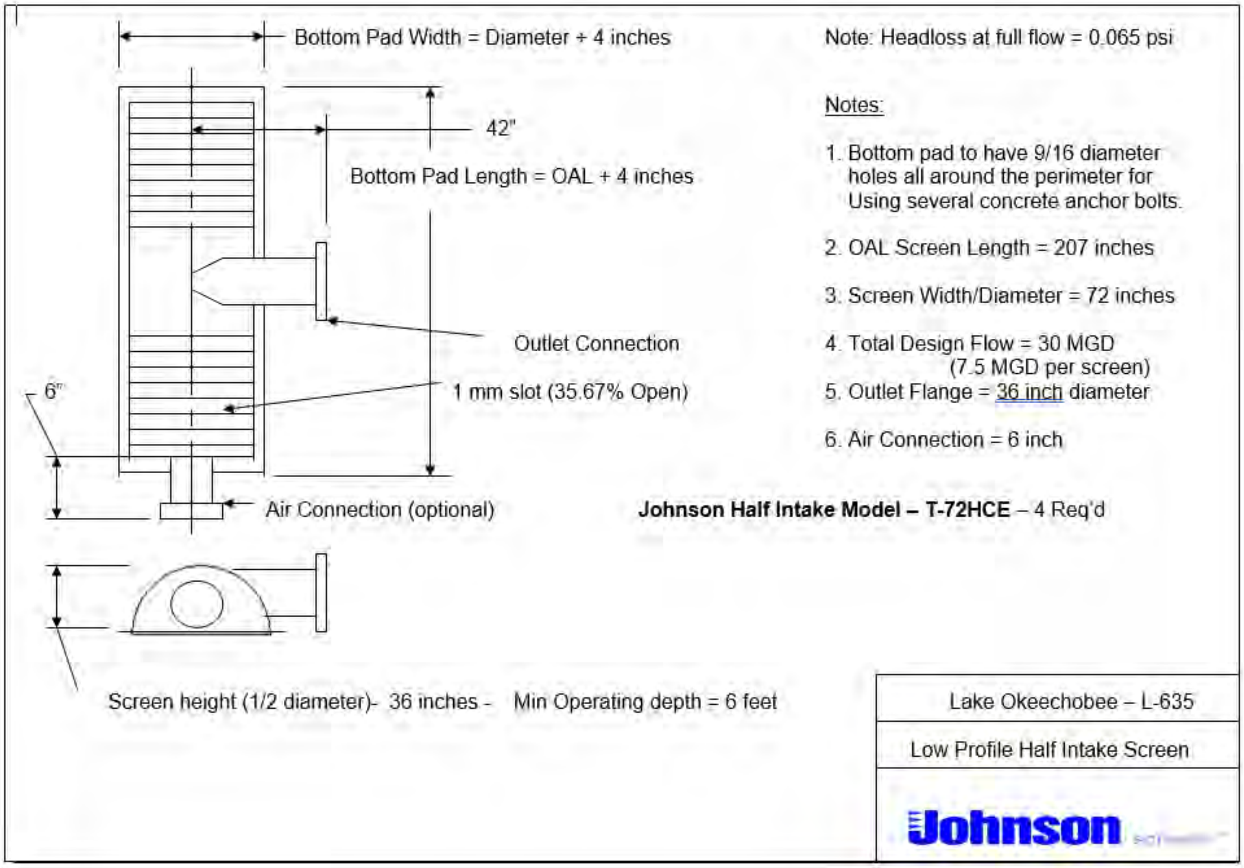
3 Flow capacities are based on use of the patented Johnson Screens flow modifier design.

4 Pressure drops below 0.1 psi should be considered an order of magnitude only, as testing data for these low values is not available.

The concepts and assemblies shown should be considered proprietary and should not be copied or redistributed without the permission of Johnson Screens. All dimensions are preliminary. Changes may be made and can affect final price and configuration.

Johnson Screens 1950 Old Hwy. 8, New Brighton, MN 55112 (651)-638-3151 (Phone), (218)-206-8004 (Fax)	Model T54MF Preliminary Intake Screen Specification Lake Okeechobee 30 MGD - 4 screens	Date: 4/8/2020

Figure 6-7 Johnson T54MF Intake Screen for Type I and Type IA Installations



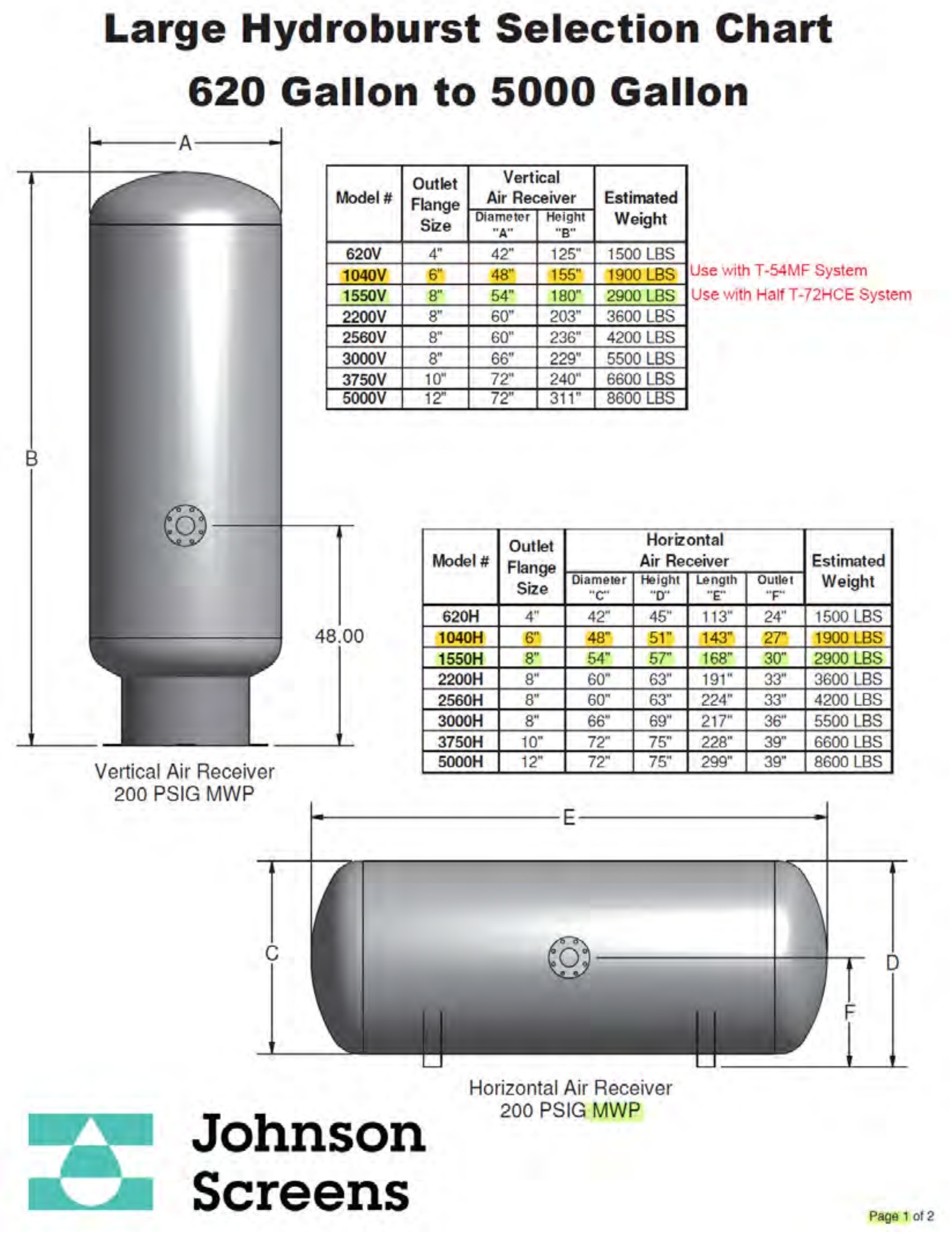
Note: Headloss at full flow = 0.065 psi

Notes:

1. Bottom pad to have 9/16 diameter holes all around the perimeter for Using several concrete anchor bolts.
2. OAL Screen Length = 207 inches
3. Screen Width/Diameter = 72 inches
4. Total Design Flow = 30 MGD (7.5 MGD per screen)
5. Outlet Flange = 36 inch diameter
6. Air Connection = 6 inch

Johnson Half Intake Model – T-72HCE – 4 Req'd

Figure 6-8 Johnson Half T-72HCE Intake Screen for Type II Installations



Large Hydroburst Selection Chart

620 Gallon to 5000 Gallon

Model #	Outlet Flange Size	Vertical Air Receiver Diameter "A"	Vertical Air Receiver Height "B"	Estimated Weight	
620V	4"	42"	125"	1500 LBS	
1040V	6"	48"	155"	1900 LBS	Use with T-54MF System
1550V	8"	54"	180"	2900 LBS	Use with Half T-72HCE System
2200V	8"	60"	203"	3600 LBS	
2560V	8"	60"	236"	4200 LBS	
3000V	8"	66"	229"	5500 LBS	
3750V	10"	72"	240"	6600 LBS	
5000V	12"	72"	311"	8600 LBS	

Model #	Outlet Flange Size	Horizontal Air Receiver Diameter "C"	Horizontal Air Receiver Height "D"	Horizontal Air Receiver Length "E"	Horizontal Air Receiver Outlet "F"	Estimated Weight
620H	4"	42"	45"	113"	24"	1500 LBS
1040H	6"	48"	51"	143"	27"	1900 LBS
1550H	8"	54"	57"	168"	30"	2900 LBS
2200H	8"	60"	63"	191"	33"	3600 LBS
2560H	8"	60"	63"	224"	33"	4200 LBS
3000H	8"	66"	69"	217"	36"	5500 LBS
3750H	10"	72"	75"	228"	39"	6600 LBS
5000H	12"	72"	75"	299"	39"	8600 LBS

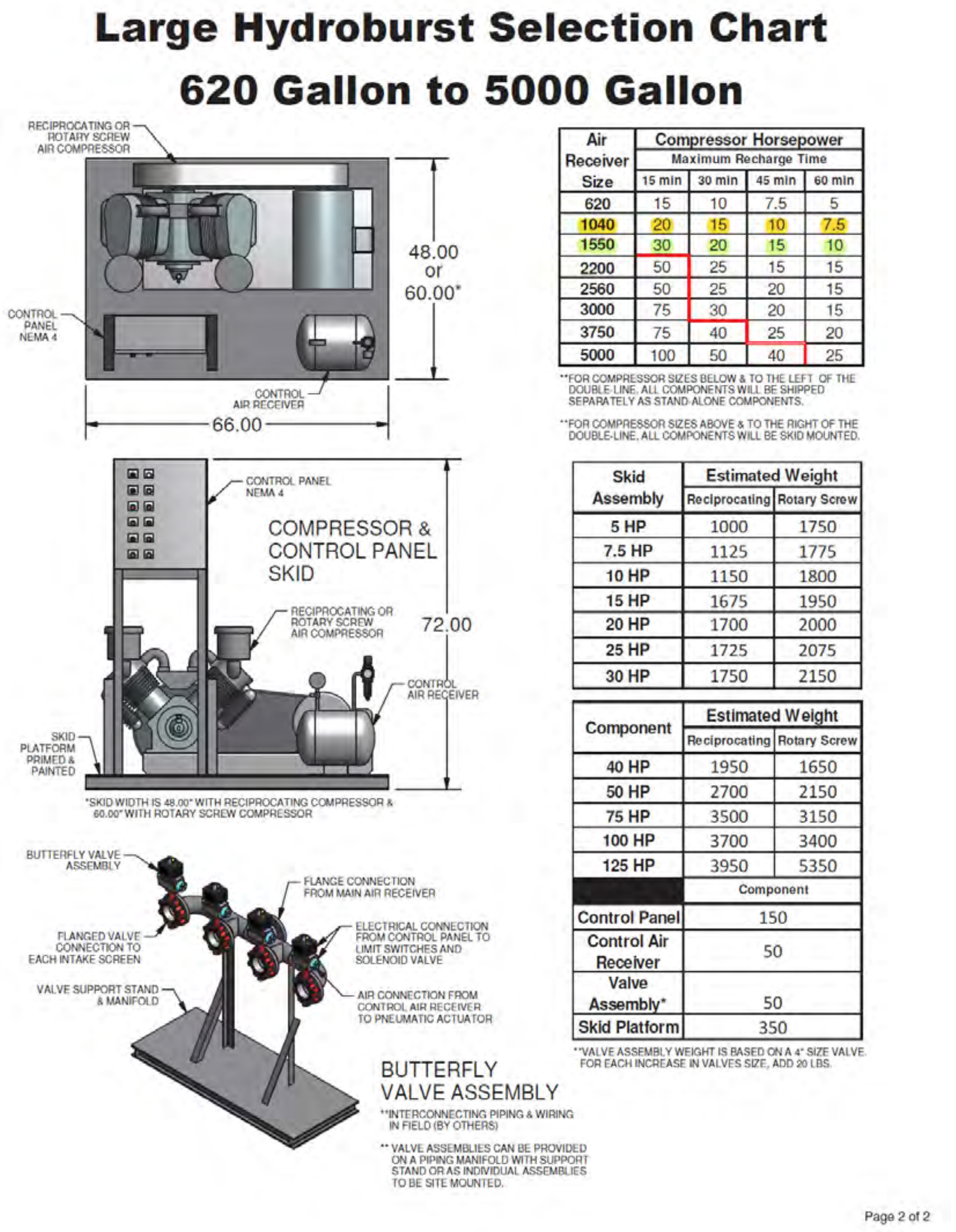
Vertical Air Receiver
200 PSIG MWP

Horizontal Air Receiver
200 PSIG MWP

Johnson Screens

Page 1 of 2

Figure 6-9 Hydroburst Selection Chart (P1)



Large Hydroburst Selection Chart

620 Gallon to 5000 Gallon

*SKID WIDTH IS 48.00" WITH RECIPROCATING COMPRESSOR & 60.00" WITH ROTARY SCREW COMPRESSOR

**INTERCONNECTING PIPING & WIRING IN FIELD (BY OTHERS)

** VALVE ASSEMBLIES CAN BE PROVIDED ON A PIPING MANIFOLD WITH SUPPORT STAND OR AS INDIVIDUAL ASSEMBLIES TO BE SITE MOUNTED.

Air Receiver Size	Compressor Horsepower			
	Maximum Recharge Time			
	15 min	30 min	45 min	60 min
620	15	10	7.5	5
1040	20	15	10	7.5
1550	30	20	15	10
2200	50	25	15	15
2560	50	25	20	15
3000	75	30	20	15
3750	75	40	25	20
5000	100	50	40	25

**FOR COMPRESSOR SIZES BELOW & TO THE LEFT OF THE DOUBLE-LINE, ALL COMPONENTS WILL BE SHIPPED SEPARATELY AS STAND-ALONE COMPONENTS.

**FOR COMPRESSOR SIZES ABOVE & TO THE RIGHT OF THE DOUBLE-LINE, ALL COMPONENTS WILL BE SKID MOUNTED.

Skid Assembly	Estimated Weight	
	Reciprocating	Rotary Screw
5 HP	1000	1750
7.5 HP	1125	1775
10 HP	1150	1800
15 HP	1675	1950
20 HP	1700	2000
25 HP	1725	2075
30 HP	1750	2150

Component	Estimated Weight	
	Reciprocating	Rotary Screw
40 HP	1950	1650
50 HP	2700	2150
75 HP	3500	3150
100 HP	3700	3400
125 HP	3950	5350
	Component	
Control Panel	150	
Control Air Receiver	50	
Valve Assembly*	50	
Skid Platform	350	

**VALVE ASSEMBLY WEIGHT IS BASED ON A 4" SIZE VALVE. FOR EACH INCREASE IN VALVES SIZE, ADD 20 LBS.

Page 2 of 2

Figure 6-10 Hydroburst Selection Chart (P2)

6.3 DISCHARGE

6.3.1 Manatee Thermal Refuge

Though Lake Okeechobee is an inland body of water, it is connected to estuarine waters on both the east and west coasts of Florida through a system of locks and dams. As such, coastal aquatic species like the federally threatened West Indian (Florida) manatee (Trichechus manatus (latirostis)), are able to access the lake and some of its associated waterways. According to a 2019 report from the USFWS, manatees have been observed within Lake Okeechobee, the L-47 Canal, the lower Kissimmee River/C-38 Canal, the C-44 Canal and the C-43 Canal. The total number of manatees in the lake and associated waterways is unknown as the FWC does not conduct specific synoptic surveys to assess manatee populations in Lake Okeechobee; rather, occurrence of manatees are assessed from opportunistic observations and mortality reports (USFWS, 2019). The locks that provide manatees access to the lake have been cited as a threat to manatees due to the potential for them to be crushed during operation of the lock structures; however, one of the most significant threats to manatees across their range is the loss of warm water habitats (USFWS, 2019).

Manatees are tropical and subtropical in their distribution and generally inhabit warm waters. Their northern winter range is limited to Florida as they are particularly vulnerable to exposure to cold temperatures. Prolonged exposure to cold water (<68° F) can cause cold stress syndrome (CSS) in manatees, resulting in physiologic and metabolic problems and can eventually lead to the death of the animal (Bossart, Meisner, Rommel, Ghim, & Jenson, 2002) (USFWS, 2019). When ambient water temperatures begin to drop, manatees seek out warmer waters, which in developed, coastal areas can include discharges from power plants, industrial and water treatment facilities. These point source discharges often provide reliable and relatively stable thermal refugia that can attract (and hold) manatees while nearby waterbodies are at much lower ambient water temperatures. For many facilities in Florida that have a regulated thermal discharge, permit conditions require them to ensure the thermal discharge is available when ambient waters reach a pre-determined “trigger” temperature at which point they must maintain the temperature within the thermal plume until ambient water temperatures rise (usually to a level higher than the trigger temperature). Recent projects involving the re-powering of power plants on the east coast of Florida set the trigger temperature at 65° F, though other existing facilities may have thermal trigger temperatures as low as 61° F (FWC Imperiled Species Section, personal communication).

Water temperatures in Lake Okeechobee and the Kissimmee River/C-38 Canal can drop to approximately 50° F or lower, depending on air temperature. Whereas the discharge from the proposed ASR is expected to be around 77° F—based on monitoring data from the pilot system at the Kissimmee River ASR (KRASR)—regardless of the ambient conditions (USFWS, 2019). The USFWS has raised concerns that if the proposed ASRs are recovering water in the wintertime when ambient conditions are colder, the discharge could create warm water refugia that may attract manatees. If an ASR then halts recovery, eliminating the warm water discharge, any manatees that were seeking refuge would be exposed to the cold ambient conditions and susceptible to CSS (USFWS, 2019). To further examine this scenario, the water temperatures at monitoring stations near the proposed ASR sites were assessed against water level data for Lake Okeechobee, as provided by SFWMD.

Based on information provided by SFWMD, recovery from ASR wells would occur as needed to maintain “Base Flow” and “Beneficial Use” releases as the lake level recedes from October-April (Robert Verrastro, SFWMD, personal communication). **Figure 6-11 SFWMD Water Management Levels for Lake Okeechobee** below presents an example of the water management levels for Lake Okeechobee. The water levels needed to maintain “Beneficial Use” release during the winter months appears to be approximately 13 feet (ft), with recovery from ASR wells occurring when lake level is predicted to fall below this trigger. .

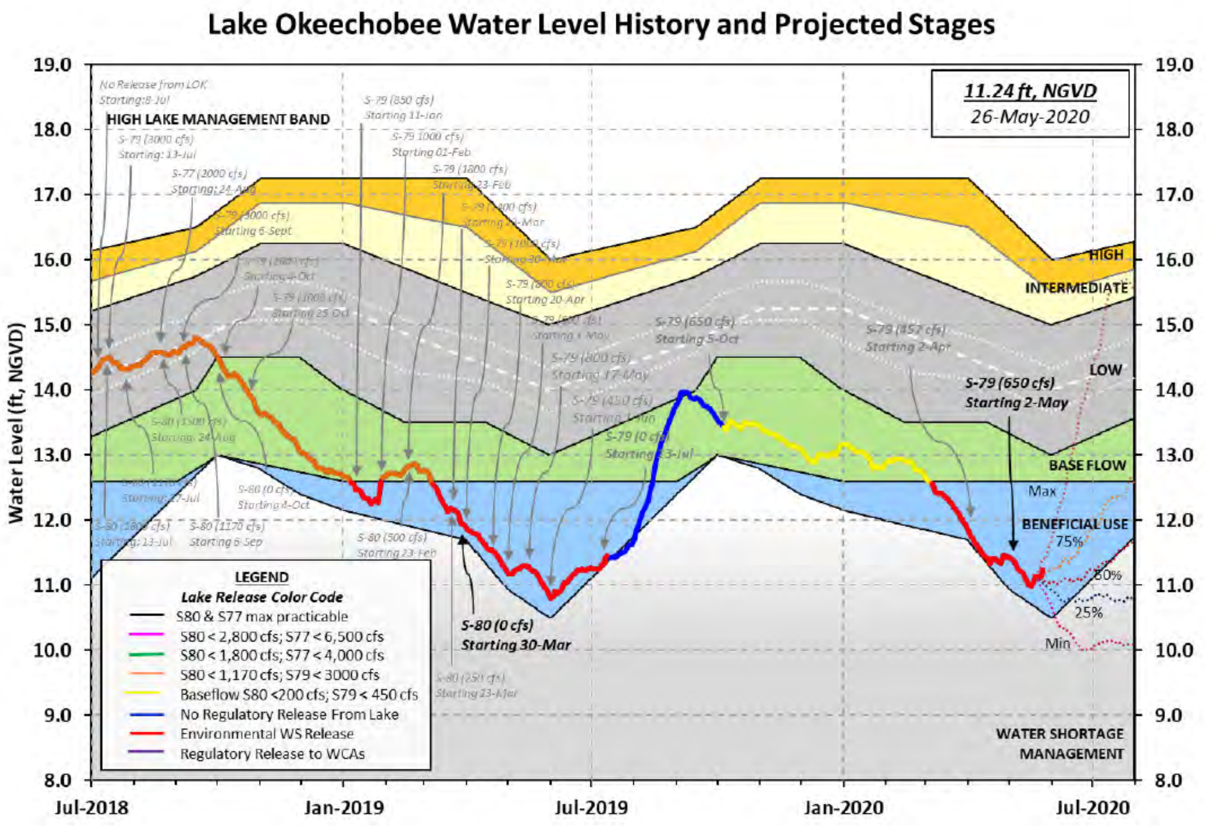


Figure 6-11 SFWMD Water Management Levels for Lake Okeechobee

To gauge the possible susceptibility of manatees to the creation, and subsequent elimination, of thermal refugia from the discharge of recovered water from the proposed ASRs, we examined the timing of possible ASR discharges based on the ranges of lake stage data within the “Beneficial Use” management zone, as described above. Using daily water level data provided by SFWMD, ASR well recovery “trigger” levels were set at 12 ft, 12.5 ft, and 13 ft. as reported for monitoring station L OKEE, which is an average of stations monitored by SFWMD and USACE. Concurrently, we examined water temperatures collected near the proposed ASR sites which may be accessible by manatees based on water control structures and prior observations as described above (USFWS, 2019). It was determined that the proposed ASRs at sites C-38S and C-38N, located on the Kissimmee River/C-38 Canal, were accessible to manatees within the Lake Okeechobee system. An ambient water temperature of 65° F was selected to represent the trigger at which point ASR well discharges could support manatee thermal refugia and require continued discharge until ambient water temperature rise.

Figure 6-12 Water Temperature versus Lake Levels for ASR C-38S below presents the monthly water temperature data from monitoring station KISSR0.0, located at the mouth of the Kissimmee River/C-38 Canal. This is the closest long-term water quality monitoring station to the proposed site for the C-38S ASR and would represent conditions that manatees would experience prior to arriving at the C-38S ASR site when traveling from the lake. Examining the water temperatures recorded monthly at this station from 2010 to 2019, there were 13 records of the water temperature dropping below the 65° F trigger temperature. Using the most conservative water level trigger for when ASR well water may be recovered (13 ft), there were three (3) instances when the lake level dropped below the trigger and the ambient water temperature was also below the trigger. These three (3) monthly water temperature readings were all recorded during a single winter season with temperature readings taken on December 15, 2010, January 4, 2011, and February 14, 2011. If the ASR recovery trigger is changed to a lake level of 12.5 ft, only the January and February 2011 samples meet the criteria. For an ASR recovery trigger set at a lake level of 12 ft, there are no instances from 2010 to 2019 when hypothetical ASR recovery water would have been discharged into ambient waters less than 65° F at this site.

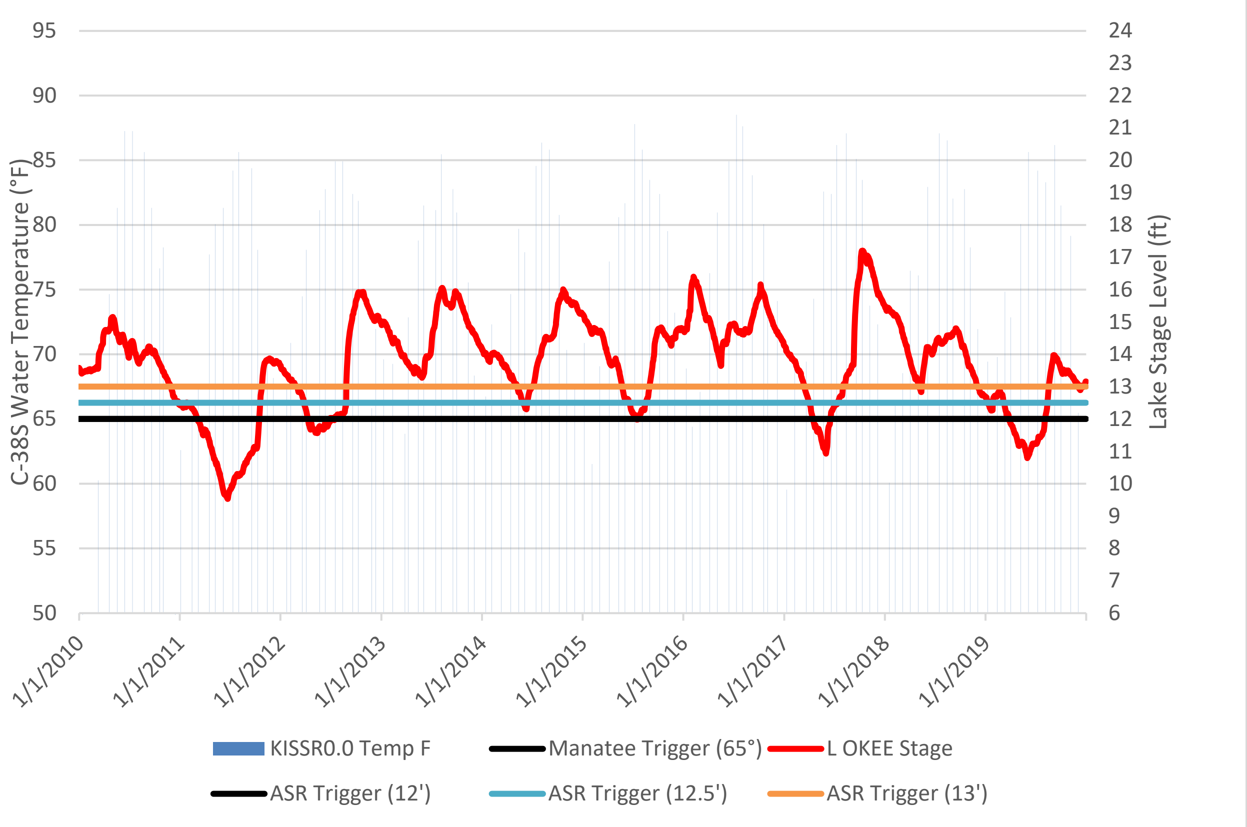


Figure 6-12 Water Temperature versus Lake Levels for ASR C-38S

Figure 6-13 Water Temperature versus Lake Levels for ASR C-38N below presents the water temperature data from monitoring stations C38W and S65E, located downstream and upstream, respectively, of the proposed site for ASR C-38N. From 2010 to 2019, water temperature readings were collected at least monthly from C38W, and approximately twice per month from S65E. Examining the water temperatures recorded at these stations, there were 14 records of water temperatures below the 65° F trigger temperature at C38W and 22 records of water temperatures below 65° F at S65E. Using the most conservative water level trigger for when ASR well water may be recovered (13 ft), there were seven (7) instances when the lake level dropped below the trigger and the ambient water temperature was also below the trigger at least one (1) of the monitoring stations. Five (5) of these readings were recorded between December 9, 2010 and January 24, 2011. The other two (2) records were from January 22 and 28, 2019. If the ASR recovery trigger is changed to a lake level of 12.5 ft, three (3) records meet the criteria recorded on January 10 and 24, 2011 and January 22, 2019. For an ASR recovery trigger set at a lake level of 12 ft, there are no instances from 2010 to 2019 when hypothetical ASR recovery water would have been discharged into ambient waters less than 65° F at this site.

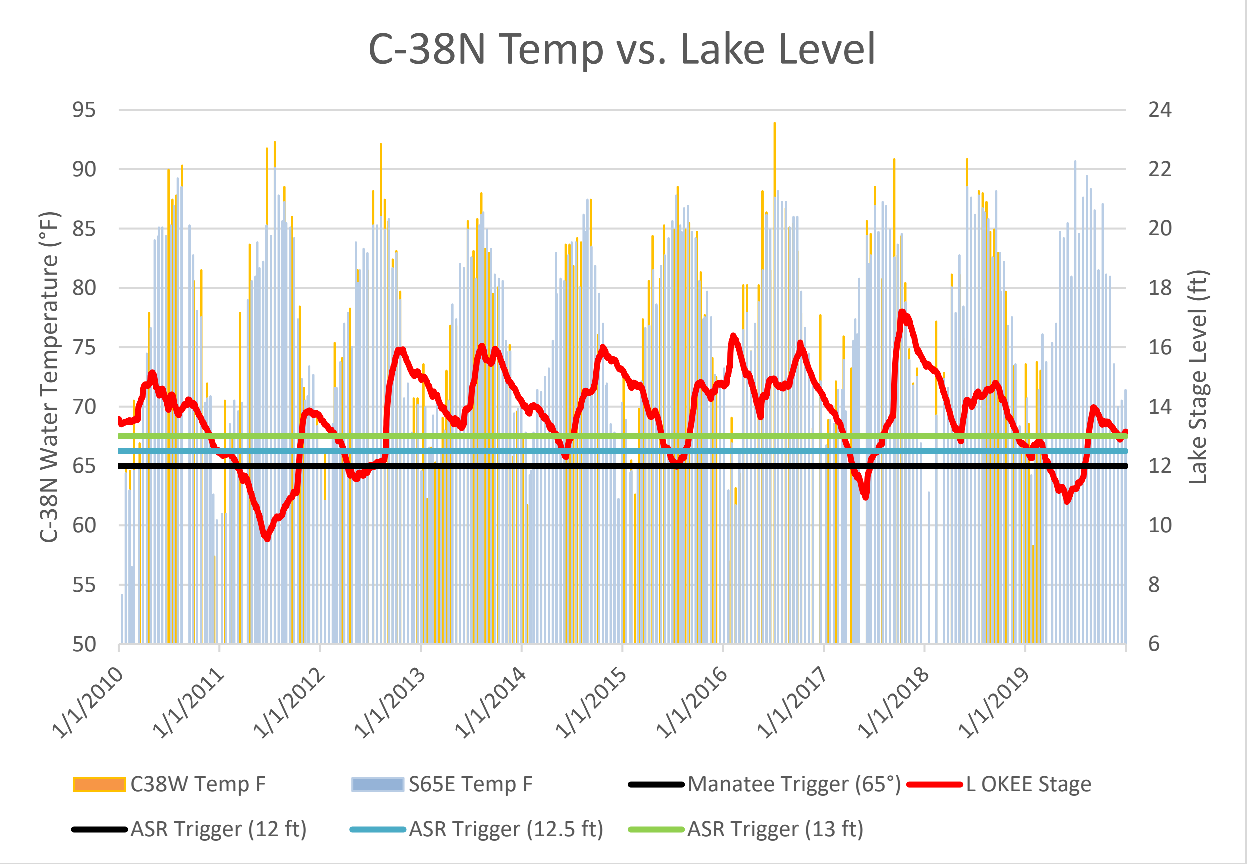


Figure 6-13 Water Temperature versus Lake Levels for ASR C-38N

In its 2019 report, USFWS writes that when ambient water temperatures in Lake Okeechobee begin to drop in winter, manatees should migrate to coastal areas. Additionally, USFWS notes that hydrologic model scenarios conducted as part of a 2014 Ecological Risk Assessment indicated no occurrences where simulated ASR discharges that were initiated in November or December, were shut off during the coldest winter months (prior to April). Due to these factors, USFWS concluded that the risk of manatee mortality from thermal stress from ASR operation was minimal (USFWS, 2019). The data presented above support these findings and indicate that the minimal occurrence of scenarios where lake water levels might initiate ASR discharges during ambient conditions that may be critical to manatees may best be managed through operational means, rather than implementation of elaborate engineering solutions.

Further evaluation of relationship between ambient water temperatures and thermal discharge associated with ASR operation can be found in **Appendix D.** The evaluation considered the assimilative capacity of the Kissimmee River as the source waterbody and how the ambient water temperature is affected by introduction of warmer discharge from ASR well recovery. Preliminary findings of this evaluation indicate that minimizing the creation of potential thermal refugia is best achieved by maintaining a low ratio of ASR discharge flow relative to Kissimmee River flow, maximizing the rate at which the two flows mix, and reducing ASR well discharge flow as the temperature differential between ASR discharge and ambient increases. Since the lake level does not appear to correlate well with the Kissimmee River flow, operational considerations to avoid creation of thermal refugia should consider Kissimmee River flow as the one of the limiting factors for determining ASR recovery flow available during periods of low lake temperature.

6.3.2 Discharge Piping

The Kissimmee River is a Class III freshwater stream, which is currently not meeting standards for dissolved oxygen (DO), so permit conditions will require discharges to meet minimum dissolved oxygen limits. During periods of recovery, water will be discharged via a single pipe from each well pair to concrete box on the adjacent canal bank. These discharge pipes would be approximately 20-inch-diameter and incorporate an eductor near the end to entrain air and increase DO prior to discharge. A conceptual layout for ASR piping discharge is included in **Figure 6-14** C-38S Conceptual Discharge Piping from ASR Wells to C-38 Canal**.** A conceptual sketch of a discharge structure is included as **Figure 6-15 .** Note that pre-mixing discharge flow with ambient from the source waterbody is identified in **Appendix D** as a potential method for minimizing potential for manatee thermal refugia. The pre-mixing can be achieved by drawing water into the raw water intake system and distributing to the various discharge location independent of the educator. Piping for pre-mix discharge is not include in **Figure 6-15 .**

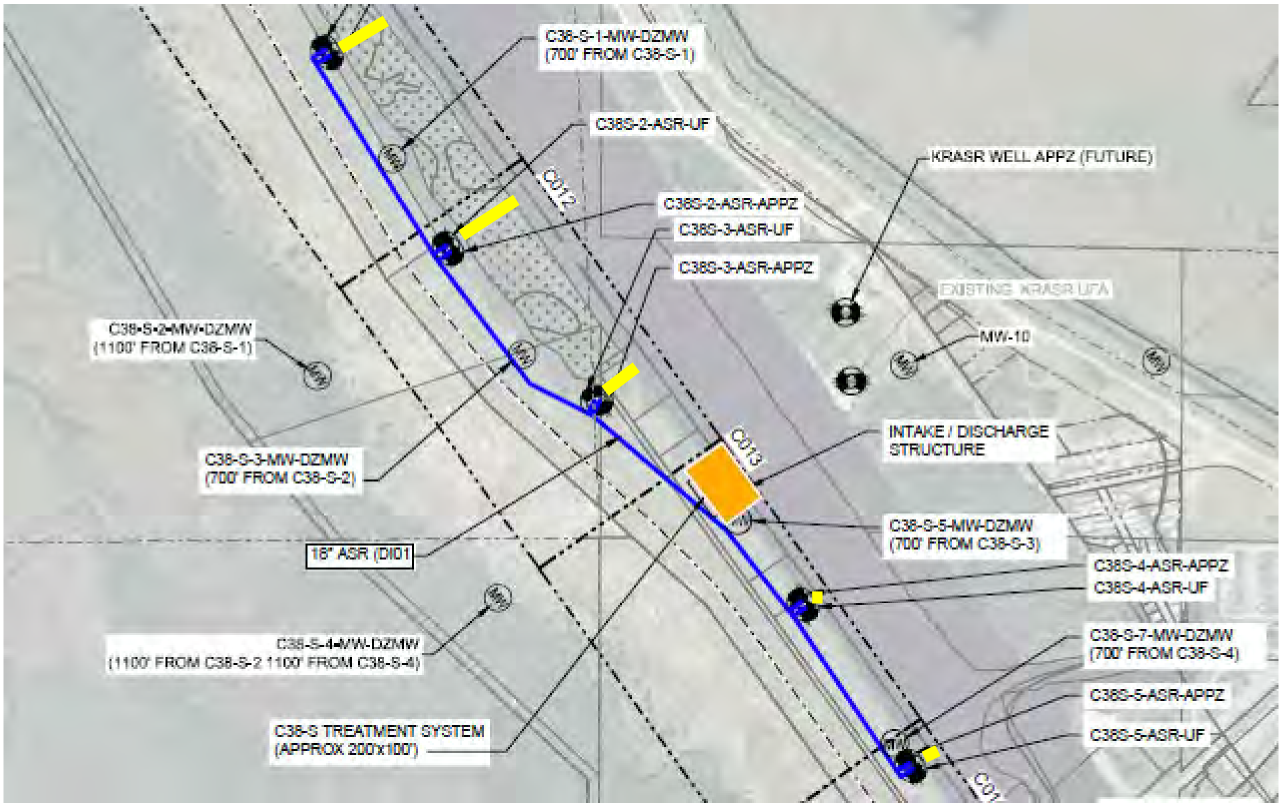


Figure 6-14 C-38S Conceptual Discharge Piping from ASR Wells to C-38 Canal

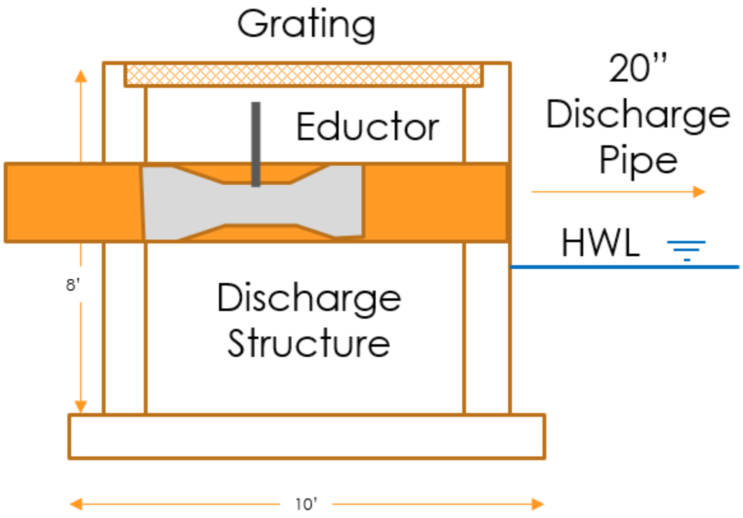


Figure 6-15 Conceptual Discharge Structure

7.0 CAPITAL AND OPERATING EXPENSE ESTIMATES

7.1 CAPITAL COST ESTIMATE

This section contains the construction cost and capital expense estimates (CAPEX) for each alternative. In line with the classification of estimating, a contingency allowance of 30% is considered in the cost estimates.

A Class 5 Opinion of Probable Construction Costs (OPCC) as defined by the Association for the Advancement of Cost Engineering International (AACEI), Recommended Practice No. 18R-97 has been developed for the plant upgrades of each of the treatment alternatives. This level of cost is a planning level order of magnitude cost with an expected accuracy range of -20% to -50% below and 30% to 100% above.

Table 7-1 CAPEX for Process/Treatment Alternatives (in Millions of Dollars)

Process/Treatment Alternative	**Alt 1A**	**Alt 1B**	**Alt 1C**	**Alt 2A**	**Alt 2B**
	Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, MF/UF	UF, NF
Intake Screening	$2.70	$2.70	$2.70	$2.70	$2.70
Raw Water Pump Station	$4.00	$4.60	$4.00	$4.60	$4.30
Strainer					$3.00
Stage 1 Media Filtration	$47.10	$34.30			
Coagulation System		$0.60		$0.60	
Stage 2 Media Filtration		$38.60			
MIEX System			$28.10		
MIEX Regeneration			$6.30		
Channel UV System	$17.90		$17.70		
MF/UF Membrane				$75.60	$29.80
Wet Well and Intermediate Pumps	$3.90		$3.90		$8.90
NF Membrane					$27.90
Pressure UV System		$19.10			
Backwash Pond System	$0.90	$0.90			
Dewatering (Centrifuge)				$7.90	
Deep Inject Well			$8.80		$15.10
Elect/Control Bldg & Misc Site/Civil	$4.60	$4.80	$4.30	$8.50	$11.50
Electrical Equip-Dist & Control	$5.20	$7.10	$4.10	$3.40	$10.70
Subtotal	**$86**	**$113**	**$80**	**$103**	**$114**

Lower CAPEX alternatives (green) are considered more favorable than lower scoring (red). CAPEX for alternatives 1B and 2B have are nearly equally high around $114 million. Alternative 1C had the lowest CAPEX cost $80 million. Alternatives 1A had a slightly higher CAPEX costs of $86 million. Alternative 2A had a mid-range CAPEX cost of $103 million, respectively. A detailed OPCC is provided in **Appendix E.**

7.2 OPERATING EXPENSE ESTIMATES

Estimates of Operating Expenses (OPEX) were evaluated on the basis of energy, chemicals, labor, maintenance and repair, sludge hauling and disposal, liquid waste disposal and miscellaneous (See **Appendix F** for details). Energy costs include pumping for primary and secondary flow streams, mixers, sludge collection, UV power draw, and other electrical equipment. Chemicals include coagulant, IX resin, membrane cleaning chemicals, and UV cleaning acid.

Labor costs include burden costs for estimated full-time equivalents (FTE) for supervisors, operators, technicians, and administrative assistants. Sludge disposal costs include aluminum sludge storage, hauling, and disposal. Ion exchange waste brine was assumed to be hauled as well. Miscellaneous operating costs are items not specifically called out above and include materials, contract labor and technicians, diesel fuel and calibration chemicals for instruments. Unit costs for each of the above operating cost categories were obtained from the similar projects or from vendors. Detailed design criteria are provided in **Appendix B.**

OPEX costs are summarized in **Table 7-2 Summary of Annual Forecasted OPEX in 2022 (in Million Dollars).**

Table 7-2 Summary of Annual Forecasted OPEX in 2022 (in Million Dollars)

OPEX Cost Category	**Alt 1A**	**Alt 1B**	**Alt 1C**	**Alt 2A**	**Alt 2B**
	Media Filtration, UV Channel	2 Stg Media Filtration, Coag, UV Vessel	Ion Exchange (MIEX), UV Channel	Coag, MF/UF	UF, NF
Energy	$1.34	$1.50	$1.28	$0.92	$2.19
Chemical	$0.00	$1.41	$2.40	$1.40	$0.03
Labor	$1.38	$1.50	$1.64	$1.52	$2.12
Sludge Hauling	$0.07	$0.39	$0.00	$0.24	$0.39
Consumables	$0.75	$1.97	$0.45	$0.40	$2.14
Total OPEX	**$3.54**	**$6.77**	**$5.77**	**$4.47**	**$6.87**
OPEX (6-Month Operation)	**$1.77**	**$3.39**	**$2.89**	**$2.24**	**$3.44**
Total OPEX ($/kgal)	$0.20	$0.38	$0.32	$0.25	$0.38

Lower OPEX cost alternatives (green) are considered more favorable than lower scoring (red) by category.

OPEX costs were assumed for a 6-month treatment/storage period annually, with costs for energy, chemical, sludge hauling, and consumables calculated accordingly. Labor, however, was assumed for a full 12-month period. For Alternative 1A - Media Filtration, UV Channel; the 6-month OPEX is forecast as $1.77 million. For Alternative 1B - 2 Stg Media Filtration, Coag, UV Vessel; the 6-month OPEX is forecast as $3.39 million. For Alternative 1C - Ion Exchange (MIEX), UV Channel; the 6-month OPEX is forecast as $2.89 million. For Alternative 2A - Coag, MF/UF; the 6-month OPEX is forecast as $2.24 million. For Alternative 2B - UF, NF; the 6-month OPEX is forecast as $3.44 million.

Energy costs are fairly consistent between the alternatives 1A, 1B and 1C (yellow). Energy costs for alternative 2A were lowest and 2B were highest, likely due to the intermediate pumping and pressure required for nanofiltration.

Chemical costs for Alternatives 1B and 2A appear very similar, however, the lower conceptual coagulant dose for alternative 2A is offset by CIP chemical cost for membranes. Chemical costs for alternative 1C were significantly higher than others due to the proprietary resin and salt required.

Labor is expected to be the highest for Alternative 2B, where additional technicians are needed for NF membranes and ancillary equipment. Alternative 1C is the next most expensive in terms of labor required for operating and maintaining IX resin regeneration systems. Labor expected for alternatives 1B and 2A were comparable. Labor for alternative 1A was lowest due in part to the lack of organics removed by coagulant or requiring sludge disposal.

Sludge disposal costs were 0 for Alternative 1C, however the organic brine from resin regeneration would require the capital cost for disposal by deep injection well. Sludge disposal for alternatives 1B and 2B were nearly identical due to sludge yield and relatively low recovery rates compared to alternative 2A which had the highest recovery rates.

Consumables for alternative 2B were highest, due to the relatively low life expectancy of polymer membranes. However, consumables for alternative 1B were not far behind, due to the high number of lamps required for pressure vessel UV disinfection, and need to change out media in a greater number of vessels for filtration compared to alternative 1A. Consumables for alternative 1C were mid-range due to resin and salt needs, despite relatively few lamps in comparison to other UV options. Comparatively, the cost for consumables of alternative 2A were higher than 1A but appear to be offset by the longer life expectancy of ceramic membranes compared to the media filtration or polymer membranes.

Forecast OPEX costs summarized in Table 7-1 are based on calculated costs, with adjustments for varying escalation rates for OPEX cost categories. These escalation rates are summarized in **Table 7-3 OPEX Cost Category Annual Escalation Rates for Unit Costs.**

Table 7-3 OPEX Cost Category Annual Escalation Rates for Unit Costs

OPEX Cost Category	Annual Escalation for Unit Cost
Energy	**5.0%**
Chemicals	**4.0%**
Labor	**3.0%**
Sludge Hauling	**5.0%**
Consumables	**2.5%**

The contribution of each cost category to the overall annual OPEX is a function of these differing escalation rates. The impact of escalation rates on total OPEX over time are illustrated in **Figure 7-1** and **Figure 7-2** (in 2022 dollars), respectively.

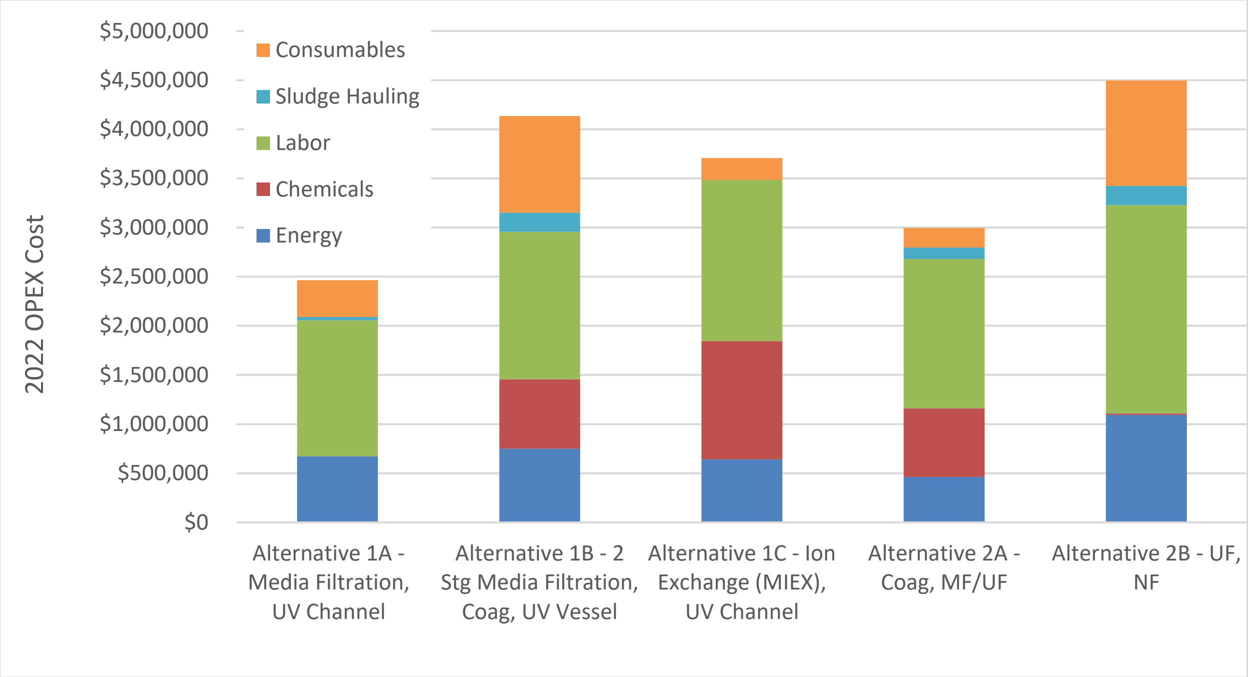


Figure 7-1 Annual 2022 Forecasted OPEX by Cost Category

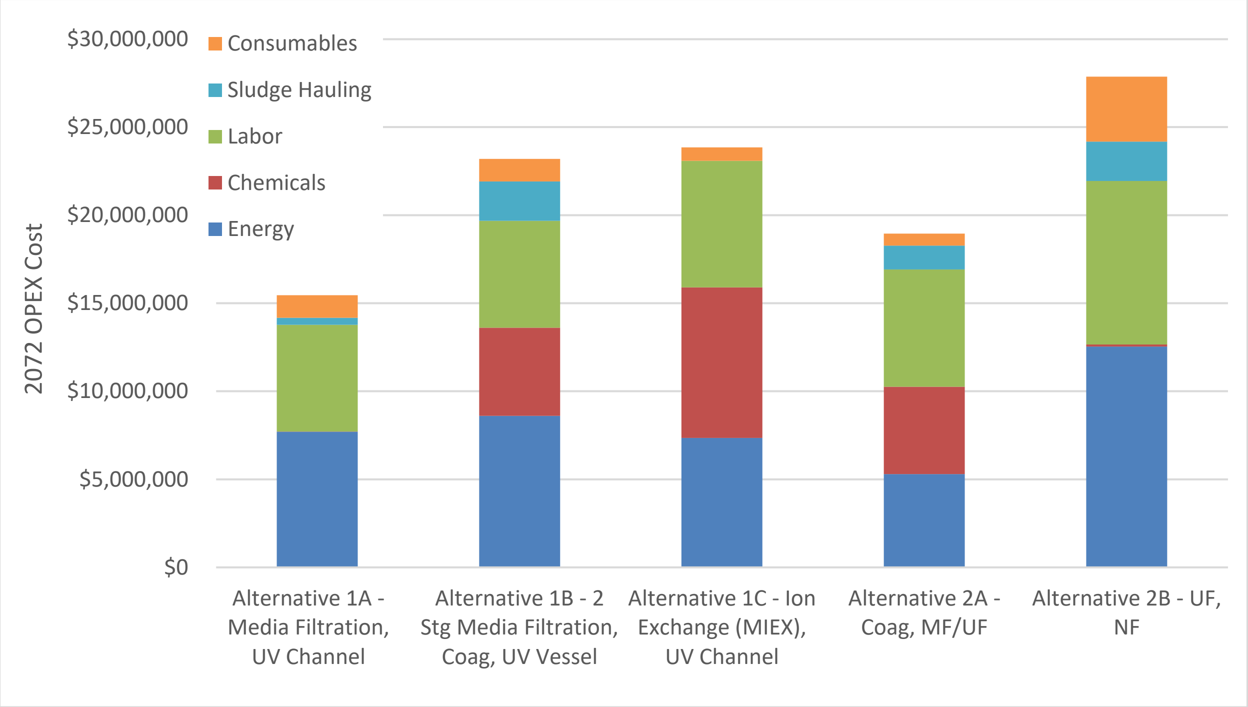


Figure 7-2 Annual 2072 Forecasted OPEX by Cost Category

The development of OPEX over the 50 years of operation for each of the alternatives is presented **Figure 7-3 Forecasted Escalation of Operational Expenditures.** The OPEX for Alternative 1A - Media Filtration, is lowest, followed closely by Alternative 2A - Coag, MF/UF. OPEX for Alternative 1C - Ion Exchange (MIEX), UV Channel is slightly higher, while Alternative 1B - 2 Stg Media Filtration, Coag, UV Vessel; and Alternative 2B - UF, NF are nearly identical and the highest.

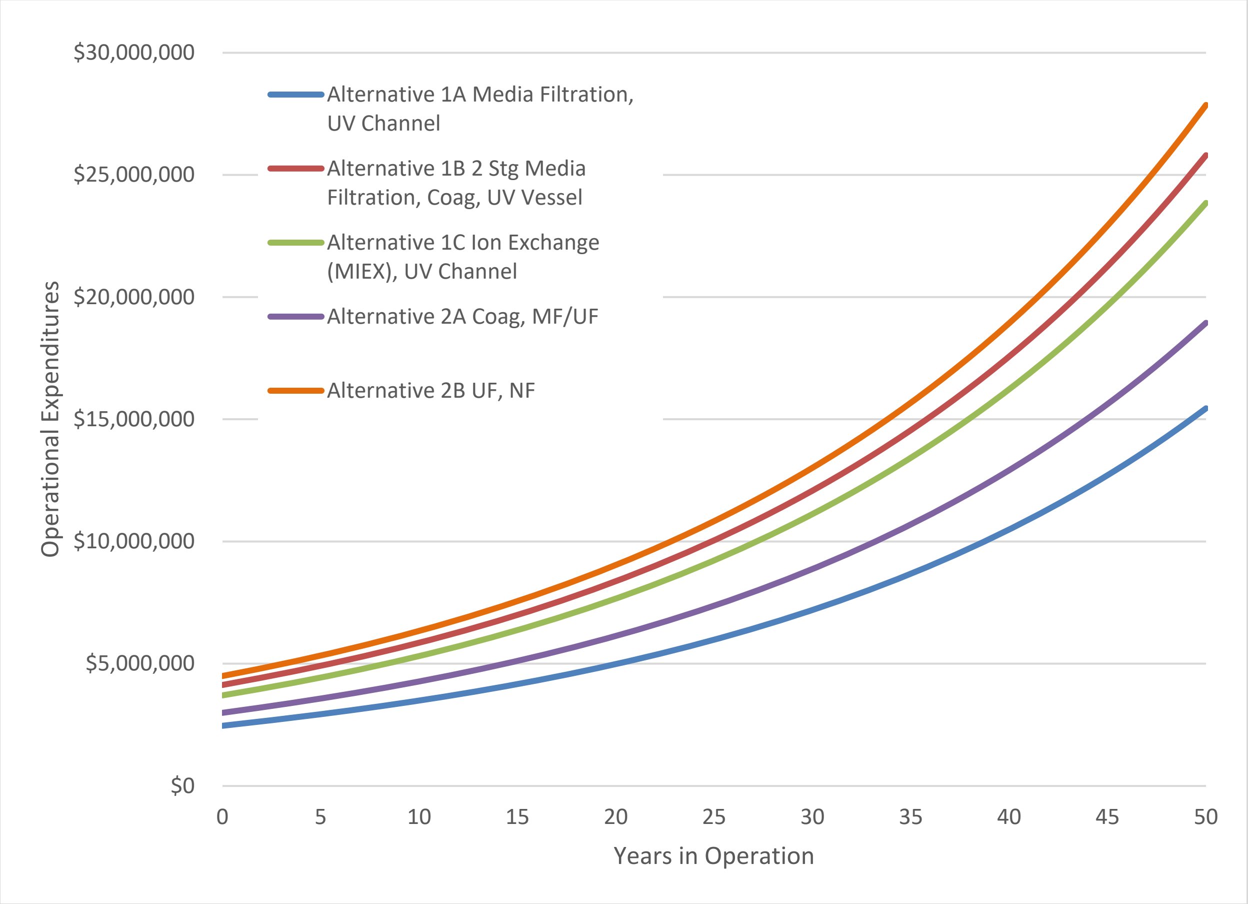


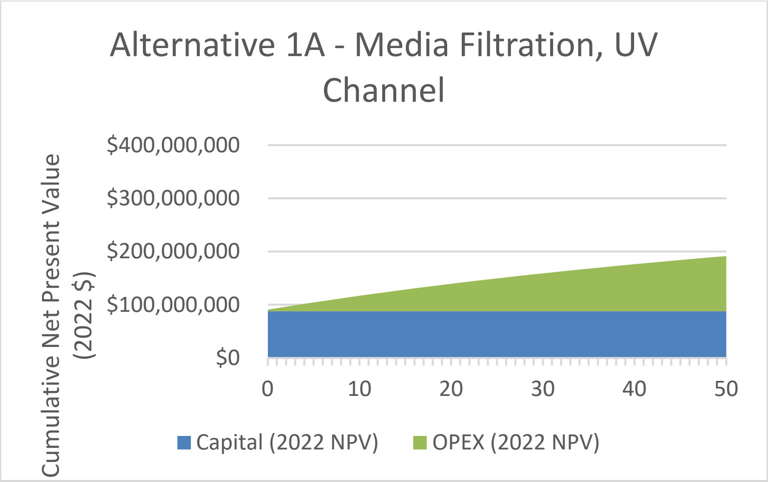
Figure 7-3 Forecasted Escalation of Operational Expenditures

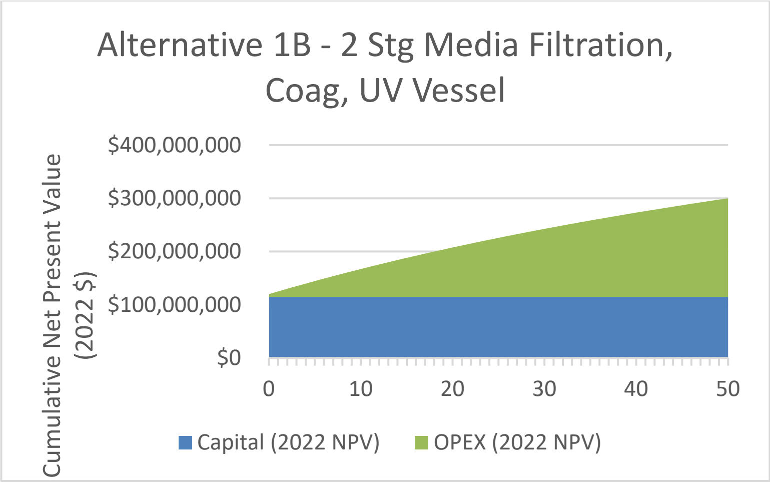
Details of all OPEX calculations are provided in **Appendix F** with unit costs for consumables. Bases for escalation rates were summarized in **Table 7-3 OPEX Cost Category Annual Escalation Rates for Unit Costs.**

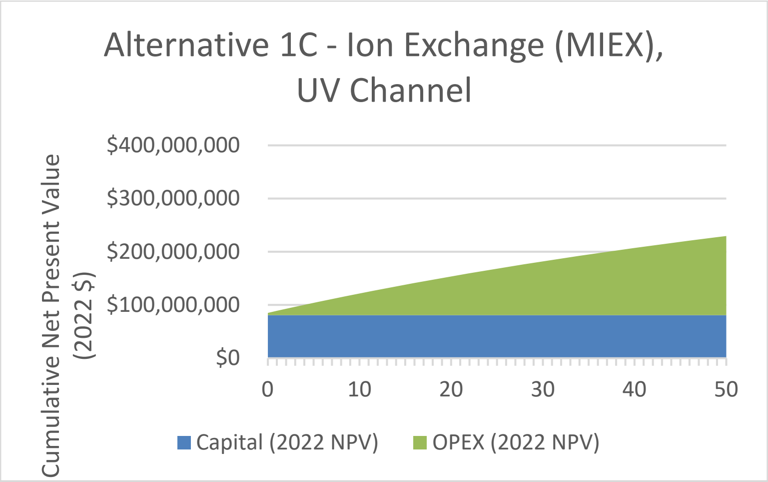
7.3 NET PRESENT VALUE

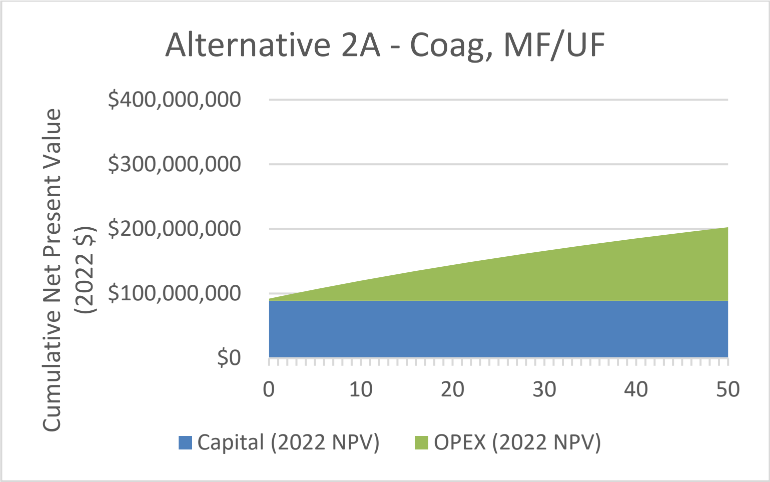
CAPEX and OPEX costs for each alternative are illustrated as stacked graphs in **Figure 7-4.** A comparison of net present value alternatives are presented in **Figure 7-5 Net Present Value of Alternatives during 50 years of Operation.**

Capital and Operating Expense Estimates


Alternative 1A - Media Filtration, UV Channel


Alternative 1B - 2 Stg Media Filtration, Coag, UV Vessel


Alternative 1C - Ion Exchange (MIEX), UV Channel


Alternative 2A - Coag, MF/UF

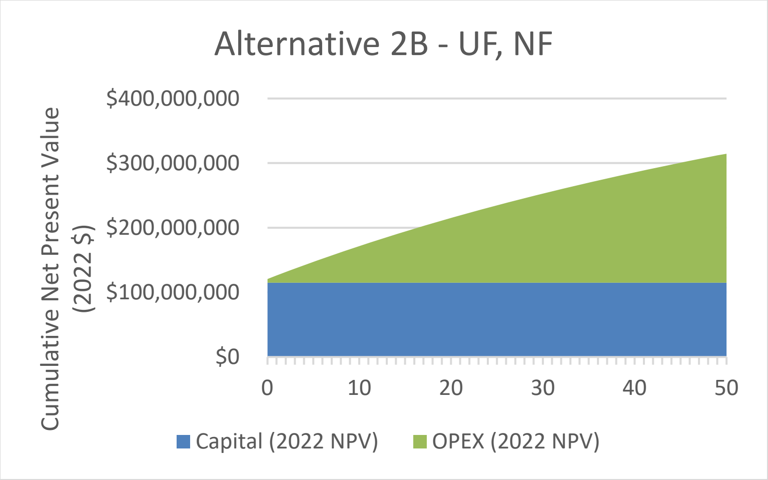


Figure 7-4 Stacked Cumulative Costs for Treatment Alternatives

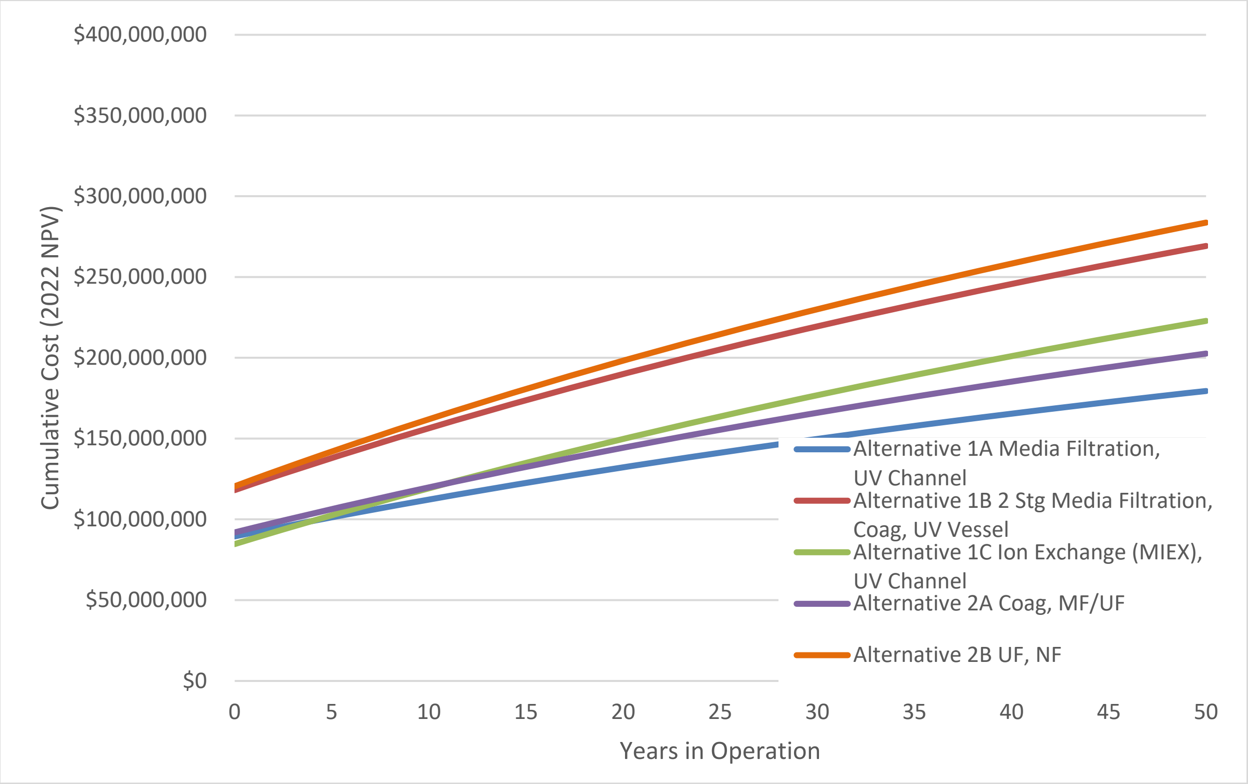


Figure 7-5 Net Present Value of Alternatives during 50 years of Operation

The details of the Net Present Value (NPV) calculations are provided in **Appendix F** Operating Cost Estimate. Net Present Value calculations assume a 50-year life cycle and an estimated construction completion date in 2022. The CAPEX of alternatives is obtained from **Section 7.1.**

8.0 CONCLUSIONS AND RECOMMENDATIONS

UIC Regulations require that water being recharged through an ASR well into an Underground Source of Drinking Water (USDW) must meet drinking water standards (DWS). A total coliform limitation of 4 cfu/100 mL is the standard applicable for the UFA and APPZ. Meeting this standard by filtration and UV has been challenging for the KRASR pilot.

Ultraviolet technologies are an attractive alternative because they do not rely on disinfectant residual for inactivation and do not create regulated by-products. In contrast, chlorine can meet the 4-log total coliform inactivation even at low UV Transmittance (UVT), but the high doses required would likely create significant regulated disinfection by-products and require post-treatment quenching to limit arsenic mobilization. Unfortunately, high color surface water and coincident low UVT present challenges to using UV disinfection. Pretreatment for color prior to disinfection is key to successful implementation as experienced at the KRASR site.

Pretreatment with mechanical strainers and filters can capture large suspended solids but are ineffective at removing dissolved organic compounds which create color. Pressure media filters can remove smaller particles but cannot remove dissolved organic compounds (DOC) without the aid of a coagulant. Coagulants can effectively help remove DOC. However, they have been shown to create maintenance issues in the filters at the KRASR site without a first-stage roughing filter. Adding a second stage would address this issue but requires approximately 50% more filtration capacity. In addition, backwashing requirements are higher for filters, requiring backwash ponds, which are not required for some membrane technologies.

Microfiltration membranes described in Alternative 2A can be used with coagulants to remove DOC. Additionally, coliform bacteria can be excluded by MF/UF membranes openings which are 5 times smaller than the organism. This provides a dual treatment/disinfection benefit by simultaneously disinfecting to meet UIC regulations and reducing DOC to secondary drinking water standards. This level of treatment can be achieved without the significant OPEX of NF membranes described in alternative 2B, or CAPEX of an accompanying deep well. Thus, MF/UF membranes can meet and exceed regulatory requirements without UV downstream, reducing operational complexity and capital cost. Notably, ceramic membrane manufacturing advancements over the past decade have yielded more durable elements which provide significantly longer life cycle than polymer membranes. Flat plate membrane dewatering systems can also help minimize footprint of this treatment process approach.

Operational measures are the preferred alternative for minimizing the potential creation of manatee thermal refugia associated with discharge of ASR recovery during the winter months. As ambient water temperatures (Kissimmee River and Lake Okeechobee surface water) approach the 65° F manatee trigger, discharge flow from ASR recovery may need to be reduced to prevent formation of a thermal refugia. The permissible discharge flow will be dependent on Kissimmee River inflow, differential temperature between ambient and recovered water, and FDEP/FWC permit conditions. Further thermal mixing analysis will be necessary to establish discharge parameters as the system design is advanced. If discharge parameters are too restrictive during periods of low flow in the Kissimmee River, inclusion of piping and valves to facility pre-mixing with source water drawn from the raw water intake may be worth further consideration. Note that manatee thermal refugia limitations are only anticipated at Kissimmee River Sites C-38N and C-38S as the remaining sites are upstream of the S-191 control structure which is expected to limit upstream passage of manatee.

To increase dissolved oxygen levels in the ASR recovery discharge and improve overall water quality in the source waterbodies, a simple concrete discharge structure with an eductor on the discharge pipe is proposed. Separate discharge structures will be provided for each well head pair to accommodate smaller piping and functional limits of eductors.

8.1 NEXT STEPS

Pilot scale testing of the selected alternative is recommended to allow demonstration of technology over a range of water quality conditions prior to full-scale investment and implementation.

- Define membrane pilot testing goals:
  1. Confirm maximum sustainable flux (and possibly how much greater flux is for ceramic than polymeric)
  2. Determine fouling characteristics, cleaning frequency, and irreversible fouling
  3. Obtain additional raw water quality information for example iron levels
- Issue Request for qualifications (RFQ) to membrane manufacturers for pre-selection to:
  1. Confirm experience with removal of organics with coagulants,
  2. Express interest in systems which can be warrantied for longer periods.
  3. Determine if the vendor can supply 50 MGD system within given footprint available
  4. Allow teaming arrangements between membrane OEMs and Integrators
     - RFQ Tech Specs could include preselection, membrane filtration system (MFS), and Net Present Worth Calculation Spreadsheet.
- Develop Pilot Testing Protocols:
  1. Determine duration of pilot testing, potential standby period, duration of remaining testing
  2. Confirm performance as proposed in response to RFQ
  3. Determine coagulant dose/response for varying raw water quality

4. Determine additional water quality sampling to confirm manganese levels and allow for speciation of iron should treatment for removal become necessary.

- Design and Install Pilot

  1. Determine if it must be bid through a GC or if a smaller specialty firm could set up
  2. Plan layout and process connections for ancillary equipment, intake screening, raw water pumping, holding tank, pilot pad, shade, protection. Make accommodations for containerized or skid-mounted pilot units.
  3. Determine permeate discharge location and pump out frequency for backwash holding tank.
  4. Allow for bench scale testing of thickened organic-coagulant backwash sludge to determine dewaterability of residuals for mechanical dewatering system design.

- Develop Pilot Operation Scope

  1. Concurrent with procurement and installation steps
  2. Determine who operates pilot and staffing requirements.
     - Shifting costs to vendors to operate pilots could save money. However, information about operational interruptions and adjustments made on-the-fly may not be fully transparent and documented for O&M understanding. Consultant operation of pilot can ensure response and documentation of failures and alarms.
  3. Conduct water quality sampling and testing in accordance with protocol

9.0 REFERENCES

Andreatta, D. (2007). *A Summary of Water Pasteurization Techniques.* Columbus, OH: SEA Ltd.

Carollo, Engineers. (2009). *L-63N Canal Aquifer Storage and Recovery System Reactivation Rehabilitation Design.* Pre-Final Design Report South Florida Water Management District.

CH2M Hill. (2003). *Aquifer Storage And Recovery Pilot Project Surface Facilities Design For The Lake Okeechobee And Hillsboro Canal Sites.* In 2004 Final ASR Pilot Project Design Report Appendix D.

CH2M Hill. (2004). *Summary of Validated Water Quality Data Lake Okeechobee ASR Pilot Project.* In 2004 Final ASR Pilot Project Design Report Appendix B.

Chapman, F. (2018, November). *Farm-raised Channel Catfish*. Retrieved from EDIS University of Florida IFAS Extension: https://edis.ifas.ufl.edu/fa010

Cooper, J. (1978). Identification of Eggs, Larvae, and JUveniles of the Rainbow Smelt, Osmerus mordax, with Comparisons to LArval Alrwife, Alosa pseudoharengus, and Gizzard Shad, Dorosoma cepedianum. *Trans American Fish Society Vol. 107, No. 1*, 56-62.

Currier, M. (2018). *Animal Diversity Web*. Retrieved from https://animaldiversity.org/accounts/Pomoxis_nigromaculatus/

Davis, J., & Lock, J. (1997, August). *Largemouth Bass Biology and Life History.* Retrieved from Southern Regional Aquaculture Center: https://appliedecology.cals.ncsu.edu/wp-content/uploads/SRAC-0200.pdf

FWC. (2017). *FWC ASR Technical Support.*

FWC. (2019). *Black Crappie Management Plan.* Florida Fish and Wildlife Conservation Commission. Retrieved from https://myfwc.com/media/18824/fwblackcrappieplan.pdf

Jones, P., Martin, F., & Hardy, J. (1978). Development of fishes of the Mid-Atlantic Bight. An atlas of eggs, larval and juvenile stages. In *Acipenseridae through Ictaluridae. U.S. Fish Wildl. Ser. Biol. Serv. Program FWS/OBS-78/12.* (p. 336). U.S. Fish and Wildlife Service.

Klumb, R., Rudstam, L., & Mills, E. (2003). Comparison of Alewife Young-of-the-Year and Adult Respiration and Swimming Speed Bioenergetics Model Parameters: Implications of Extrapolation. *Transactions of the American Fisheries Society*.

Lundgren, E. (2014). *A method for water disinfection with solar pasteurisation for rural areas of Bangalesh.* Uppsala, Sweden: Department of Earth Sciences, Air, Water and Landscape Science, Uppsala University.

Meng, L. (1993). Sustainable Swimming Speeds of Striped Bass Larvae. *Transactions of the American Fisheries Society, 122*(5), 702-708.

Meyer, F. (2011). Development of Some Larval Centrarchids. *The Progressive Fish-Culturist*, 130-136.

Michaletz, P. (1998). Effect of Body Size on Fecundity, the Gonadosomatic Index, Egg Size, and Timing of Spawning of Gizzard Shad. *Journal of Freshwater Ecology*.

Murdy, E., Baker, R., & Musick, J. (1997). Fishes of Chesapeake Bay. *Smithsonian Institution Press*.

Oplinger, R., & Wahl, D. (2014). Egg characteristics and larval growth of bluegill from stunted and non-stunted populations. *Journal of Freshwater Ecology* .

Peterson, R. H., & Harmon, P. (2001). Swimming Ability of Pre-Feeding Striped Bass Larvae. *Aquaculture International*, 361-366.

R2T, Inc. (2009). *Source Water Pre-Treatment Technical Memoranda .* In 2013 Draft CERP ASR Technical Data Report Appendix E.

Scott, W., & Crossman, E. (1973). Freshwater Fishes of Canada. *Bulletin 184*, 184-966.

Sharp, T. S., Rodriguez, J., Rearden, K., McLaughlin, G., & Pyne, R. D. (2000). *Aquifer Storage and Recovery Permitting -A Historical and Future Perspective.* CH2M Hill.

Steed, E. (2018). *Micropterus salmoides*. Retrieved from Animal Diversity Web: https://animaldiversity.org/accounts/Micropterus_salmoides/

Tetra Tech. (2007). *Comprehensive Everglades Restoration Plan Aquifer Storage and Recovery Baseline Environmental Monitoring Summary Report.* Water Quality Assessment Division. West Palm Beach: South Florida Water Management District.

Tomljanovich, D., & Heuer, J. (1986). Passage of Gizzard Shad and Threadfin Shad Larvae through a Larval Fish Net with 500-µm Openings. *American Fisheries Society*.

USACE. (2004). Comprehensive Everlades Restoration Plan. In USACE, *Aquifer Storage and Recovery Pilot Project Design Report* (pp. 27-28). https://books.google.com/books?id=ijo0AQAAMAAJ&pg=RA2-PA27&lpg=RA2-PA27. Retrieved from https://books.google.com/books?id=ijo0AQAAMAAJ&pg=RA2-PA27&lpg=RA2-PA27

USACE. (2008). *Summary of UV Disinfection Testing Done at Kissimmee ASR in November 2008.* USACE.

USACE and South Florida Water Management District. (2013). *CERP Aquifer Storage and Recovery Pilot Project.* Final Technical Data Report.

USACE and South Florida Water Management District. (2015). *Regional Aquifer Storage And Recovery Technical Data Report.* ASR Regional Study.

Wallus, R., Yeager, B., & Simon, T. (1990). Reproductive Biology and Early Life History of Fishes in the Ohio River Drainage, Volume 1. In *Acipenseridae through Esocidae.* (p. 273). Chattanooga: Tennessee Valley Authority.

APPENDIX H:
SURVIVAL OF BACTERIAL INDICATORS AND THE FUNCTIONAL DIVERSITY OF NATIVE MICROBIAL COMMUNITIES IN THE FLORIDAN AQUIFER SYSTEM, SOUTH FLORIDA

Survival of Bacterial Indicators and the Functional Diversity of Native Microbial Communities in the Floridan Aquifer System, South Florida

By John T. Lisle

Open-File Report 2014-1011

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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Conversion Factors

Multiply	By	To obtain
Length		
nanometer (nm)	0.00000003937	inch (in.)
micrometer (µm)	0.00003937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.394	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.621	mile (mi)
Volume		
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.264	gallon (gal)
Flow velocity		
meter per day (m/d)	3.281	foot per day (ft/d)
Flow rate		
milliliter per minute (mL/min)	0.0002642	gallon per minute (gal/min)
liter per minute (L/min)	0.2642	gallon per minute (gal/min)
liter per day (L/d)	0.2642	gallon per day (gal/d)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
Energy		
joule (J)	0.0000002	kilowatthour (kWh)
kilojoule (kJ)	0.0002	kilowatthour (kWh)
Diffusion rate		
millimeter per hour (mm/hr)	0.03937	inch per hour (in/hr)
Diffusion coefficient		
centimeter squared per second (cm^2/s)	0.1550	inch squared per second (in^2/s)
meter squared per second (m^2/s)	10.76	foot squared per second (ft^2/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Acronyms

ANAMMOX	anaerobic ammonia oxidation
AOM	anaerobic oxidation of methane
APPZ	Avon Park permeable zone
ASR	aquifer storage and recovery
ATP	adenosine triphosphate
BGE	bacterial growth efficiency
CERP	Comprehensive Everglades Restoration Plan
CFU	colony forming unit
DIC	dissolved inorganic carbon
DNA	deoxyribonucleic acid
DOC	dissolved organic carbon
DPM	disintegrations per minute
EC	*Escherichia coli*
EPA	Environmental Protection Agency
FDEP	Florida Department of Environmental Protection
FEF	free energy flux
fg	femtogram
FI	fluorescence index
FIB	fecal indicator bacteria
HPOA	hydrophobic organic acid
MAR	maximum acquisition rate
λ	wavelength
µg	microgram
µL	microliter
µM	micromolar
mL	milliliter
mM	millimolar
mV	millivolt
mol	mole
NCBI	National Center for Biotechnology Information
nM	nanomolar
NMR	nuclear magnetic resonance
ORP	oxidation/reduction potential
OTU	operational taxonomic unit
PA	*Pseudomonas aeruginosa*
PBS	phosphate buffered saline
PCA	principal component analyses
PCR	polymerase chain reaction
PIA	*Pseudomonas* isolation agar
PTFE	polytetrafluoroethylene
RASA	Regional Aquifer-System Analysis
RMSE	root mean sum of squared error
rpm	revolutions per minute
rRNA	ribosomal ribonucleic acid
SAGMEG	South Africa Gold Mine Euarchaeotic Group
SUVA	specific ultraviolet absorbance
TCA	trichloroacetic acid
TDS	total dissolved solids
TEAP	terminal electron acceptor process
TOC	total organic carbon
TPIA	transphilic organic acid
UFA	Upper Floridan aquifer
UIC	Underground Injection Control
USDW	Underground Sources of Drinking Water
USGS	U.S. Geological Survey
UV	ultraviolet
VFA	volatile fatty acid

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Survival of Bacterial Indicators and the Functional Diversity of Native Microbial Communities in the Floridan Aquifer System, South Florida

By John T. Lisle

Executive Summary

The Upper Floridan aquifer in the southern region of Florida is a multi-use, regional scale aquifer that is used as a potable water source and as a repository for passively recharged untreated surface waters, injected treated surface water and wastewater, industrial wastes, and greenhouse gases (for example, carbon dioxide). The presence of confined zones within the Upper Floridan aquifer that range in salinity from fresh to brackish allow regulatory agencies to permit the injection of these different types of product waters into specific zones without detrimental effects to humans and terrestrial and aquatic ecosystems. The type of recharge that has received the most regulatory attention in south Florida is aquifer storage and recovery (ASR). The treated water, prior to injection and during recovery, must meet primary and secondary drinking water standards. The primary drinking water standard for the microbiological quality is total coliforms, which have been shown to be difficult to inactivate below the regulatory standard during the treatment process at some ASR facilities. The inefficient inactivation of this group of indicator bacteria permits their direct injection into the storage zones of the Upper Floridan aquifer. Prior to this study, the inactivation rates for any member of the total coliform group during exposure to native geochemical conditions in groundwater from any zone of the Floridan aquifer had not been derived.

Aboveground flowthrough mesocosm systems that maintained native groundwater geochemical conditions, except for pressure, were used to quantify the inactivation rates of two bacterial indicators during exposure to groundwater from six wells that collect water from two ASR storage zones: the Upper Floridan aquifer (UFA) and Avon Park Permeable Zone (APPZ). Each mesocosm contained eight membrane diffusion chambers filled with *Escherichia coli* or *Pseudomonas aeruginosa*. Both bacterial strains followed a biphasic inactivation model. The *E. coli* populations had slower inactivation rates in the UFA (range: 0.217–0.628 per hour (h^{-1})) during the first phase of the model than when exposed to groundwater from the APPZ (range: 0.540–0.684 h^{-1}). These same populations had significantly slower inactivation rates during the second phase of the model, ranging from 0.006 to 0.001 h^{-1} and 0.013 to 0.018 h^{-1} for the UFA and APPZ, respectively. Published inactivation rates of *E. coli* retained in membrane diffusion chambers and exposed to diverse groundwater sources range from 0.004 to 0.029 h^{-1}. The inactivation rates for the first phase of the inactivation models for *P. aeruginosa* were not significantly different between the UFA (range: 0.144–0.770 h^{-1}) and APPZ (range: 0.159–0.772 h^{-1}) aquifer zones. The inactivation rates for the second phase of the model for this bacterial species were also similar between UFA (range: 0.003–0.008 h^{-1}) and APPZ (0.004–0.005 h^{-1}) zones, although significantly slower than the model's first phase rates. There are currently no inactivation data for *P. aeruginosa* in groundwater that is geochemically similar to that in UFA and APPZ for comparison.

Geochemical data were used to determine which dissimilatory biogeochemical reactions were most likely to proceed under the native conditions in the UFA and APPZ aquifer zones using

thermodynamics principles to calculate free energy yields and other cell-related energetics data. The biogeochemical processes of acetotrophic and hydrogenotrophic sulfate reduction and methanogenesis and anaerobic oxidation of methane dominated in all six groundwater sites. All energetically favorable reactions proceeded at, or slightly greater than, the minimum free energy yield (–20 kilojoules per mole, (kJ mol^{-1})), which is the threshold for maintaining cell viability. The free-energy flux rates generated per bacterial cell for performing these biogeochemical reactions ranged from -4.4×10^{-19} to -3.3×10^{-16} kilojoules per cell per second l (kJ $cell^{-1}$ s^{-1}). These flux rate values are similar to those recorded in deep subsurface microbial communities and are threefold to three orders of magnitude greater than the average cell maintenance energy requirement of -1.55×10^{-19} kJ $cell^{-1}$ s^{-1}). The maximum acquisition rates of the limiting substrate (that is, hydrogen, acetate, methane) in each of the energetically favorable reactions by the total native bacterial communities at each sample site ranged from 1.1 to 648 micromolar per day (µM d^{-1}).

A high throughput microarray platform technology, PhyloChip G3, was used to characterize the functional diversity in the native aquifer bacterial communities (bacteria and archaea). The diversity data were used to corroborate the most likely biogeochemical processes with the presence of one or more bacterial phylotypes capable of performing those processes. The bacterial diversity in the groundwater samples was dominated by members of the Pseudomonadaceae and to a lesser extent by members of Anaerolineaceae, Desulfobacteraceae, Peptostreptococcaceae, Lachnospiraceae and Ruminococcaceae families and the phylum Euryarchaeota. The physiological capabilities of members within these groups have been shown to include the biogeochemical processes of primary and secondary fermentation, acetogenesis, methanogenesis, anaerobic methane oxidation, syntrophy with methanogens, ammonification, and sulfate reduction. The functional bacterial diversity data support the likelihood of the energetically favorable biogeochemical reactions being present in this region of the Upper Floridan aquifer and provide insight into the capacity of the native bacterial communities to perform additional types of processes that would be required to sustain viability over geologic time scales.

The data from this study provide the first determination of bacterial indicator survival during exposure to native geochemical conditions of the Upper Floridan aquifer in south Florida. Additionally, the energetics and functional bacterial diversity characterizations are the first descriptions of native bacterial communities in this region of the Upper Floridan aquifer and reveal how these communities persist under such extreme conditions. Collectively, these types of data can be used to develop and refine groundwater models.

Introduction

During 2005, the most recent year for which data have been compiled, a total of 3.1×10^{11} liters per day (L d^{-1}) of groundwater were withdrawn in the United States and 1.6×10^{10} L d^{-1} were withdrawn in Florida (Kenny and others, 2005). The majority of the groundwater in Florida is removed from the Floridan aquifer system, one of the most productive aquifers in the world (Miller, 1990). Although the Upper Floridan aquifer is a primary source of potable water, it is also a multi-use aquifer system because it contains isolated zones of moderate-to-high salinity . These nonpotable zones are currently targeted for passive recharge of stormwater runoff (Bradner, 1991), injection for the disposal of treated sewage and industrial wastes (Anonymous, 2012; Anonymous, 2013c), and recharge of treated surface water for aquifer storage and recovery (ASR) (Anonymous, 2013c). Additionally, the Cedar Keys Formation in the south Florida region of the Floridan aquifer system (Meyer, 1989; Reese and Alvarez-Zarikian,

2006) has been identified as a possible carbon dioxide repository (Poiencot and Brown, 2011; Szulczewski and others, 2012).

The retention of any type of recharged water in the injection zone of a well is dependent upon the stratigraphy of the aquifer in that area, which can be highly variable in this region of the Upper Floridan aquifer (Renken and others, 2005). Describing the hydrogeologic framework of the Upper Floridan aquifer was not part of this project. The reader is directed to detailed descriptions of the Upper Floridan aquifer contained within the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) program reports (Bush and Johnston, 1988; Johnston and Bush, 1988; Krause and Randolph, 1989; Maslia and Hayes, 1988; Miller, 1986; Ryder, 1985; Sprinkle, 1989; Tibbals, 1990). The RASA report by Meyer (1989) specifically describes the hydrogeology of the Upper Floridan aquifer in south Florida where this study was performed. Additionally, the reader is directed to more detailed descriptions of the hydrogeologic framework of two zones within the Floridan aquifer system: the Upper Floridan aquifer (UFA) and Avon Park Permeable Zone (APPZ) (Reese and Richardson, 2008); these zones were sampled during this study.

Although there are several applications for aquifer recharge, ASR has received the most attention in south Florida because of its inclusion in the Comprehensive Everglades Restoration Project (CERP) (*http://www.evergladesplan.org*) as a source of water to augment Lake Okeechobee and maintain surface-water flow rates through the Everglades during periods of drought (U.S. Army Corps of Engineers and South Florida Water Management District, 1999). ASR has also been used successfully to supplement potable water sources (that is, surface water and groundwater) in coastal communities in south Florida. Recharge water injected into Florida ASR wells will reside in or above zones that contain potential sources of potable water (Anonymous, 2013b; Anonymous, 2013c). To protect these native and pristine potable sources from chemical, nutrient, and microbiological contamination, recharge water must meet primary and secondary drinking water standards prior to injection and during recovery (Anonymous, 2013a). Although significant changes in geochemistry have been shown to occur during storage of recharged water in this region of the Upper Floridan aquifer (Mirecki, 2006), these regulatory-related metrics provide little if any insight into the biogeochemical processes that drive these changes (for example, depletion of dissolved oxygen, reduction in oxidation-reduction potential, increase in hydrogen sulfides, reduction in phosphates, and so forth). In addition, the monitoring criterion for the microbiological quality of recharge water is total coliforms (Anonymous, 2013a). Although this group of bacteria is irrelevant to biogeochemical processes in aquifers, their fate and transport in recharge water during treatment and storage is important from a public health perspective (Anonymous, 1989).

Native bacterial communities are viable and productive inhabitants of all subsurface biospheres, including the Upper Floridan aquifer. These communities are capable of aerobic, fermentative, and anaerobic respiration, which can significantly influence the rates of mineral dissolution and (or) precipitation and the fate and transport of metals, organic substrates, and greenhouse gases within the aquifer. The byproducts of these processes can greatly alter the native geochemistry along a natural flow path and along a similar flow path within an artificially recharged or contaminated zone of an aquifer (Chapelle, 2000; Fredrickson and Balkwill, 2006). The south Florida region of the UFA and APPZ zones in the Upper Floridan aquifer are anaerobic, extremely reduced, and oligotrophic. Few biogeochemical studies have focused on these types of groundwater, and are non-existent for this region of the Upper Floridan aquifer. As the interest in injecting, and possibly recovering, different types of aqueous products into and from one or more zones of the Upper Floridan aquifer increases, the need for modeling the effects of the injectate on the aquifer's geologic matrix and changes in the geochemistry of the native and recharged water will also increase. The inclusion of the bacterial community "variable" in geochemical reactive transport models and geochemical interactions in microbial inactivation models will improve the predictive power of those models and their applicability to managing groundwater resources in the Upper Floridan aquifer as well as other aquifer systems.

Problem Statement

A major component of the Comprehensive Everglades Restoration Plan (CERP) involves the use of ASR wells to pump excess surface water during the summer rainy season into the Upper Floridan aquifer for recovery during drier months for stabilization of water flows through the Everglades ecosystem. The scale of this proposed use for ASR is unprecedented. Under current regulations, ASR wells are classified by the U.S. Environmental Protection Agency (EPA) as Class V Underground Injection Control (UIC) wells, and thus subject to regulation under the U.S. Safe Drinking Water Act. Development of controls on (and oversight of) Class V UIC wells, and generally other classes of UIC wells, falls primarily on State environmental protection agencies. As such, the Florida Department of Environmental Protection (FDEP) has set rules regulating ASR systems utilizing aquifer regions classified as Underground Sources of Drinking Water (USDW), which encompasses aquifers of under 10,000 milligrams per liter (mg L^{-1}) TDS, including the Upper Floridan aquifer. A key component of these regulations is that ASR wells may not inject water that violates the Total Coliform Rule of the U.S. Safe Drinking Water Act, which specifies that potable water must have no total coliform bacteria per 100 milliliters (mL) (Anonymous, 1989, 2012, 2013a). Because surface water in Florida would most always violate this rule, the water used for injection in ASR systems must be disinfected prior to aquifer recharge to reduce total coliform concentrations below detection in 100 mL and, if the water is to be utilized for potable water, treated again after withdrawal. The need for this is to avoid introducing harmful microbial organisms possibly present in surface water, such as bacteria, protozoa, and viruses, into relatively pristine groundwater.

To date, only one study has characterized the inactivation rates of members of the total coliform group and other microbes (bacterial pathogens, *Giardia* sp., *Cryptosporidium* sp., and viruses) in the Upper Floridan aquifer (John, 2003). This study used autoclaved and oxidized groundwater from the Upper Floridan aquifer in bench top (laboratory beaker) microcosms to investigate the influence of total dissolved solids (TDS) and temperature on the inactivation rates of the microbial indicators and pathogens. The geochemical conditions in these microcosms did not mimic those in the anaerobic and extremely reduced south Florida region of the Upper Floridan aquifer. Therefore, inactivation rates of total coliforms and other microbial indicators and bacterial, encysted parasitic, and viral pathogens during exposure to native geochemical conditions in the Upper Floridan aquifer are still unknown.

Project Objectives

Determine the inactivation rates of *Escherichia coli* (a member of the total coliform group) and *Pseudomonas aeruginosa* (an opportunistic bacterial pathogen common in surface water) when exposed to native geochemical conditions in the Upper Floridan aquifer (UFA) and Avon Park Permeable Zone (APPZ) of the Floridan aquifer system. An aboveground flowthrough mesocosm system was used to maintain native geochemical conditions, except for pressure, during the exposure experiments.

Characterize the geochemistry in the UFA and APPZ in regard to the organic and inorganic carbon and inorganic substrates used by bacterial communities to drive biogeochemical reactions that generate energy for cell maintenance and growth while altering the geochemistry of these zones of the aquifer.

Identify members of the native bacterial communities that are known to perform the types of biogeochemical reactions that the geochemical data show are thermodynamically feasible. In addition, identify members of these same communities that perform the biogeochemical reactions that would be necessary to maintain the native geochemical conditions in these aquifer zones, even though supporting geochemical data are not available.

Methods

Site Descriptions

Three well sites were selected, each being artesian and having dual production zones that accessed groundwater in the Upper Floridan aquifer (UFA) aquifer and Avon Park Permeable Zone (APPZ) of the Floridan aquifer system (table 1). All wells were placed and constructed as monitoring wells for CERP and had never been impacted by artificial or natural recharge (fig. 1).

Table 1. Sampling-site locations and well characteristics.

[fbs, feet below surface; UFA, upper Floridan aquifer; APPZ, Avon Park permeable zone]

Well designation	Station name	Florida county	Location		Aquifer zone	Casing diameter	Production interval	Screen type
			Latitude	Longitude		(inches)	(fbs)	
MZ1	LAB-MZ1	Glades	26° 45’ 11.42”	-81° 21’ 17.72”	UF	18	670-837	Annular
MZ3	LAB-MZ3				APPZ	7	1645-1759	Open
42U	HIF-42U	Highlands	27° 13’ 11.16”	-80° 57’ 21.98”	UF	24	560-1040	Annular
42L	HIF-42L				APPZ	14	1310-1540	Open
15U	PBF-15U	Palm Beach	26° 44’ 16.08”	-80° 21’ 48.68”	UF	18	908-1144	Annular
15M	PBF-15M				APPZ	12	1400-1583	Annular

Field Data Collection

During each site visit, data were collected at the wellhead for temperature, specific conductance, dissolved oxygen, pH, and oxidation/reduction potential (ORP) using an YSI 556 MPS system (YSI Inc., Ohio) attached to a flow cell. The flow cell was attached via polytetrafluoroethylene (PTFE) tubing to the stainless steel fitting that had been attached to the wellhead. This same system was also attached to the discharge side of the stainless steel inner chamber that retained the diffusion chambers in the aboveground mesocosm. Regardless of which source was being monitored, the YSI 556 MPS system was allowed to equilibrate to in situ conditions for at least 30 minutes prior to initiating an automatic data collection interval of 5 minutes for at least an hour.

Geochemical and Nutrient Sample Collection and Analyses

Samples were collected from each well, appropriately preserved and delivered to the TestAmerica Laboratory (Tampa, Fla.) on the day of collection. Each sample was analyzed for the constituents listed in table 2. Separate water samples from each well were collected for determination of dissolved inorganic carbon (DIC) and total alkalinity at the USGS laboratory in St. Petersburg, Fla.

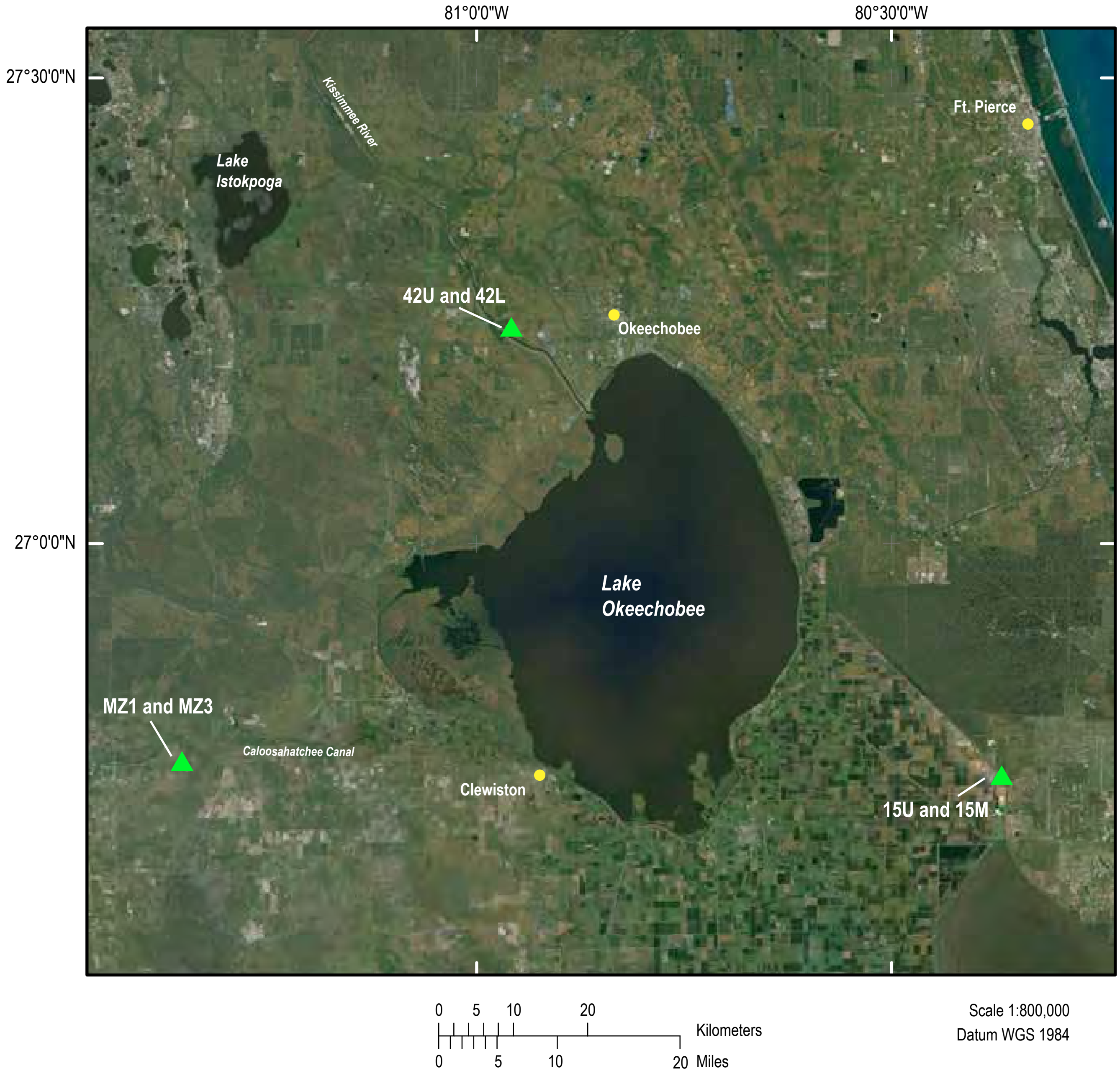


Figure 1. Aerial photograph showing sampling-site locations, indicated by green triangles.

The concentrations of bicarbonate, carbonate, and carbon dioxide were calculated using the pH, DIC, and total alkalinity data using the software program CO2calc (Robbins and others, 2010). Data for the recharge water were provided by Dr. June Mirecki (2013). Samples for quantifying the concentrations of dissolved hydrogen (H_2) and methane (CH_4) were collected from all wells using a modified "bubble strip" system and method (Chapelle and others, 1997) as provided by Microseeps, Inc. (Pittsburg, Pa.). Stabilized dissolved-gas samples were shipped to Microseeps, Inc. for analyses.

Table 2. Water-quality data for the six sampling sites.

[ORP, oxidation/reduction potential; °C, degrees centigrade; mS/cm, millisiemens per centimeter; g/L, grams per liter; ppt, parts per thousand; mV, millivolts; mg/L, milligrams per liter; nM, nanomolar; µM, micromolar; BDL, below detection limit; ND, not determined]

Parameter	Units	Well designation						
		MZ1	MZ3	42U	42L	15U	15M	Recharge
Temperature	°C	28.7	27.8	28.2	28.5	27.9	28.0	25.5
Specific conductance	mS/cm	3.146	27.98	1.029	6.044	5.876	5.009	0.223
Total dissolved solids	g/L	2.045	18.19	0.669	3.928	3.819	3.255	0.208
Salinity	ppt	1.63	17.03	0.5	3.26	3.17	2.67	ND
pH		8.02	7.38	8.04	7.61	7.60	7.64	6.70
ORP	mV	-312	-309	-338	-351	-355	-365	132
Aluminum	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.091
Barium	mg/L	0.039	0.035	0.034	0.040	0.015	0.028	0.019
Bromine	mg/L	2.0	34.0	BDL	5.1	4.8	4.3	0.1
Calcium	mg/L	80	550	44	200	120	110	19
Chloride	mg/L	640	9700	160	1600	1600	1300	31
Chromium	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.001
Cobalt	mg/L	BDL	BDL	BDL	0.002	BDL	BDL	0.0001
Copper	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.0010
Fluoride	mg/L	0.78	BDL	0.57	0.29	0.97	1.10	0.10
Lead	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.0003
Magnesium	mg/L	75.0	650.0	33.0	140.0	130.0	120.0	6.9
Nickel	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.0007
Potassium	mg/L	24.0	230.0	5.5	40.0	36.0	29.0	4.0
Selenium	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.0009
Silica	mg/L	9.8	9.1	14.0	12.0	13.0	13.0	1.2
Sodium	mg/L	440	4700	98	800	890	740	16
Zinc	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.0447
Dissolved oxygen	mg/L	0	0	0	0	0	0	4.4
Manganese	mg/L	0.013	0.035	0.007	0.006	0.011	0.010	0.005
Ferric iron	mg/L	0.14	0.19	0.10	0.17	0.28	0.38	ND
Ferrous iron	mg/L	0.03	0.03	0.03	0.03	0.06	0.02	ND
Iron (total)	mg/L	0.17	0.22	0.12	0.20	0.34	0.40	0.26
Ammonium	mg/L	0.19	0.28	0.20	0.26	0.44	0.33	0.09
Nitrate	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.15
Nitrite	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.016
Kjeldahl Nitrogen	mg/L	0.25	0.38	0.21	0.29	0.52	0.53	1.10
Sulfate	mg/L	380	1800	180	510	450	370	16
Sulfide	mg/L	2.1	1.6	1.4	1.6	3.7	4.2	BDL
Phosphate	mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.067
Dissolved organic carbon	mg/L	1.2	1.1	1.1	1.2	1.7	1.9	15.7
Acetic acid	mg/L	0.120	0.070	0.095	0.070	0.120	0.070	ND
Lactic acid	mg/L	BDL	3.8	BDL	BDL	BDL	BDL	ND
Propionic acid	mg/L	0.071	BDL	BDL	BDL	BDL	0.190	ND
Pyruvic acid	mg/L	0.067	BDL	BDL	BDL	BDL	BDL	ND
Total inorganic carbon	mg/L	160	200	210	190	310	330	ND
Bicarbonate	mg/L	151.5	190.0	199.1	181.7	296.4	315.8	ND
Carbonate	mg/L	6.8	4.2	8.8	3.4	5.3	6.0	ND

Table 2. Water-quality data for the six sampling sites.— Continued.

[ORP, oxidation/reduction potential; °C, degrees centigrade; mS/cm, millisiemens per centimeter; g/L, grams per liter; ppt, parts per thousand; mV, millivolts; mg/L, milligrams per liter; nM, nanomolar; µM, micromolar; BDL, below detection limit; ND, not determined]

Parameter	Units	Well designation						
		MZ1	MZ3	42U	42L	15U	15M	Recharge
Carbon dioxide	mg/L	1.7	5.9	2.2	4.9	8.3	8.2	ND
Hydrogen	nM	120.0	1.2	95.0	6.4	62.0	35.0	ND
Methane	µM	2.00	0.94	0.69	0.54	1.00	1.06	ND

Statistical Analyses

The geochemical data from the respective wells were analyzed using the multivariate statistical procedure for principal component analyses (PCA) on a derived correlation matrix. The oxidation/reduction potential (ORP) data for all wells were negative because of the reduced conditions. Prior to the data processing, these were changed to positive values to allow data transformation. All data were log10-transformed, normalized, and used to derive a correlation matrix on which the PCA was performed. These data were used to determine relative similarities between each well site and each depth within a well site. All statistical analyses were conducted using PRIMER 6 (version 6.1.12; PRIMER–E, Ltd., Plymouth, U.K.).

Native Bacterial Abundances

Samples (50 mL) were collected from each well and immediately preserved with filter-sterilized formalin at a final concentration of 3.0 percent. The samples were placed in an container and kept in the dark during transport. Upon return to the USGS laboratory in St. Petersburg, Fla., samples were stored at 4 °C. Samples were filtered and stained using SYBR Gold (Molecular Probes, Inc.), as previously described for the enumeration of bacteria (Lisle and Priscu, 2004). All bacteria on the prepared slides were counted using an epifluorescent microscope equipped with a filter cube set specifically designed to optimize the visualization of the SYBR Gold stain.

Aboveground Mesocosms

The diffusion chambers used in this study are an alternative design of the McFeters diffusion chamber (McFeters and others, 1974; McFeters and Stuart, 1972; McFeters and Terzieva, 1991; Terzieva and McFeters, 1991; Zaske and others, 1980). A series of diffusion chambers were used to retain the previously described bacterial suspensions, using 0.02-micrometer (µm)-pore-size membranes (Lisle, 2005). The membrane physically isolates the *E. coli* and *P. aeruginosa* cells from predation by native bacteria, while allowing the diffusion of dissolved groundwater constituents into and from the chambers.

The diffusion chambers, when constructed, measure (w×l×d) 4.0×12.0×2.3 centimeters (cm) with an internal volume of approximately 15.0 mL (appendix 1). Because of wellhead access constraints and the multiple time point sampling design of the experiments, down-well deployments of the diffusion chambers were not practical. An aboveground mesocosm system was designed that allowed easy access to the diffusion chambers while insulating the chambers from the elevated surface temperatures and minimizing alterations in the geochemistry of the native groundwater (appendix 1).

The mesocosm system is a two chamber system; the outermost chamber is a commercial ice-cooler adapted to connect directly to the wellhead via PTFE tubing on one end with a 5.0×15.0-cm discharge opening on the other to allow high flow rates through the chamber (appendix 1). The PTFE tubing leading from the wellhead has a valve system connected that allows the diversion of water through a flow-regulating valve and then through the side of the chamber. The second chamber is stainless steel (45.1×20.3×17.8 cm), sits inside the outer chamber, and has an internal volume of approximately 16.0 liters (L). The inner chamber is baffled with vertical stainless steel inserts that ensure laminar and plug flow, while allowing the placement of diffusion chambers between the baffles. The lid of the inner chamber is made of a nontoxic polymer that has been engineered to receive threaded plugs made of the same material, preventing water outside of this chamber from entering. These plugs have attachment points on their undersides for hanging diffusion chambers that contain the bacterial suspensions. There are eight plugs per stainless steel chamber. The PTFE tubing leading from the flow regulating valve is attached to one end of the outer chamber. A discharge PTFE tube is connected to the down-flow end of this chamber and run to the outside the outermost chamber (that is, the cooler). Flow through the outer most chamber (approximately 10.0 liters per minute (L min^{-1})) is maintained at high enough rates that the water insulates from temperature and isolates from oxygen the water and diffusion chambers that contain the bacterial suspensions inside the stainless steel chamber. The flow rate inside the stainless steel chamber was maintained at approximately 152 milliliters per minute (mL min^{-1}) for all of the wells. This flow rate provides a linear flow velocity of approximately 6.0 meters per day (m d^{-1}) with a residence time of approximately 2.0 hours. Therefore, the flow rate through the outermost chamber is approximately 64 times greater than that inside the stainless steel chamber. The ambient air and groundwater temperatures at the wellhead and in the outer and inner chambers were monitored throughout each experiment using HOBO Pro v2 temperature loggers (Onset Computer Corp., Inc., Pocasset, Mass.).

Bacterial Cultures

Treated surface water that will be injected into aquifers is regulated for chemical and microbiological quality as per the Safe Drinking Water Act; therefore, fecal indicator bacteria (FIB) in the treated water is a regulatory concern. However, data on the in situ inactivation and survival of FIB in the Upper Floridan aquifer are not available. To model the inactivation of FIB in the region of the Upper Floridan aquifer that underlies south Florida, two representative bacterial strains were selected from a commercial source. An *E. coli* (ATCC #BAA–1159) (EC) and *P. aeruginosa* (ATCC#29260) (PA) strain were selected that had been originally isolated from freshwater sources. The EC strain is the most recognizable member of the FIB group and the PA strain was selected because it is an emerging opportunistic pathogen of public health concern in recreational waters.

Both bacterial strains were grown, processed, and used to load the diffusion chambers as follows. A 5.0-mL primary culture of the EC and PA strains were grown in Tryptic Soy Broth (#211824; BD Diagnostics, Md.) and Nutrient Broth (#233000; BD Diagnostics, Md.), respectively, at 37 °C with gently rotational shaking (160 rpm) overnight. A 100-microliter (µL) sample of each primary culture was used to inoculate a secondary 5.0-mL culture of the same media and grown under the same conditions. The next day, 1.0 mL of each culture was used to inoculate a 150-mL culture of the same media and again grown overnight under the same conditions. Between 20 and 25 mL of each of these overnight cultures were centrifuged for 5 minutes at 10,000×g and 4 °C. The resulting pellets were resuspended in 20 mL of phosphate buffered saline (PBS) (137.0 millimolar (mM) NaCl; 2.7 mM KCl; 11.9 mM PO_4; pH 7.3–7.5) and centrifuged again using the same parameters. The resulting pellet from this step was then adjusted to a spectrophotometric absorbance value (λ=420 nanometers (nm)) using PBS that represented a cell concentration of 5×10^9 cells mL^{-1} based on a laboratory-generated standard curve. These adjusted cell suspensions were placed in a cooler with coolant and transported to the well site. The travel time ranged from 1.5 to 3.0 hours.

At the well site, 1.0 L of the native groundwater was collected in sterile bottles and filter sterilized. Two 198-mL volumes were transferred to separate flasks, one for EC and the other for PA, and

2.0 mL of the respective concentrated cell suspensions were added. These final bacterial suspensions were gently mixed, and 15.0 mL of each were transferred by syringe to fill a separate diffusion chamber for each strain, giving an estimated cell concentration of 5×10^8 to 1×10^9 cells per chamber (approximately $3–7\times10^7$ cells mL^{-1}). This process was repeated for a total of eight diffusion chambers per strain. Each loaded diffusion chamber was immediately transferred to the stainless steel inner chamber, which was filled with native groundwater, sealed, and submerged in the native groundwater flowing through the outer chamber of the aboveground mesocosm.

At each sampling time point, the groundwater flow into the outer chamber of the aboveground mesocosm was diverted to waste and the remaining water in the outer chamber drained until it was below the top of the inner chamber, which contained the diffusion chambers. One EC and one PA diffusion chamber were removed and immediately transferred to a container filled with native groundwater that was placed in a cooler and stored in the dark. The inner chamber was then resealed, groundwater flow into the aboveground mesocosm system was restarted, and the diffusion chambers were taken to the field laboratory. Once in the laboratory, the water in each chamber was extracted using a syringe and transferred to sterile tubes; the extracted volume was serially diluted with PBS. Selected dilutions were filtered through membrane filters (47-millimeter (mm) diameter, 0.45-µm pore size) and placed on modified mTEC agar (BD Diagnostics, Md.; #214884), hereafter referred to as mTEC agar, for EC and incubated at 35 °C for 2 hours and then transferred to a 44.5 °C incubator for an additional 22 to 24 hours. mTEC agar was included because this medium is one of the required media listed in the U.S. EPA regulations for the recovery of EC from water samples (U.S. Environmental Protection Agency, 2002).

The membrane filters inoculated with PA were placed on Pseudomonas Isolation Agar (BD Diagnostics, Md.; #292710) and incubated at 35.0 °C for 18 to 48 hours. At the end of the respective incubation periods, all filters were counted for the number of colony forming units (CFU) per filter based on the diagnostic colony characteristics (Zimbro and others, 2009). All data were normalized to volumes plated and expressed as CFU mL^{-1}

In addition to the strain specific media, a select set of the dilutions for both strains were also plated on R2A agar (BD Diagnostics, Md.; #218263) using a modified drop plate technique (Hoben and Somasegaran, 1982). These samples were incubated at room temperature in the dark for as many days as it took for the CFU values to stabilize, namely between 10 and 14 days. All data were normalized to volumes plated and expressed as CFU mL^{-1} The concentrations of EC and PA in the native groundwater were also quantified using the same media, dilution scheme, and respective incubation conditions as described previously.

Inactivation Data Analyses

The CFU mL^{-1} data for EC and PA on mTEC and PA agars, respectively, and R2A agar were used to model the inactivation rates in native groundwater from each well, as measured by the loss of culturability on the respective media over time. The best-fit inactivation model was selected by analyzing each dataset with a suite of six equations that have been shown to represent the most common inactivation data distributions for bacteria based on culturability (Crane and Moore, 1986; Xiong and others, 1999).

Quantification and Characterization of Dissolved Organic Carbon (DOC)

Routine monitoring of groundwater systems includes quantification of total organic carbon (TOC). Although of general interest from an operational perspective, this parameter provides little insight into how carbon is utilized by the microbial populations in groundwater systems. The percentage of TOC that is assimilable for microbial populations is typically very small, making this parameter relatively insensitive when trying to assess microbial processes. The dissolved organic carbon (DOC) component of TOC has been shown in all ecosystems studies to be the preferred source of carbon for microbial populations. Not all DOC is available for microbial assimilation, however, so an understanding of which DOC constituents are bioavailable is of interest. In addition, the source of the DOC in this region of the Upper Floridan aquifer is of interest because it is assumed that photosynthetically fixed carbon has not been introduced into this groundwater since it was recharged into the subsurface over 20,000 years before present (Meyer, 1989; Plummer and Sprinkle, 2001).

Groundwater samples (3.0 L) were collected in sterile bottles from each well, packed in coolers, and shipped overnight to the USGS National Research Program laboratory in Boulder, Colo. The samples were processed upon receipt by passing the water through a series of XAD resin columns as previously described for the separate isolation and elution of hydrophobic organic acid (HPOA) and transphilic organic acid (TPIA) fractions of the total DOC (Aiken and others, 1992; Aiken, 1992). The different eluted samples were characterized by elemental, molecular-weight titration and ^{13}C–NMR analyses. The specific UV absorbance (SUVA) was also determined for each eluted fraction at a wavelength of 254 nm (Weishaar and others, 2003).

The analysis just described was used to estimate the quantity of dissolved aromatic carbon constituents in the water samples. In addition, the fluorescence index (FI) was determined for the total and eluted fractions of the DOC (McKnight and others, 2001). The FI provides information about the source (terrestrial versus microbial) of fluorescing organic matter in the samples. FI values are normally in the range of 1.0 to 2.0, with values of 1.0 to 1.3 indicating the DOC is from a terrestrial source and 1.7 to 2.0 indicating microbial source. FI values of 1.4 to 1.6 indicate mixtures of DOC that originate from terrestrial and microbial sources.

Volatile Fatty Acid (VFA) Data Collection

Volatile fatty acids are short carbon-chain compounds that are byproducts of, and nutrient sources for, bacterial communities in groundwater systems. Samples were collected (100 mL) from each well, preserved and packaged per the analyzing laboratory's instructions, and shipped overnight to Microseeps, Inc. (Pittsburg, Pa.). This additional analysis was necessary because one of the VFAs, namely acetic acid (CH_3COO^-) or acetate (CH_3COOH), was used as the substrate to determine bacterial community respiration rates. For the derived respiration rate data to be meaningful, the concentration of acetate added to the assay must be significantly lower than the native concentration (Wright and Burnison, 1979). In addition, the presence and relative concentrations of VFAs provide insight into the microbial biogeochemical processes (for example, fermentation, acetogenesis, and sulfate reduction) that most likely dominate in these aquifer systems.

Bacterial Respiration and Carbon Turnover and Carbon Dioxide Production Rates

Respiratory rates of the native bacterial populations were determined using radiolabelled substrates, which are appropriate for the geochemical conditions in aquifers (Hobbie, 1973; Wright, 1978; Wright and Hobbie, 1966). ^{14}C-labeled acetate was the choice for these groundwater systems because this volatile fatty acid is naturally present and assumed to be a carbon source the native bacterial populations could utilize. All sample processing in the field and laboratory was performed under a constant stream of nitrogen gas to ensure the in situ anaerobic conditions were maintained. Prior to the collection of the groundwater samples, the appropriate volume of ^{14}C-acetate was added to sterile flasks to achieve a final concentration in the sample of 20 nanomolar (nM) and left open under continuous nitrogen gas flow until the ethanol carrier had evaporated. This step ensured a second and nonradiolabelled carbon substrate (that is, ethanol) was not available for assimilation by the microbial communities, thereby confounding the growth-rate measurements based on radiolabelled acetate. A 70-mL sample from each well was added to pre-dosed flasks, and gently mixed; after which 5.0 mL subsamples were transferred to separate 25-mL serum bottles that were immediately sealed with butyl rubber stoppers. The biological activity in the time-zero replicate set of bottles was immediately inactivated by adding 500 microliters (µL) of 4N H_2SO_4. After adding the acid, each bottle was gently shaken on a rotary shaker between 8-16 hours. The remaining samples were returned to the laboratory and placed in an anaerobic chamber that had been flushed and filled with nitrogen gas for continued incubation at room temperature in the dark.

For the time-zero samples and those for all other time points, both bottles of the replicate set were processed for the recovery of $^{14}CO_2$ and ^{14}C-labelled bacterial biomass. Each sample bottle was connected to a CO_2 scrubbing system that consisted of three airtight vials, the last two of which contained 4.0 mL of Carbo-Sorb E™ (PerkinElmer, Waltham, Mass.). The sample was inactivated, as described previously, and gently shaken for 5 minutes. A nitrogen gas source was then attached and used to gently flush the head space of the sample and scrubbing bottles for 5 minutes. The two bottles containing the Carbo-Sorb E were removed and 5.0 mL of Permafluor E^{+}™ (PerkinElmer, Waltham, Mass.) added. The acidified sample in each bottle, which contains the bacterial biomass, was filtered through a 25-mm-diameter 0.20-µm-pore-size filter. The filters were then rinsed three times with sterile water, briefly dried, and placed in a scintillation vial to which 5.0 mL of Permafluor E^{+} was added. All scintillation vials were allowed to set overnight at room temperature to quench, and then read the next day in a scintillation counter to record disintegrations per minute (DPM). The DPM data from the two bottles of Carbo-Sorb E per sample were added to give a single value that was used to calculate the mean DPM at each time point. Each set of mean DPM per unit time data were used in all respiration and productivity calculations.

The DPM per unit time data were used to calculate the acetate turnover rates using the following relationship (Wright and Burnison, 1979):

$$T_n = \frac{S_n + A}{v_n} = \frac{t}{f}, \qquad (1)$$

where

T_n is the turnover rate for, in this case, acetate;

S_n is the natural concentration of acetate in the groundwater;

A is the concentration of radiolabeled acetate added to each experiment;

t is the time of each experiment;

f is the decimal fraction of total radiolabelled acetate utilized by the microbial community during the experiment; and

v_n is the acetate utilization rate by the native microbial communities.

The rates of community respiration and production (v_n) were the slopes of the mean DPM per unit time data in the linear portion of each dataset and subsequently analyzed using model I linear regression.

Bacterial community biomass turnover rates can also be estimated from the incorporation rates of an amino acid, leucine, into cellular proteins (Bastviken and Tranvik, 2001; Buesing and Marxsen, 2005; Phelps and others, 1994; Simon and Azam, 1989). Accordingly, tritium-labeled leucine (^{3}H-leucine) was added to the native groundwater from the six wells following the method of Kirchman (2001). Briefly, ^{3}H-leucine was added to 35 mL of the respective groundwater sources to achieve a final concentration of 20 nM leucine, gently mixed, then followed by the transfer of 1.7 mL of the suspension to multiple 2.0-mL screw-cap vials under a continuous flow of nitrogen gas. A set of three vials representing the time-zero samples were immediately inactivated with the addition of 89 µL of ice-cold trichloroacetic acid (TCA) and gently mixed. The vials were centrifuged at approximately 16,000×g for 10 minutes at room temperature and the supernatant aspirated. A 1.0-mL volume of ice-cold 5.0-percent (v/v) TCA was added to each vial, gently mixed, and centrifuged as before. The supernatant was again aspirated and 1.0 mL of ice-cold 80-percent (v/v) ethanol was added, gently mixed, and centrifuged as described. The supernatant was aspirated and the remaining pellet air-dried to remove residual ethanol. To each dried pellet, 1.0 mL of Ultima Gold™ (PerkinElmer, Mass.) scintillation fluid was added, gently mixed, and allowed to sit at room temperature overnight. The remaining sample vials were transferred to an activated GasPak™ (BD Diagnostics, N.J.) for transportation back to the laboratory where the vials were transferred to an anaerobic chamber for incubation at room temperature in the dark. At each time point, three vials from each groundwater source were inactivated and processed as described previously. All processed samples were analyzed in a scintillation counter to record the DPM.

The equation used for relating leucine incorporation rates to bacterial biomass production (Kirchman, 1993; Kirchman and Ducklow, 1993) (BP_{leu}; grams carbon per liter per hour) is

$$BP_{leu} = Leu_i \cdot MW_{leu} \cdot Leu_f^{-1} \cdot CPR \cdot D_i \,, \tag{2}$$

where

MW_{leu} is the formula weight of leucine (131.2 grams per mole (g mol^{-1}));
Leu_f is the fraction of leucine in bacterial proteins (0.073);
CPR is the cellular carbon-to-protein ratio in bacteria (0.86);
D_i is the isotope dilution factor (2); and
Leu_i is the leucine incorporation rate (moles leucine per liter per hour), which was determined from linear portion of the scintillation count (DPM) per unit time regression data as described for the ^{14}C-acetate experiments.

The acetate mineralization and leucine assimilation rates were used to calculate the quantity of bacterial biomass produced per unit of organic carbon substrate assimilated as expressed by bacterial growth efficiencies (*BGE*) (del Giorgio and Cole, 1998). The *BGE* for the respective native microbial communities is estimated from the following equation:

$$BGE = {BP}\big/{(BP + BR)} \,, \tag{3}$$

where

BP is the microbial community production rate (that is, ^{3}H-leucine data for biomass production expressed as micrograms carbon per hour); and
BR is the microbial community respiration rate (that is, CO_2 production from ^{14}C-acetate expressed as micrograms carbon per hour).

Biogeochemical and Energetics Analyses

Data for the biogeochemical analyses were selected from those groundwater constituents in table 2 that were above the respective detection limits. Based on the geochemical data that provided a complete set of reactants and products for the respective reactions, a set of 14 biogeochemical reactions were selected that are commonly known to be driven by bacteria in groundwater systems (Davidson and others, 2011; Onstott, 2005) (table 3).

Table 3. Balanced biogeochemical reactions.

Reaction number	Reaction equations
1	$4H_2 + H^+ + SO_4^{2-} \rightarrow HS^- + 4H_2O$
2	$CH_3COO^- + SO_4^{2-} \rightarrow 2HCO_3^- + HS^-$
3	$4H_2 + H^+ + HCO_3^- \rightarrow CH_4 + 3H_2O$
4	$CH_3COO^- + H_2O \rightarrow CH_4 + HCO_3^-$
5	$4HCOO^- + H^+ + H_2O \rightarrow CH_4 + 3HCO_3^-$
6	$4H_2 + H^+ + 2HCO_3^- \rightarrow CH_3COOH + 4H_2O$
7	$2CO_2 + 4H_2 \rightarrow CH_3COOH + 2H_2O$
10	$HS^- + NO_3^- + H_2O \rightarrow SO_4^{2-} + NH_3$
12	$CH_4 + SO_4^{2-} \rightarrow H_2O + HCO_3^- + HS^-$
17	$H_2S + 4NO_3^- \rightarrow SO_4^{2-} + 4NO_2^- + 2H^+$
19	$3H_2S + 4NO_2^- + 2H^+ + 4H_2O \rightarrow 3SO_4^{2-} + 4NH_4^+$
25	$NH_3 + 1.5O_2 \rightarrow NO_2^- + H^+ + H_2O$
26	$2NO_2^- + O_2 \rightarrow 2NO_3^-$
27	$HS^- + 2O_2 + H_2O \rightarrow SO_4^{2-} + H^+$

The biogeochemical data were also used to calculate the ionic strength of the groundwater in each well and the respective activities coefficients of each reactant and product using Geochemist's Workbench (release 7.0) (RockWare, Inc., Golden, Colo.). The activity coefficients were used to adjust the concentrations of the constituents to their respective activities, and these activities were used in the biogeochemical reaction calculations, exemplified by

$$aA + bB \rightleftarrows cC + dD \quad , \qquad 4$$

where

A, B and C, D represent the activities of the reactants and products, respectively, and
a, b, c, d are the respective stoichiometric reaction constants from the balanced equations.

The Gibbs free energies (in joules per mole), under standard conditions ($\Delta G°$) (that is, 298.15 °K, 1.0 atmosphere, pH = 0, ionic strength = 0, and the concentrations of all reactants and products are 1.0 molar) were calculated for the balanced reactions, as follows:

$$\Delta G^\circ = \sum \Delta G_f^\circ(products) - \sum \Delta G_f^\circ(reactants) \quad , \qquad 5$$

where $\Delta G_f°$ (joules per mole) represents the standard free energy of formation values for the respective products and reactants in each reaction. The equilibrium constant (K_{eq}) for each reaction was derived using the $\Delta G°$ values from equation 4 and solving for K_{eq}:

$$K_{eq} = e^{-\left(\Delta G^{\circ}/RT\right)}, \qquad 6$$

where

R is the universal gas constant (8.3145 joules per degree Kelvin per mole (J °K^{-1}mol^{-1})), and

T is temperature (°K).

The ΔG° data were used to calculate the free energy values under in situ conditions (ΔG_r) for each reaction using the groundwater temperatures (table 2) and activities of the reactants and products (table 3), denoted by square brackets, using the following relationship:

$$\Delta G_r = \Delta G^{\circ} + RT \ln Q, \qquad 7$$

where

$$Q = \frac{[C]^c}{[A]^a} \frac{[D]^d}{[B]^b}. \qquad 8$$

Each reaction was balanced and ΔG° and ΔG_r values calculated using the CHNOSZ software package (Dick, 2008).

The quantity of energy that can be released from biogeochemical reactions can be assessed by comparing the energy available at equilibrium to the energy available under in situ conditions. A convenient method for doing these types of comparisons is chemical affinities (A) (kilojoules per mole):

$$A = RT \ln \frac{K_{eq}}{Q}. \qquad 9$$

Positive chemical affinity values indicate the reaction, as written, will proceed to the right and release the calculated free energy for use by the members of the microbial community that are capable of performing that reaction.

The calculation of free energy yields provide insight into which of the biogeochemical reactions has the greatest likelihood of occurring under in situ conditions in the aquifers; however, these estimates do not indicate the rates at which the microorganisms acquire the necessary energy for cellular activities. Because molecular diffusion is the mechanism through which microorganisms obtain the required reactants for biogeochemical reactions, the limiting reactant's rate of diffusion from the groundwater to the microbial cell surface will equal the overall reaction rate (Schulz and Jorgensen, 2001).

The amount of energy the bacterial cell can potentially generate from performing the biogeochemical reaction, assuming the reaction rate is controlled by the limiting reactant, can be expressed as the steady state free energy flux (FEF, in kilojoules per cell per second):

$$FEF = 4\pi \cdot r \cdot D_c \cdot C \cdot \Delta G_r, \qquad 10$$

where

r is the radius (micrometers) of the microbial cell,

D_c (meters squared per second) is the diffusion coefficient of the limiting reactant,

C (moles per cubic meter) is the concentration of the limiting reactant, and

ΔG_r is the free energy of reaction (kilojoules per cell per second) for the respective biogeochemical reactions.

The relationship between the FEF and the list of biogeochemical reactions in table 3 is predicated on the use of the calculated free energy yields for the production of adenosine triphosphate (ATP) (Schink, 1997; Thauer and others, 1977). In addition to the dependence on diffusion rates, this relationship is based on the additional assumptions that the conservation of energy occurs through electron transport processes for all of the biogeochemical reactions shown in table 3 and that the conversion of this energy to ATP proceeds with maximum efficiency, which sets a minimum free energy yield for ATP production. This minimum free energy yield is commonly set at –20 kilojoules per mole (kJ mol^{-1}) of limiting reactant. Accordingly, only those biogeochemical reactions whose ΔGr were < –20 kJ mol–1 (that is, more negative) were used in the FEF calculations. The rate at which a cell can access the limiting reactant is expressed by the maximum acquisition rate (*MAR,* in micromoles per day) (Onstott and others, 2006):

$$MAR = 4\pi \cdot r \cdot D_c \cdot C \cdot BA \quad , \qquad 11$$

where *BA* is the abundance of bacterial cells (cells per liter) in the respective groundwater samples.

Microbial Community Diversity Sample Collection and Analyses

Samples were collected from each well into sterile 20-L carboys during three sampling events (table 4). A cartridge filter (Sterivex GP, 0.22-µm pore size; Millipore Corp., Mass.) was connected to each carboy and, under gravity-induced flow, allowed to filter until flow had stopped. After removing the cartridge filter, its protective plastic housing was aseptically removed and the filter transferred to a sterile container. All filters were stored at –80 °C in separate containers. All filters were shipped frozen and on dry ice to Second Genome, Inc. (San Bruno, Calif.) for DNA extraction, amplification, and application on their proprietary PhyloChip™ G3 Array technology. The PhyloChip G3 microarray is capable of identifying approximately 60,000 operational taxonomic units (OTU) that represent approximately

Table 4. Sample volumes for bacterial diversity analyses samples from the six sampling sites.

Well site	Sample date	Volume collected (Liters)	Total volume (Liters)
MZ1	8/3/2010	7.3	18.4
	9/20/2010	11.1	
MZ3	8/3/2010	7.0	17.6
	9/20/2010	10.6	
42U	9/1/2010	6.7	16.3
	9/21/2010	9.6	
42L	9/1/2010	5.2	14.7
	9/21/2010	9.5	
15U	9/1/2010	5.9	17.9
	9/27/2010	12.0	
15M	9/1/2010	5.7	17.7
	9/27/2010	12.0	

840 subfamilies within the Eubacteria and Archaea kingdoms (DeSantis and others, 2007; Hazen and others, 2010). The coverage of total bacterial diversity by the PhyloChip G3 has been shown to be comparable to 454 pyrosequencing technology (DeAngelis and others, 2011).

DNA was isolated and polymerase chain reactions (PCR) were carried out using bacterial and archaeal primers. The eubacterial 16S rRNA genes were amplified using the degenerate forward primer, 27F.1 (5'–AGRGTTTGATCMTGGCTCAG–3'), and the nondegenerate reverse primer, 1492R (5'– GGTTACCTTGTTACGACTT–3'). The archaeal 16S rRNA genes were amplified using the degenerate forward primer, 4fa (5'–TCCGGTTGATCCTGCCRG–3'), and the nondegenerate reverse primer, 1492R (5'–GGTTACCTTGTTACGACTT–3') (Hazen and others, 2010). Twenty seven cycles of PCR for eubacterial 16S rRNA gene amplification and 32 cycles of PCR for archaeal 16S rRNA gene amplification was performed. For each sample, amplified products were concentrated by centrifuge filtration and quantified by electrophoresis using an Agilent 2100 Bioanalyzer. PhyloChip Control Mix was added to each amplified product.

PCR products from each sample were pooled, 5 parts to 1 part, and fragmented, biotin labeled, and hybridized to the PhyloChip Array, version G3. PhyloChip arrays were washed, stained, and scanned using a GeneArray® scanner, and each scan was captured using GeneChip® Microarray Analysis Suite (Affymetrix, Inc., Santa Clara, Calif.). Hybridization values, the fluorescence intensity, for each taxon were calculated as a trimmed average, with maximum and minimum values removed before averaging. To calculate the summary intensity for each feature on each array, the central nine pixels of individual features were ranked by intensity and the 75th percentile was used. Probe intensities were background-subtracted and scaled to the PhyloChip Control Mix. The hybridization score for an OTU was calculated as the mean intensity of the perfectly matching probes exclusive of the maximum and minimum.

The description and discussion of OTU data treat "bacteria" as an inclusive term for the eubacterial and archaeal OTUs. In this report, the term "bacteria" is used synonymously to describe the prokaryotes collectively, namely the members of the domains Bacteria (Eubacteria) and Archaea (Archaebacteria) (that is, organisms that are not eukaryotes). Although profound differences between Bacteria and Archaea are acknowledged, the two are quite similar with respect to basic cellular organization and general functional properties, such as biogeochemical processes in anaerobic systems. Because one of the objectives of this study was to characterize the functional diversity of prokaryotic communities and how these diversities influence groundwater geochemistry in the Upper Floridan aquifer, it was less important to, for example, describe which members of the Bacteria and Archaea reduce sulfate than to determine that sulfate reduction is energetically favorable, regardless of which members in each domain were driving the process.

Statistical Analyses

The presence and (or) absence microbial community diversity data generated from the PhyloChip G3 array for each groundwater sample were inter-compared in a pairwise fashion using the Sorensen index to determine dissimilarity scores, which were stored in a distance matrix. The statistical significance between comparisons was determined using the adonis test. These statistical analyses were conducted by Second Genome, Inc.

Results and Discussion

Water Quality

The underlying hypothesis that the geochemistry of the Upper Floridan aquifer was relatively consistent between and within sample sites was tested using principal component analysis (PCA). A visual estimation of relatedness between sample sites can be made by comparing the relative closeness of the well site designations along the x-axis (that is, PC1) and then the y-axis (that is, PC2) (figs 2–7).

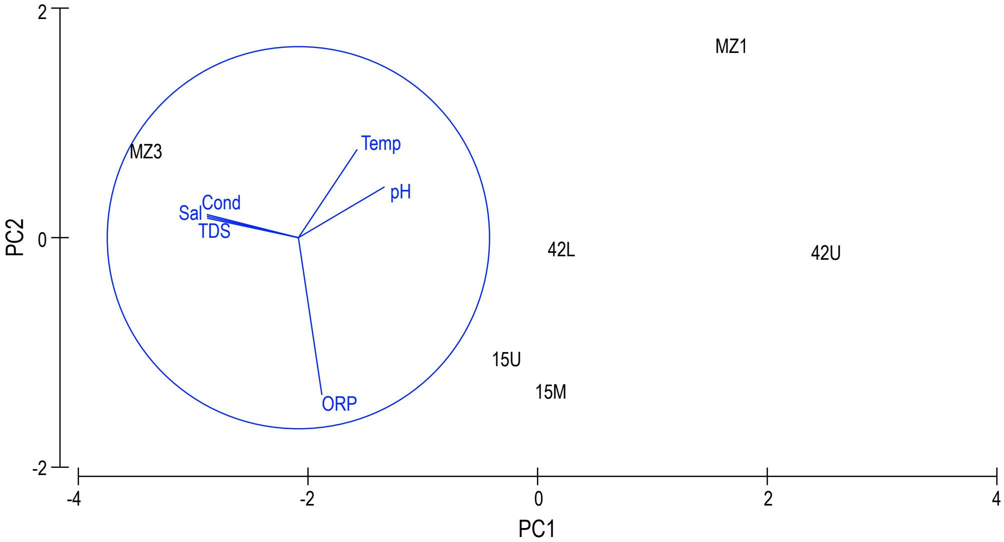


Figure 2. Graph showing principal component analysis of field data from the six sampling sites [PC1, principal component 1; PC2, principal component 2].

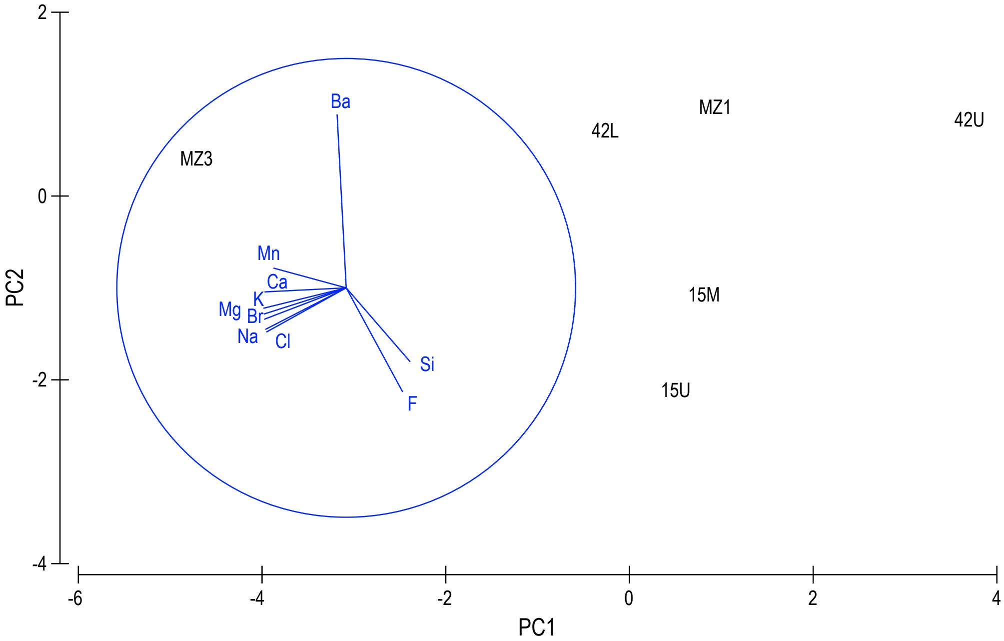


Figure 3. Graph showing principal component analysis of ionic species data from the six sampling sites [PC1, principal component 1; PC2, principal component 2].

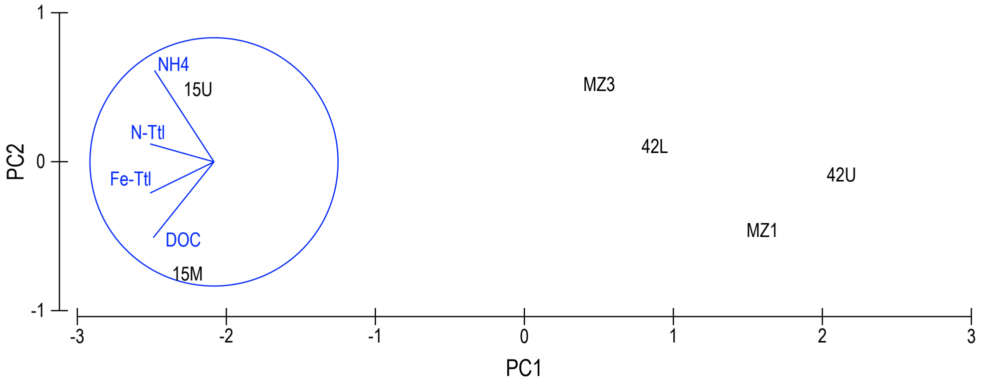


Figure 4. Graph showing principal component analysis of nutrient data from the six samplng sites [PC1, principal component 1; PC2, principal component 2] .

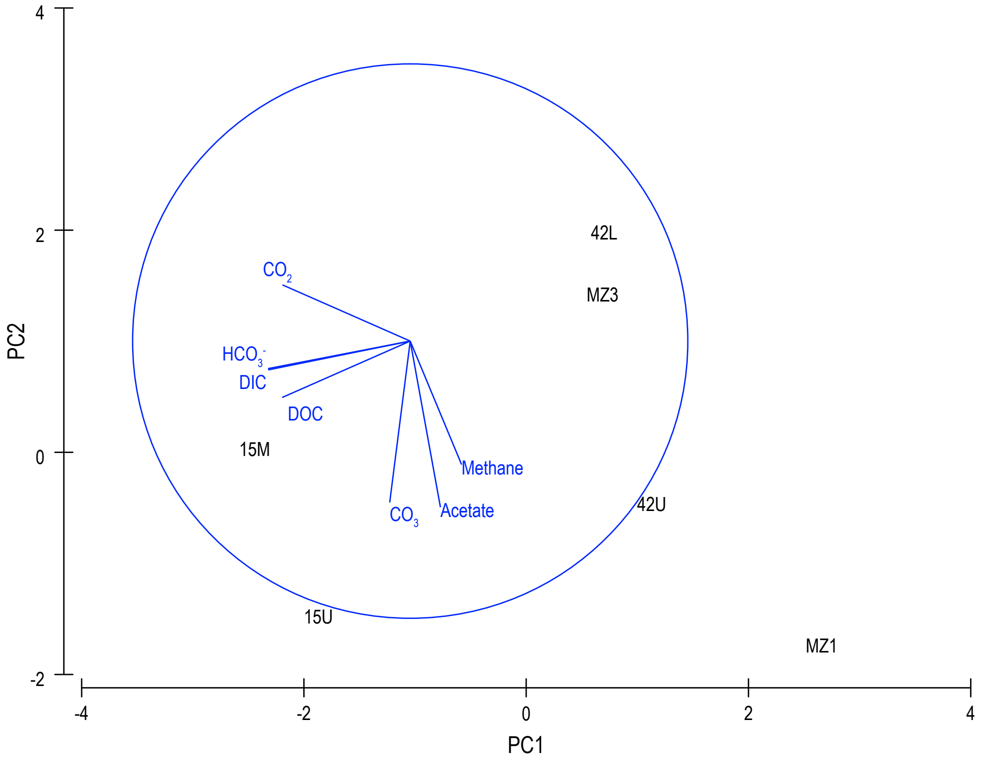


Figure 5. Graph showing principal component analysis of carbon substrate data from the six sampling sites [PC1, principal component 1; PC2, principal component 2] .

The proximity of well-site names along the respective axes is directly proportional to the similarity of their geochemical data (table 2). The interpretation of the PCA graphs for the water-quality variables is facilitated by the superimposition of the calculated eigenvectors (table 5), whose direction is most like the variable (for example, pH) represented by the vector. The length of the vector is proportional to that variable's contribution to the overall variance; that is, the longer the vector, the more significant the influence of that variable on the overall variance.

The PCA was applied to subsets of the data in table 2. These data subsets were grouped as follows: field data (fig. 2), ionic geochemical species (fig. 3), nutrients (fig. 4), organic and inorganic carbon (fig. 5), geochemical constituents that predominate in terminal electron acceptor processes (TEAPs) (fig. 6), and the geochemical constituents that were used as the reactants and products in the energetics

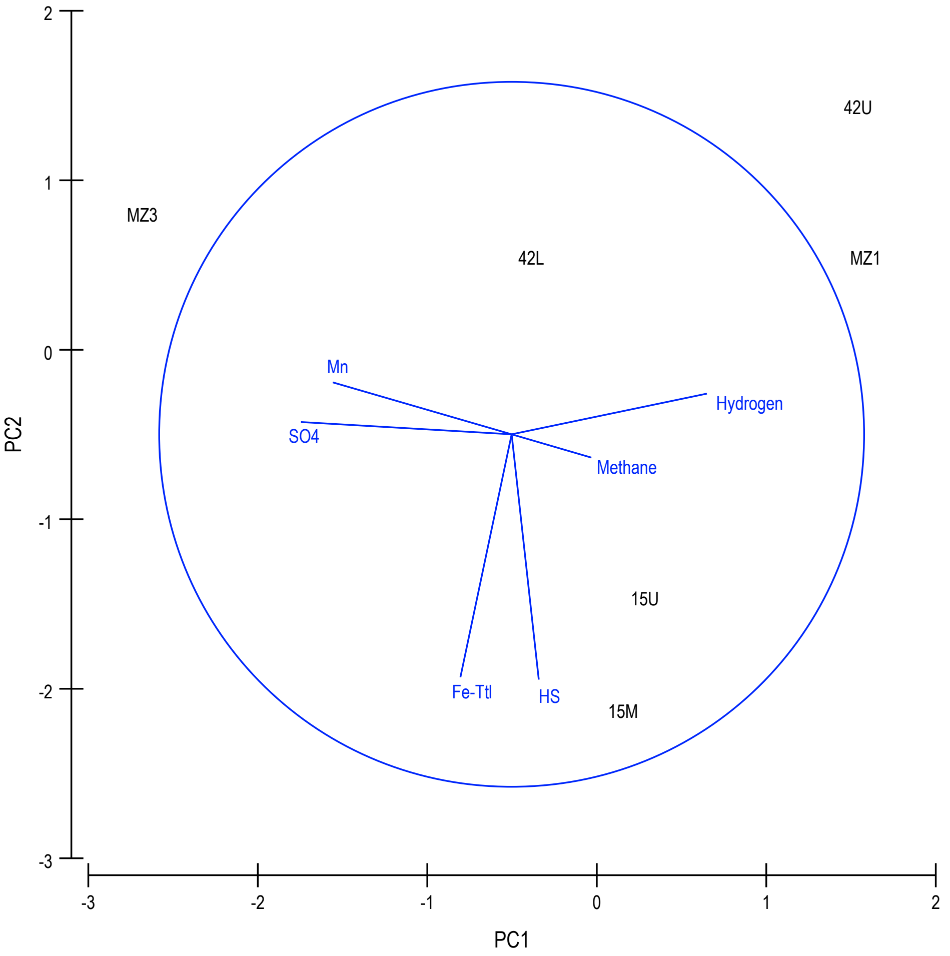


Figure 6. Graph showing principal component analysis of terminal electron acceptor data from the six sampling sites [PC1, principal component 1; PC2, principal component 2].

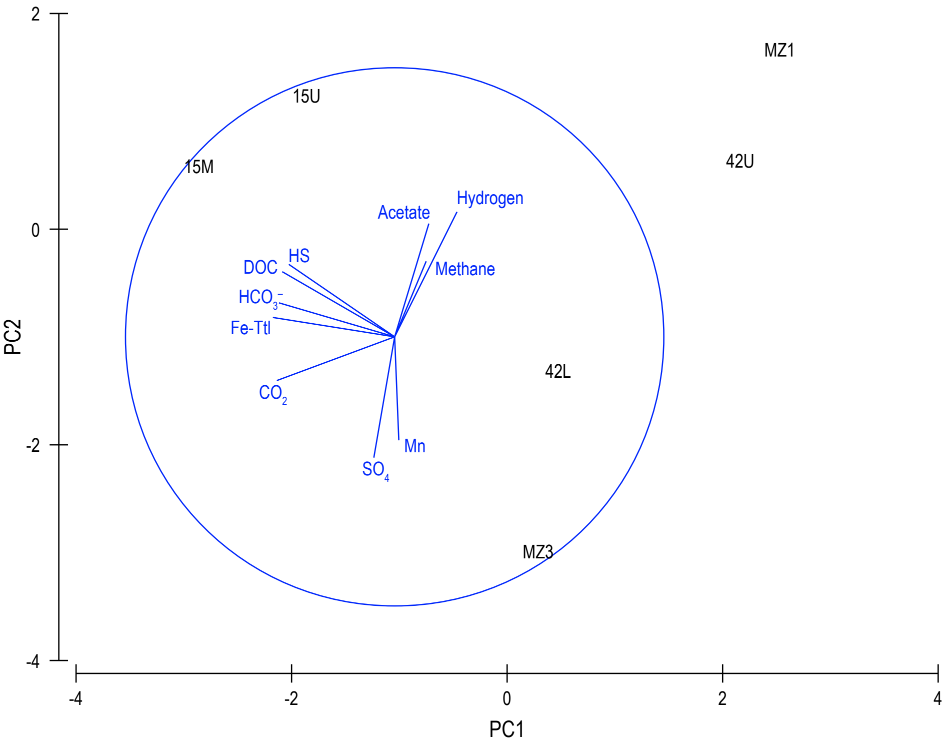


Figure 7. Graph showing principal component analysis of reactant data from the six sampling sites for the thermodynamically favorable biogeochemical reactions [PC1, principal component 1; PC2, principal component 2] .

Table 5. Principal component analyses eigenvector data for the six sampling sites.

Comparison group	Variable	Graph notation	Principal components	
			PC1 coefficients	PC2 coefficients
Field data	Protons	pH	0.450	0.266
	Temperature	Temp	0.308	0.462
	Oxidation/reduction Potential	ORP	0.123	-0.823
	Conductivity	Cond	-0.478	0.102
	Total dissolved solids	TDS	-0.479	0.112
	Salinity	Sal	-0.479	0.121
Ionic species	Silica	Si	0.279	-0.323
	Fluorine	F	0.246	-0.454
	Potassium	K	-0.361	-0.089
	Magnesium	Mg	-0.359	-0.114
	Bromine	Br	-0.358	-0.137
	Calcium	Ca	-0.356	-0.018
	Sodium	Na	-0.352	-0.181
	Chlorine	Cl	-0.348	-0.193
	Manganese	Mn	-0.317	0.086
	Barium	Ba	-0.040	0.757
Nutrients	Ammonium	NH4	-0.480	0.737
	Dissolved organic carbon	DOC	-0.490	-0.610
	Total iron	Fe-Ttl	-0.515	-0.251
	Total nitrogen	N-Ttl	-0.515	0.145
Organic and inorganic carbon	Bicarbonate	HCO3-	0.512	-0.099
	Dissolved inorganic carbon	DIC	0.511	-0.104
	Dissolved organic carbon	DOC	0.461	-0.204
	Carbon dioxide	CO2	0.460	0.203
	Carbonate	CO3	0.074	-0.582
	Acetate	Acetate	-0.109	-0.599
	Methane	Methane	-0.185	-0.446
Terminal electron acceptor process substrates (TEAPs)	Di-hydrogen	Hydrogen	0.554	0.115
	Methane	Methane	0.226	-0.066
	Hydrogen sulfide	HS	0.077	-0.696
	Total iron	Fe-Ttl	-0.145	-0.689
	Manganese	Mn	-0.508	0.147
	Sulfate	SO4	-0.598	0.035
Reactants	Di-hydrogen	Hydrogen	0.232	0.465
	Acetate	Acetate	0.127	0.421
	Methane	Methane	0.117	0.281
	Manganese	Mn	0.015	-0.385
	Sulfate	SO4	-0.077	-0.449
	Hydrogen sulfide	HS	-0.393	0.269
	Dissolved organic carbon	DOC	-0.418	0.242
	Bicarbonate	HCO3-	-0.430	0.126
	Carbon dioxide	CO2	-0.438	-0.163
	Total iron	Fe-Ttl	-0.453	0.072

Table 6. Principal component analyses percent variance per axis data for the six sampling sites.
[TEAPs, terminal electron acceptor process substrates]

Data sets	Percent variation		Cumulative percent variation
	PC 1	PC 2	
Field data	71.0	21.0	92.0
Ionic species	75.4	15.8	91.2
TEAPs	41.0	33.2	74.2
Nutrients	91.2	6.6	97.8
Organic and inorganic carbon	52.7	32.4	85.1
Reactants	45.9	32.1	78.0

calculations (fig. 7). The eigenvector loadings for the first two principal components (PC1 and PC2) for each of these comparisons are provided in table 5. Table 6 lists the respective contributions to the overall variance that each principal component represents. The cumulative percent variation represented by the first two principal components for each data comparison was relatively high, ranging from approximately 76 to 96 percent, indicating the relationships between variables are reasonably represented by PC1 and PC2 in the data distributions.

The field data coefficients for PC1 (table 5) indicate the horizontal relationships are best described by specific conductance, TDS, and salinity data at one extreme (negative coefficients) and pH (positive coefficient) at the other. The MZ3 site is most influenced by the variables related to specific-conductance, whereas 42U is most influenced by pH, relative to the other sites. The alignment of the other well sites between these two extremes indicates these sites are more related to each other and less related to the MZ3 and 42U sites (fig. 2). PC2 is dominated by ORP and, to a lesser extent, temperature (table 5). Figure 2 shows that the groundwater from 15U and 15M are similar and most influenced by ORP. Groundwater temperature separates MZ1 from the other wells, whereas 42U, 42L, and MZ3 are similar to each other in regard to the field data variables included in this analysis.

The ionic geochemical species, except for silica and fluorine, were all similarly weighted (table 5). The groundwater from MZ3 was most impacted by these constituents, whereas 42U was least influenced. The vertical distribution of the remaining sites indicates these groundwaters were all similar in regard to these ionic species. The PC2 data indicate that barium concentrations in MZ1, MZ3, 42U, and 42L were similar and different from those in 15U and 15M. The groundwater in 15U and 15M had relatively higher concentrations of silica and fluorine (fig. 3).

The groundwater nutrients were all similarly weighted for PC1. The groundwater from 15U and 15M were most similar to each other and dissimilar from MZ1, MZ3, 42U, and 42L. These similarities and differences are due to the relatively higher concentrations of all the nutrients in 15U and 15M groundwaters (table 5). PC2 was dominated by ammonium and total nitrogen at the upper end of the continuum and total iron and DOC at the lower end (fig. 4). This combination of nutrient factors shows 15U, MZ3, and 42L being relatively similar in their nitrogen-based nutrients and 15M, MZ1, and 42U being relatively similar in the DOC and total iron concentration (fig. 4).

The principal components for the inorganic and organic carbon data were weighted for the inorganic and dissolved organic carbon substrates that drive chemolithotrophic and heterotrophic metabolisms, respectively (table 5). In regard to PC1, MZ1 was most dissimilar to 15U and 15M, with the other three groundwater samples being similar to each other but slightly dissimilar to the groundwater at each extreme of the PC1 axis. PC2 is best described by the concentrations of methane, acetate, and carbonate (fig. 5). Samples from the APPZ from 15U, 42U, and MZ1 were most influenced by their respective concentrations of these organic and inorganic carbon substrates, which are known to be primary energy sources in anaerobic and reduced ecosystems like this region of the Upper Floridan aquifer.

The TEAPs PCA (fig. 6) shows that PC1 is dominated by hydrogen concentrations in the groundwater, with all sites having higher concentrations relative to MZ3 grouped together (table 5). The total iron and sulfides data dominate PC2, with the higher concentrations of both in 15U and 15M driving their location as more dissimilar than the other four groundwater samples (fig. 6).

When assessing each groundwater for the constituents used in the biogeochemical reactions, PC1 is dominated by the inorganic carbon variables, total iron, and hydrogen sulfide concentrations (table 5). Again, 15U and 15M are similar and distinctly different from the remaining sites, which are more similar in their hydrogen, acetate, and methane concentrations (fig. 7). The relationships derived from PC2 are not as definitive (table 5); 42L and MZ3 are more similar in their sulfate and manganese concentrations, whereas the remaining sites are more similar in their hydrogen, acetate, and methane concentrations (fig. 7).

Collectively, the PCA analyses show that groundwaters within the UFA and APPZ are, as would be predicted, geochemically different. These zones are not homogenous on a regional basis, however, because there are significant differences in geochemistry between sites for a given zone. The types of water-quality variables (for example, methane, hydrogen, total inorganic carbon, acetate, sulfides, and ammonium) that show differences within and between zones in this region of the Upper Floridan aquifer indicate these differences are driven by microbial activities. The application of multivariate statistical analyses to geochemical data from groundwater samples provides (1) a quantitative platform for establishing native geochemical conditions and determining which variables are most influential in the aquifer, (2) baseline datasets to which temporally distinct data from the same site can be compared for determining if changes in geochemistry have occurred, and (3) a method to identify which geochemical variables change over time and the influence of those changes on the overall geochemistry following an event that disrupts the aquifer ecosystem (for example, aquifer recharge, storage and recovery, groundwater extraction, treated waste water injection, and carbon dioxide sequestration).

Bacterial Abundances

The mean bacterial abundances in all groundwater samples were relatively consistent, ranging from 3.92×10^{4} to 8.01×10^{5} cells mL^{-1} (table 7). These bacterial abundances are similar to those recovered from a series of samples collected from wells in the Upper Floridan aquifer located in central and south Florida (Lisle, 2005).

Additionally, native groundwater from each of the well sites was collected during each sampling event and filtered or directly plated onto each of the media used in the inactivation experiments. None

Table 7. Bacterial total direct count data for the six sampling sites.

Well site	Cells per milliliter
42U	$3.92\times10^{4} \pm 1.49\times10^{3}$
42L	$4.12\times10^{5} \pm 3.32\times10^{4}$
15U	$7.21\times10^{5} \pm 7.80\times10^{4}$
15M	$7.28\times10^{5} \pm 8.10\times10^{4}$
MZ1	$8.01\times10^{5} \pm 6.87\times10^{4}$
MZ3	$6.79\times10^{5} \pm 3.84\times10^{4}$

of the native water samples produced colonies on mTEC agar, an average of 0.7 CFU mL^{-1} (range: 0.04–1.1 CFU mL^{-1}) were recovered on the PIA agar and 0.7 CFU mL^{-1} (range: 0–1 CFU mL^{-1}) on R2A agar; none of these colonies were identified. The recovery of culturable bacteria from the native waters on the nonselective PIA and R2A agars is not surprising because these groundwater systems contain viable bacteria and both media promote the recovery of heterotrophic bacteria, regardless of their identity. More importantly, the numbers of culturable bacteria on these media are not great enough to influence the colony counts of the *E. coli* or *P. aeruginosa* recovered from the diffusion chambers, even if a contamination event (such as a membrane rupture, chamber gasket leak, or contamination during chamber recovery) had occurred.

Bacterial Indicator Inactivation

The colony counts from each of the experiments were first log$_{10}$-transformed and analyzed using a suite of bacterial inactivation models to determine the best-fit model. The biphasic model (Cerf, 1977) provided the best fit for all datasets based on root mean sum of squared error (RMSE) values (data not shown).

This biphasic model describes the inactivation of bacterial communities that can be subdivided into two subpopulations. One subpopulation is more susceptible to inactivation than the other, which generates an inactivation curve with an initial steep and negative slope that follows into a tail with a significantly smaller negative slope. The two subpopulations are assumed to be independently and irreversibly inactivated with the respective inactivation rates following first order reaction kinetics. The equation for this inactivation model is

$$\frac{N_t}{N_0} = fe^{-k_1 t} + (1-f)e^{-k_2 t} , \qquad 12$$

where

N_0 and N_t	are the log$_{10}$-transformed colony counts at time zero and time t, respectively;
t	is the elapsed time (hours);
f	is the decimal fraction of the total bacterial community in the major subpopulation that is inactivated at a higher rate (that is, less resistant) (k_1; log$_{10}$ CFU per milliliter per hour); and
$(1–f)$	is the decimal fraction of the total bacterial community in the minor subpopulation that is inactivated at a slower rate (that is, more resistant) (k_2; log$_{10}$ CFU per milliliter per hour); the higher the k-value, the faster the inactivation rate.

An estimation of the time required for a 1.0 log$_{10}$ reduction ($t_{\log_{10}}$) in the two bacterial subpopulations was derived using the following relationship:

$$t_{\log_{10}} = 2.303 / k_n , \qquad 13$$

where k_n is the k_1 or k_2 inactivation rate (table 8). The calculated inactivation curves for each experiment are given for *E. coli* in figures 8–10 and *P. aeruginosa* in figures 11–13. The general biphasic curve shape is evident in each dataset. Table 8 lists the data for each of the inactivation relevant variables described for the biphasic equation.

Table 8. Biphasic inactivation rate curve data for *Escherichia coli* and *Pseudomonas aeruginosa* from the six sampling sites.

[k_1 and k_2, inactivation rate constants; *f*, decimel fraction of total bacterial counts; t_{log10}, time to achieve a one log reduction in bacterial cell counts; hr^{-1}, per hour; %, percent; hrs, hours]

Indicator bacterium	Medium	Variable	Units	Well designation					
				42U	42L	15U	15M	MZ1	MZ3
Escherichia coli	mTEC	k_1	hr^{-1}	0.2950	0.6842	0.2171	0.5400	0.6275	0.5642
		f	%	98.3	95.9	99.8	99.0	98.3	98.8
		t_{log10}	hrs	7.8	3.4	10.6	4.3	3.7	4.1
		k_2	hr^{-1}	0.0088	0.0182	0.0064	0.0135	0.0112	0.0125
		1-*f*	%	1.7	4.1	0.2	1.0	1.5	1.2
		t_{log10}	days	11.0	5.3	15.1	7.1	8.6	7.7
	R2A	k_1	hr^{-1}	0.1850	0.1721	0.2013	0.1950	0.6063	0.2550
		f	%	98.2	99.6	99.6	99.5	99.5	99.8
		t_{log10}	hrs	12.5	13.4	11.4	11.8	3.8	9.0
		k_2	hr^{-1}	0.0065	0.0003	< 0.0001	0.0026	0.0080	0.0035
		1-*f*	%	1.8	0.4	0.4	0.5	0.5	0.2
		t_{log10}	days	14.7	329.0	> 959.58	36.6	12.1	27.1
Pseudomonas aeruginosa	PIA	k_1	hr^{-1}	0.7696	0.6917	0.1442	0.1592	0.3871	0.7717
		f	%	70.9	78.2	98.2	94.0	97.0	95.6
		t_{log10}	hrs	3.0	3.3	16.0	14.5	6.0	3.0
		k_2	hr^{-1}	0.0048	0.0044	0.0034	0.0054	0.0080	0.0050
		1-*f*	%	29.1	21.8	1.8	6.0	3.0	4.4
		t_{log10}	days	20.0	21.9	28.1	17.7	12.0	19.4
	R2A	k_1	hr^{-1}	0.2917	0.0479	0.4696	0.6833	0.6213	0.6704
		f	%	83.9	86.0	96.7	92.8	97.3	96.7
		t_{log10}	hrs	7.9	48.1	4.9	3.4	3.7	3.4
		k_2	hr^{-1}	0.0041	0.0040	0.0023	0.0047	0.0094	0.0074
		1-*f*	%	16.1	14.0	3.3	7.2	2.7	3.3
		t_{log10}	days	23.3	23.7	41.9	20.4	10.2	12.9

Escherichia coli Inactivation

The *E. coli* inactivation rates (that is, loss of cultivability over time) calculated from the mTEC agar data for the most susceptible subpopulation (k_1) were relatively consistent for 42L (0.6842 h^{-1}), 15M (0.5400 h^{-1}), MZ1 (0.6275 h^{-1}), and MZ3 (0.5642 h^{-1}) (table 8). The inactivation rates in 42U (0.2950 h^{-1}) and 15U (0.2171 h^{-1}) were approximately 2 to 3 times slower. When expressing the inactivation rates as time required for a 1.0 $\log_{10}$ reduction in CFU mL^{-1} ($t_{\log_{10}}$), the most sensitive *E. coli* subpopulation required between 3.4 and 10.6 hours (table 8).

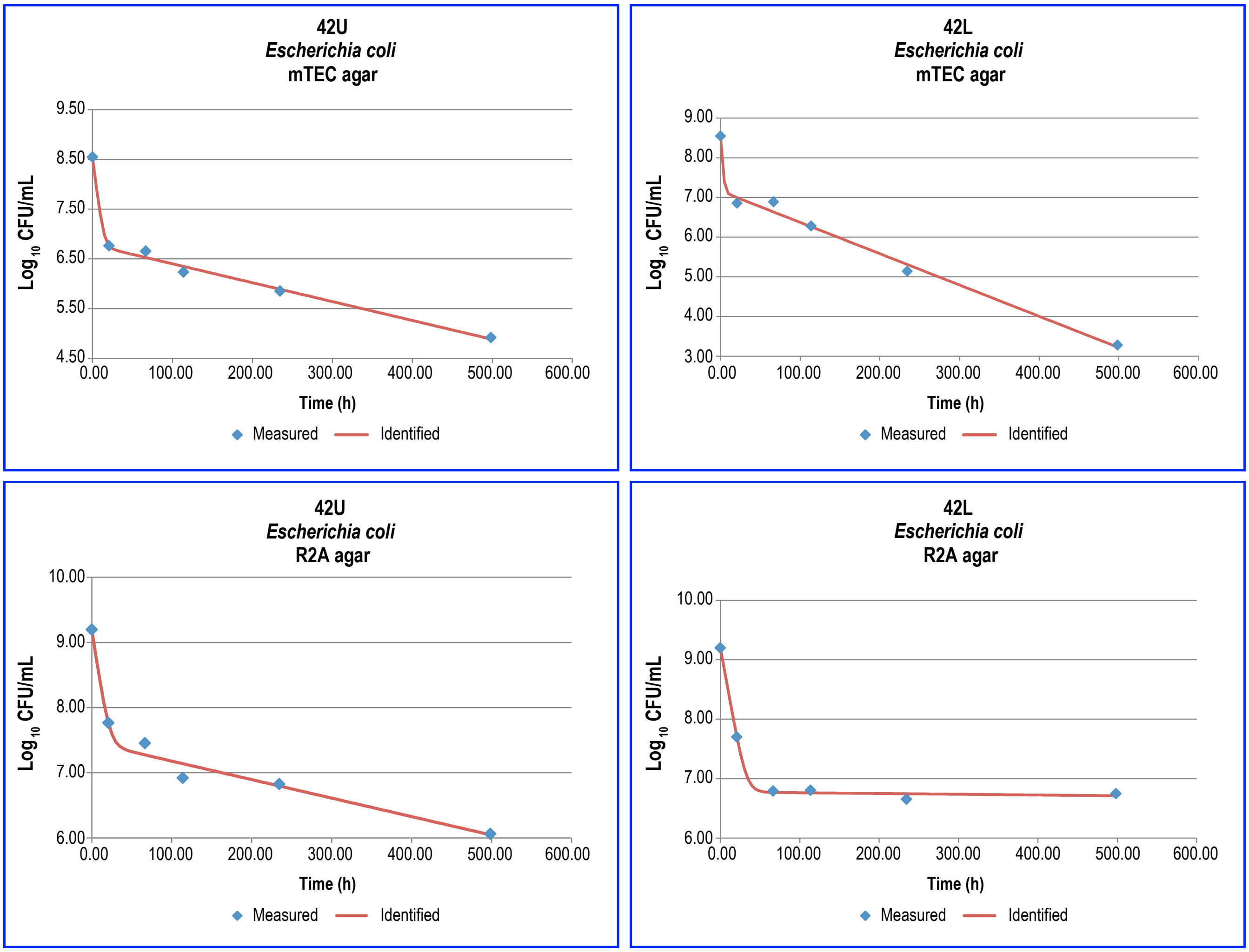


Figure 8. Graphs showing *Escherichia coli* decay rates for the 42U and 42L sampling sites [Log_{10} CFU/mL, log_{10} colony-forming units per milliliter; h, hours].

The inactivation rates for the less susceptible *E. coli* population (k_2) followed a similar ranking as those for k_1, but the rates were between approximately 33 to 56 times slower (table 8). The times required for a 1.0 $\log_{10}$ reduction were similar for 42L, 15M, MZ1, and MZ3 (range: 5.3–8.6 d) and approximately two times slower than the other groundwater for 42U (11.0 d) and 15U (15.1 d) (table 8).

The *E. coli* k_1 inactivation rates calculated from the R2A agar data also were relatively consistent, ranging between 0.1721 and 0.2550 h^{-1}, except for MZ1 (0.6063) (table 8). These rates are between 1.0 to 4.0 times slower than the k_1 values for the same groundwater on mTEC agar. The k_1 rates for the R2A agar data are between 1.1 to 4.0 times slower than the respective k_1 rates on mTEC agar (table 8). The time required for a 1.0 $\log_{10}$ reduction on R2A agar for this subpopulation was similar to that on mTEC agar, ranging from 3.8 to 13.4 hours (table 8).

The inactivation rates for the less susceptible *E. coli* populations (k_2) on R2A agar for 15M, MZ1, and MZ3 were approximately 72 to 75 times slower than their respective k_1 rates, whereas the 42L rate was 590 times slower (table 8). The k_2 rate in the groundwater from 15U was approximately 2,000 times slower than the k_1 value because of the persistent culturability of this strain of *E. coli* after the initial inactivation event (table 8). When compared to the k_2 values from the mTEC agar data, the

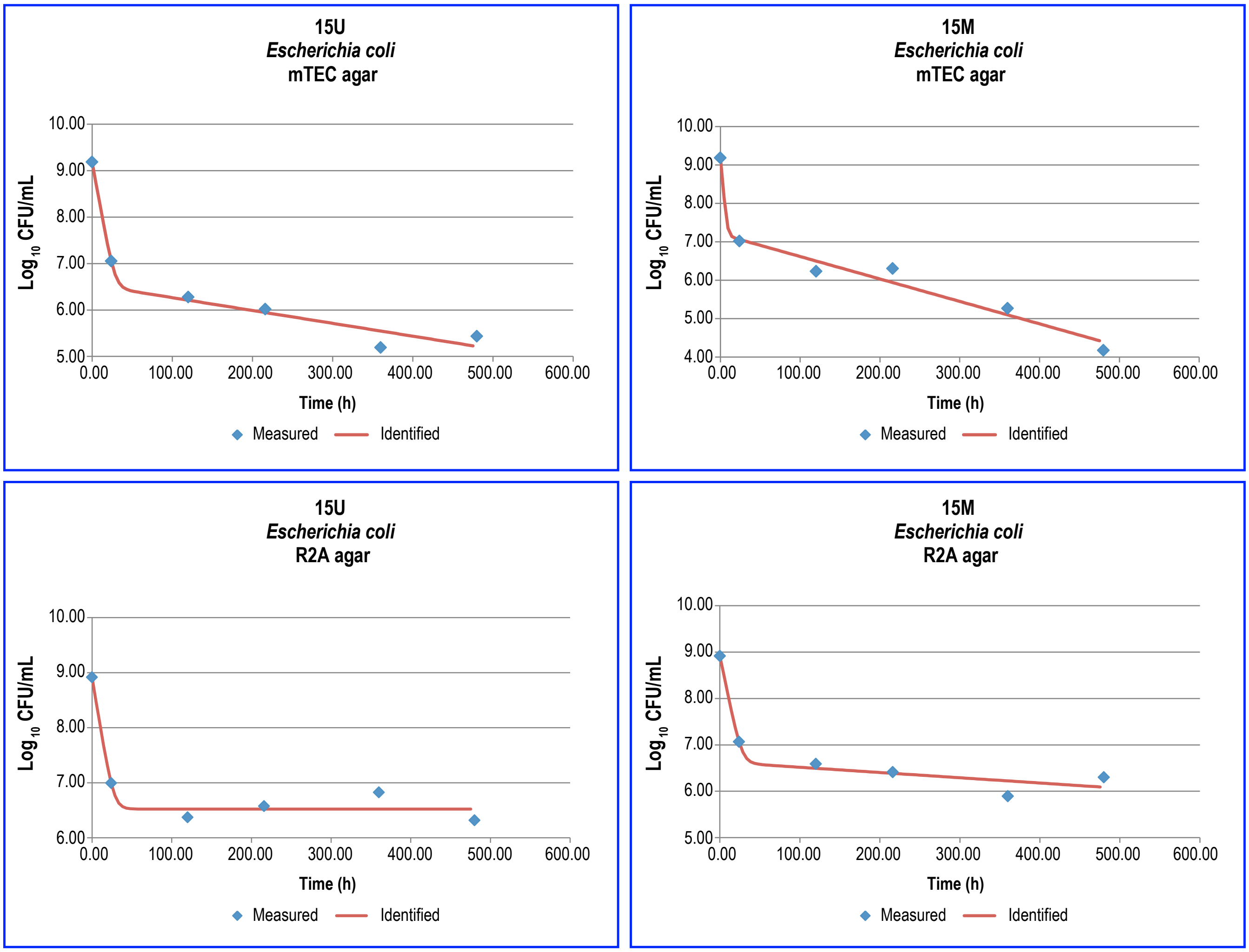
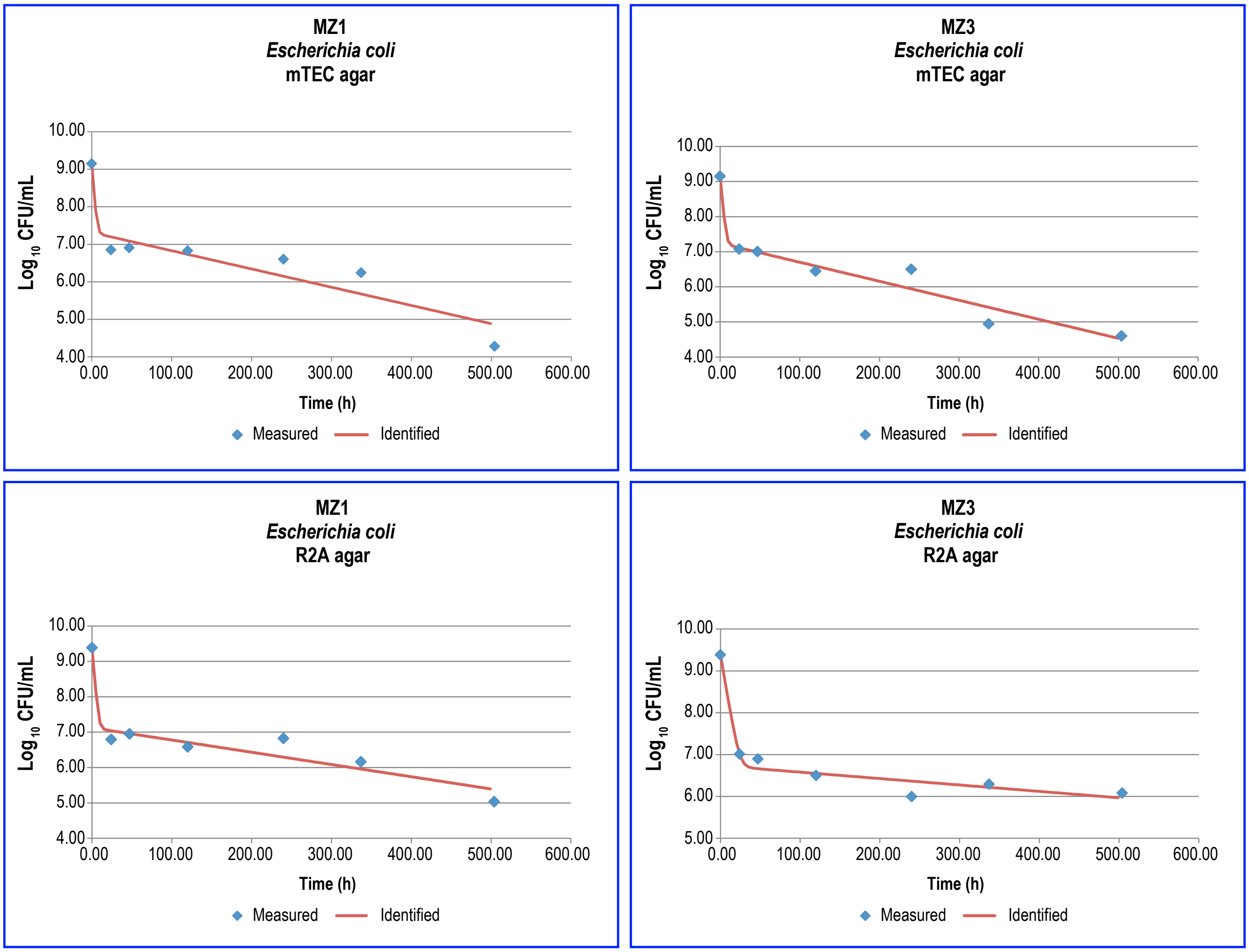


Figure 9. Graphs showing *Escherichia coli* decay rates for the 15U and 15M sampling sites [Log$_{10}$ CFU/mL, log$_{10}$ colony-forming units per milliliter; h, hours].

values from the R2A agar data are between 1.3 and 5.1 times slower for 42U, 15M, MZ1, and MZ3 and approximately 63 times slower for 42L and 15U. Although the 1.0 log$_{10}$ reduction times for the more susceptible subpopulations were similar between mTEC and R2A agars, this was not the case for the more resistant subpopulations at all of the well sites. 42U (14.7 days) and MZ1 (12.1 days) were similar to each other and their respective mTEC agar data. It took approximately a month to achieve this level of inactivation at 15M (36.6 days) and MZ3 (27.1 days). The significantly lower inactivation rate for 42L and persistent culturability recorded in 15U provided estimated 1.0 log$_{10}$ reduction times of 329 days and > 960 days, respectively.

The differences in inactivation rates and times between mTEC agar and R2A agar, regardless of the groundwater source, can be partially attributed to the different compositions of the media. mTEC agar is a selective and differential medium whose formulation and incubation conditions (that is, elevated temperature) were specifically designed to preferentially recover *E. coli* in water samples while inhibiting the growth of all other bacteria (Zimbro and others, 2009). Additionally, mTEC agar contains a chromogenic substrate that, when catabolized by *E. coli*, imparts a diagnostic color to each colony, whereas colonies formed by other bacteria remain colorless. Collectively, these conditions also apply


MZ1
Escherichia coli
mTEC agar

MZ3
Escherichia coli
mTEC agar

MZ1
Escherichia coli
R2A agar

MZ3
Escherichia coli
R2A agar

Figure 10. Graph showing *Escherichia coli* decay rates for the MZ1 and MZ3 sampling sites [Log$_{10}$ CFU/mL, log$_{10}$ colony-forming units per milliliter; h, hours].

additional physiological stresses on *E. coli* cells that have been shown to reduce bacterial recovery efficiencies, resulting in lower final CFU mL^{-1} values (Bissonnette and others, 1975; LeChevallier and others, 1983; McFeters, 1990). On the contrary, the formulation of R2A agar was designed to minimize the physiological stresses from incubation conditions, components of the recovery media, disinfectants, and environmental conditions, thereby increasing the recovery of injured and non-injured bacteria from water samples (Reasoner and Geldreich, 1985). R2A agar is a nonselective medium that contains reduced concentrations of nutrients that are essential for bacterial growth under environmental stress (that is, natural conditions) and following disinfection. Recovery rates of all heterotrophic bacteria are enhanced on this medium if incubated at lower temperatures, as described for this study. R2A agar has been used to compare recovery rates of *E. coli* and other bacteria of public health concern to those on selective media following starvation and disinfection (Keswick and others, 1982; Lisle and others, 1998).

Pseudomonas aeruginosa Inactivation

The k_1 inactivation rates calculated from the PIA agar data for *P. aeruginosa* were relatively similar for 42U (0.7696 h^{-1}), 42L (0.6917 h^{-1}), and MZ3 (0.7717 h^{-1}), with 15U (0.1442 h^{-1}) and

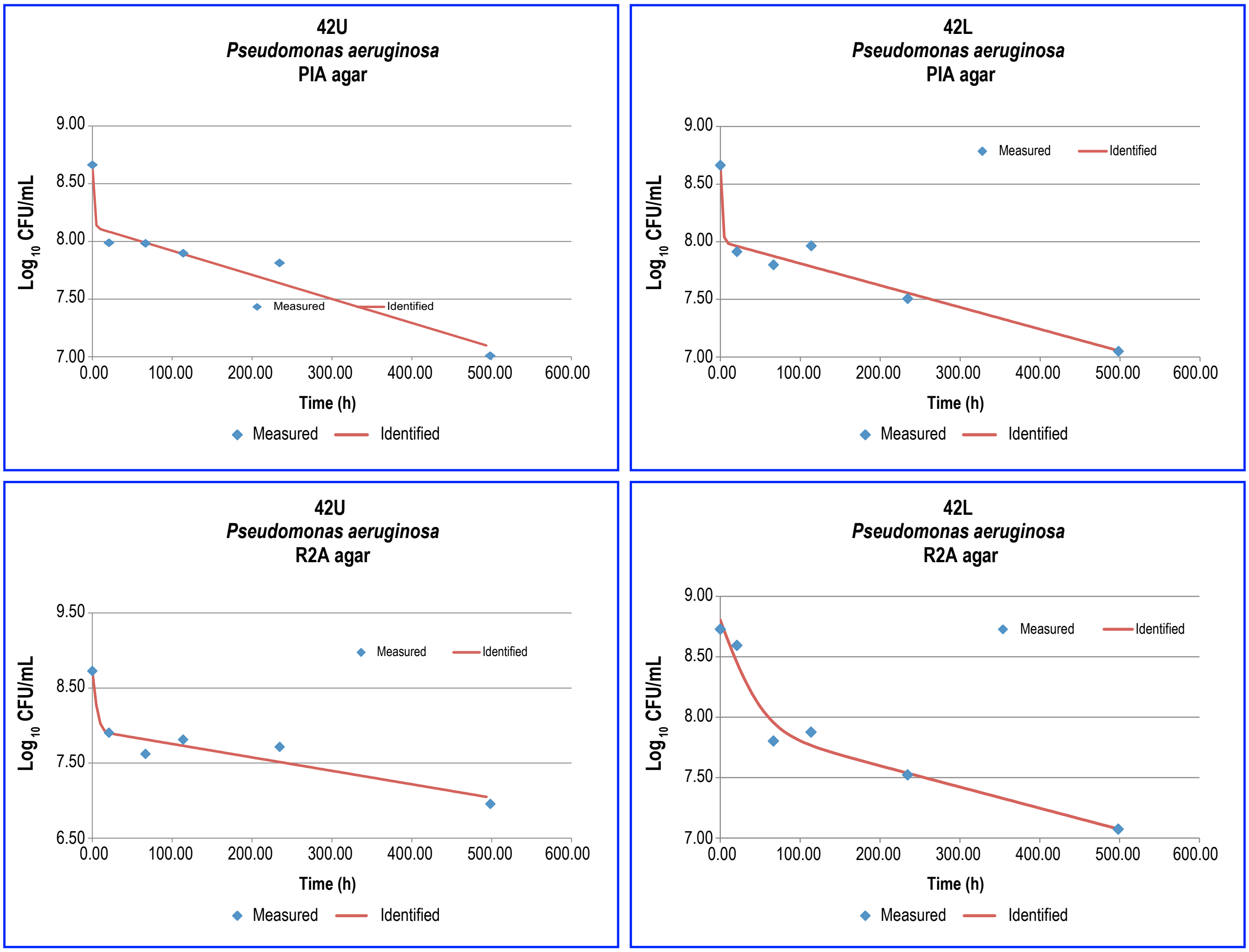


Figure 11. Graph showing *Pseudomonas aeruginosa* decay rates for the 42U and 42L sampling sites [Log$_{10}$ CFU/mL, log$_{10}$ colony-forming units per milliliter; h, hours].

15M (0.1592 h^{-1}) being approximately 5 times slower and MZ1 (0.3871 h^{-1}) positioned between the two sets of inactivation rates (table 8). The more susceptible subpopulations in the 42U, 42L, MZ1, and MZ3 diffusion chambers had similar 1.0 log$_{10}$ reduction times, ranging from 3.0 to 6.0 h (table 8). These reduction times were 2 to 5 times slower for 15U (16.0 h) and 15M (14.5 h) (table 8).

The k_2 inactivation rates from these same experiments were similar for 42U, 42L, 15U, 15M, and MZ3 (range: 0.0034–0.0054 h^{-1}), with MZ1 being moderately higher (0.0080 h^{-1}) (table 8). The k_2 inactivation rates were 29.4 to 48.4 times slower than the respective k_1 rates for 15M, 15U, and MZ1 and 155.6 to 160.6 times slower for MZ3, 42U, and 42L (table 8). The $t_{\log_{10}}$ values were grouped by site as for the k$_2$ rates, ranging from 17.7 to 28.1 days, with MZ1 having a moderately faster rate of 12.0 days.

The k_1 inactivation rates for *P. aeruginosa* on R2A agar were similar and relatively greater for 15M (0.6833 h^{-1}), MZ1 (0.6213 h^{-1}), and MZ3 (0.6704 h^{-1}). The k_1 rate for 15U (0.4696 h^{-1}) was slightly slower than the other rates, whereas the 42U (0.2917 h^{-1}) and 42L (0.0479 h^{-1}) rates were significantly slower (table 8). The k_2 inactivation rates were similar and relatively greater for MZ1 (0.0094 h^{-1}) and MZ3 (0.0074 h^{-1}), which were approximately two times greater than the rates from 42U (0.0041 h^{-1}), 42L (0.0040 h^{-1}), and 15M (0.0047 h^{-1}) and four times greater than 15U (0.0023 h^{-1}) (table 8).

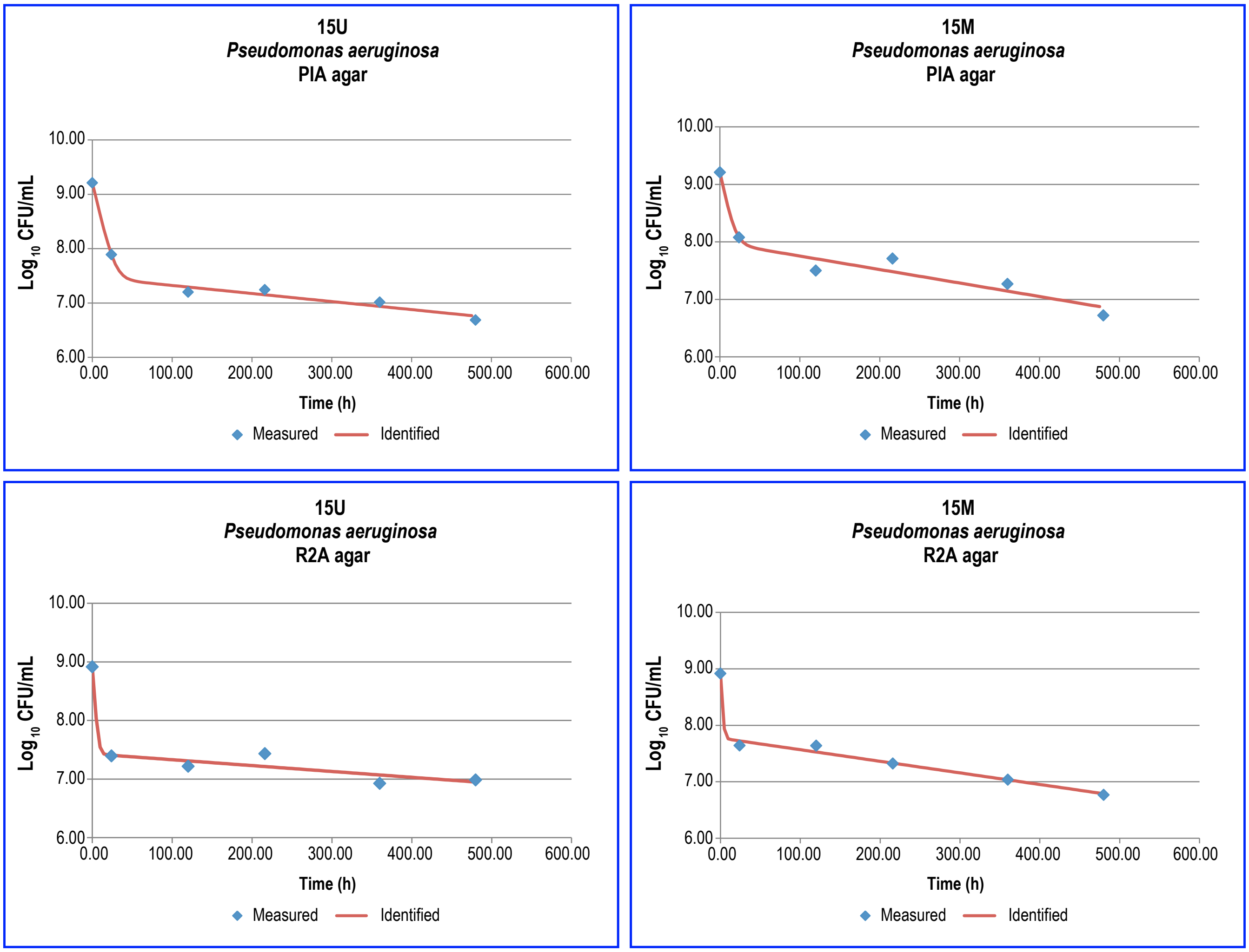


Figure 12. Graph showing *Pseudomonas aeruginosa* decay rates for the 15U and 15M sampling sites [Log$_{10}$ CFU/mL, log$_{10}$ colony-forming units per milliliter; h, hours].

This second phase of the respective inactivation models was between approximately 12 times (42L) and 205 times (15U) slower than the respective k_1 inactivation rates (table 8). The time periods for a 1.0 log$_{10}$ reduction of the more susceptible subpopulations on R2A agar were not consistently similar to those from the PIA agar data, except for MZ3 (3.4 and 3.0 h, respectively) (table 8). Unlike the systematic differences between these same rates on mTEC and R2A agars, where the R2A agar data were all slower (with the exception of MZ1), some of the $t_{\log_{10}}$ rates from the PIA agar were greater than those on R2A agar (15U, 15M, and MZ1), whereas those for 42U and 42L were significantly slower (table 8).

PIA agar is also a selective and differential medium but the selective agents are not identical to those in mTEC agar in regard to their structures, activities, and degrees of inhibition (Zimbro and others, 2009). The higher incubation temperature for mTEC agar also increases the inhibitory effects. Collectively, the media formulation of and incubation conditions for mTEC agar exerts a significantly greater level of physiological stress on target bacteria than PIA agar. The lack of consistent differences between the recovery and inactivation data for PIA and R2A agars, as with the mTEC and R2A agar data, are due to the lower physiological stresses.

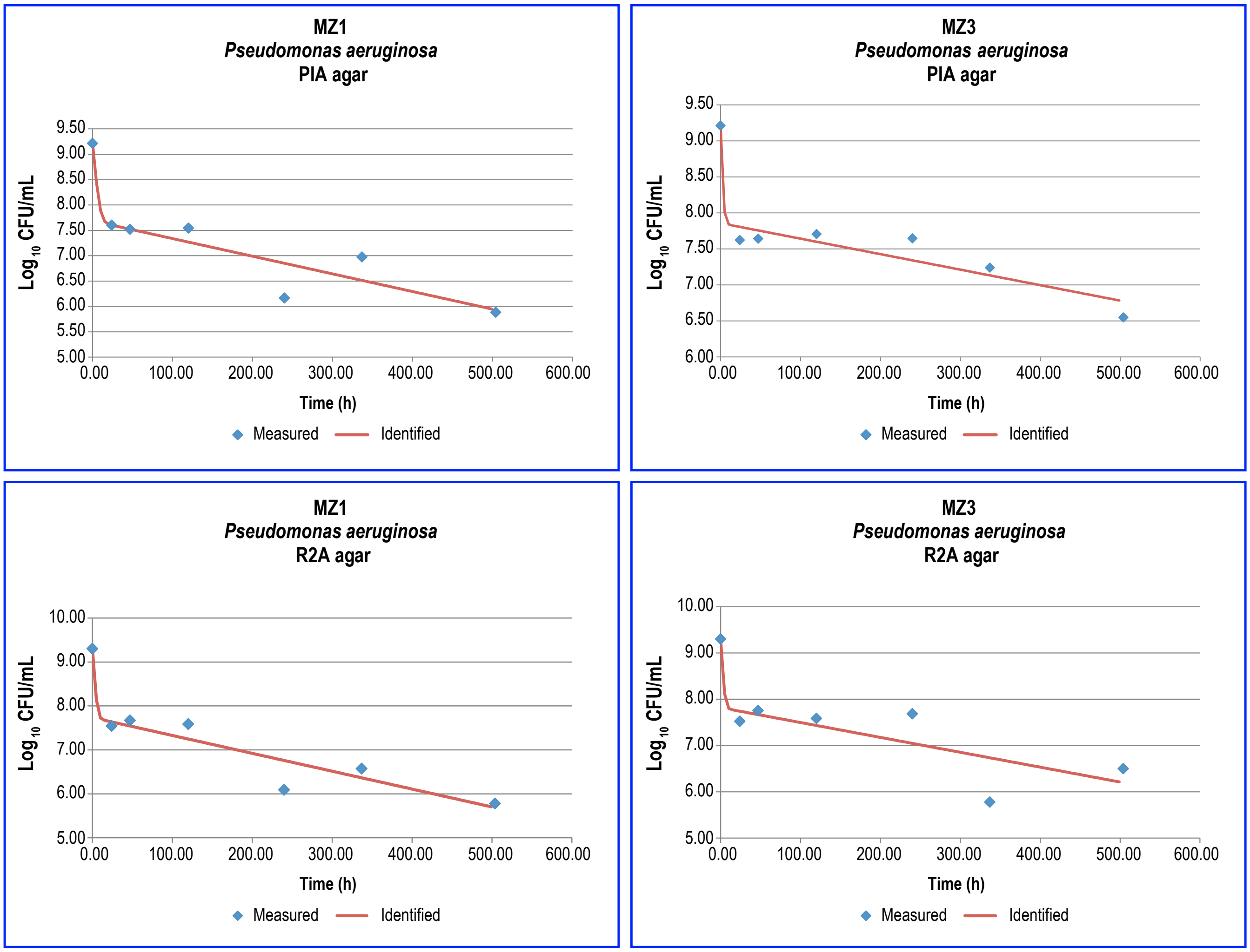


Figure 13. Graph showing *Pseudomonas aeruginosa* decay rates from the MZ1 and MZ3 sampling sites [Log$_{10}$ CFU/mL, log$_{10}$ colony-forming units per milliliter; h, hours].

Relevance of *Escherichia coli* Inactivation Rates in the Upper Floridan aquifer

The number of published studies on inactivation rates of *E. coli* in groundwater are few (John and Rose, 2005). Of these, a small percentage describe the use of diffusion chambers, and studies that have used diffusion chambers in situ or in systems that maintain in situ conditions are rare. Table 9 lists the published studies that have specifically quantified inactivation rates of *E. coli* in groundwater. Except for the study by Sidhu and Toze (2012), these studies did not record the native groundwater geochemical conditions, nor make an effort to maintain those conditions during the inactivation experiments. In addition, all of the studies listed in table 9 used linear regression methods to derive the inactivation rates, except for John (2003), who selectively used a polynomial equation to model data with an initial increase that was followed by a decrease in culturability. A visual inspection of the graphed data presented in these publications revealed that most of the datasets were not linear throughout the entire time of the experiments, especially for the first few sampling events. Most datasets appeared to have an initial and rapid decrease in culturability, followed by a more gradual decrease that closely resembled the data from this study (figs. 8–13).

Table 9. *Escherichia coli* inactivation rate data from the published literature.

[hr^{-1}, per hour; mL, milliliter]

Inactivation rate (hr^{-1})	Experimental design	Reference
0.013	Diffusion chambers in an above ground container open to air	Bitton and others (1983)
0.0066	Spiked groundwater in bench top flasks	Cook and Bolster (2007)
0.004-0.007	Spiked groundwater in bench top flasks	Davies and Davies (2010)
0.004	Spiked groundwater in 50 mL tubes	Keswick and others (1982)
0.029	Diffusion chambers that were placed in situ	Sidhu and Toze (2012)

In the Sidhu and Toze (2012) study, diffusion chambers filled with *E. coli* cells were inserted into the production zones of groundwater wells. Although this aspect of their study is similar to this study, the geochemistry of their groundwater systems was significantly different from that in the region of the Upper Floridan aquifer investigated in this study. For example, the aquifer in their study maintained a dissolved oxygen concentration of 2.0 mg L^{-1} and an ORP of 222 millivolts (mV), whereas all of the groundwaters in this study are strictly anaerobic and extremely reduced (table 2).

It is worth noting that the doctoral dissertation by John (2003) describes a set of experiments that used water from two wells whose production zones are located in the Upper Floridan aquifer (ROMP TR7–4: lat 27.427781, long –82.489095 and PBF–3: lat 26.675833, long –80.103056). The focus of his experimental design was the influence of total dissolved solids (TDS) on the survival of microbial indicators in groundwater. The groundwater collected for these experiments was pasteurized at 70 °C for 30 minutes and stored at 4 °C until used for the bench-top microcosm (that is, open beaker) studies. Only temperature, pH, total organic carbon, specific conductance, and TDS data were collected. No geochemical data were collected on the native or pasteurized groundwater samples prior to, during, or after each experiment. The k_1 rates from this study are orders of magnitude greater, and the k_2 rates are 1.3 to 2.6 times greater than the fastest inactivation rate of 0.007 $h^{-1 \text{ in John (2008)}}$, except for rates obtained for 15U which were similar between these studies (tables 8 and 9).

To place the *E. coli* inactivation rates in a more applied context, an example that uses data from the Hillsboro ASR pilot project's treatment facility is presented. The pumping rate for recharge water by this facility is 5 million gallons per day (Mgal d^{-1}). This facility has detected *E. coli* in the recharge water at a concentration ranging from below detection (<1.0 CFU 100 mL^{-1}) to 65 CFU 100 mL^{-1}. At this recharge rate and maximum *E. coli* concentration, there could be 1.23×10^{10} *E. coli* introduced into the aquifer at the completion of a 1-day recharge event. The biphasic model used to calculate the inactivation rate data in table 8 assumes that both subpopulations independently follow first order reaction kinetics, which permits the use of Chick's Law for calculating the times required for total inactivation of both subpopulations. The most familiar form of Chick's Law is as follows:

$$\frac{N_t}{N_0} = e^{-kt} , \qquad 14$$

where

N_t	is the concentration (CFU per milliliter) of injected bacteria at time t (hours),
N_0	is the concentration (CFU per milliliter) of bacteria at the end of the recharge event, and
k	is the inactivation rate constant (per hour).

The variable N_t is set at 0.9 (assuming a value of <1.0 CFU represents total inactivation), N_0 is adjusted for the respective subpopulations using the f or $1–f$ values, and the k_1 and k_2 values (table 8) are used with the appropriate N_0 values. Solving for t yields an estimate of the length of storage time required for the respective subpopulations of *E. coli* to be reduced to less than 1.0 CFU (table 10). The more sensitive subpopulation of *E. coli* (k_1 data) was reduced to less than 1.0 CFU in all the wells at a similar rate when using mTEC agar, ranging from 1.4 to 4.5 days (table 10). The same subpopulation on R2A agar was completely inactivated at a generally slower rate, ranging from 1.6 to 5.6 d.

The more resistant subpopulations (k_2 data) were inactivated at significantly slower rates, regardless of which medium was used. Using the mTEC agar data, this *E. coli* subpopulation was inactivated after 1.5 to 3.7 months of storage in the respective aquifer zones. The R2A agar data were generally slower than the rates calculated from the mTEC agar data, ranging from 3.1 to 9.5 months for 42U, 15M, MZ1, and MZ3, and 7.1 years for 42L. The outlier in the dataset is for 15U, where a predicted > 120.6 years of storage are required to totally inactivate the more resistant *E. coli* subpopulation to less than 1 CFU (table 10).

Bacteria that live in natural environments are considered to be under varying degrees of physiological stress that result in significant reductions or loss of culturability (Finkel and others, 2000; McDougald and others, 1998; Nystrom, 2004). The type and severity of stress is dependent upon the in situ physical and geochemical conditions of the natural systems, disinfectants (for example, oxidants, UV irradiation) in engineered systems, and culture media and incubation conditions. However, the loss of culturability does not necessarily ensure that the noncultured cells are nonviable (that is, dead). The recovery or resuscitation of stressed and previously nonculturable bacteria from aquatic systems has been demonstrated (Barer and others, 1993; Barer and Harwood, 1999; Blatchley and others, 2007; Kell and others, 1998). This nonculturable physiological state in stressed bacteria (Roszak and Colwell, 1987) has important implications when monitoring groundwater systems for the presence of bacterial indicators of fecal contamination. As shown in this study, for both bacterial strains, the geochemical conditions in the aquifer reduce the culturability of a proportion of the total bacterial populations in the diffusion chambers. Under treatment-plant operational conditions, the storage of recharged water in this region of the Upper Floridan aquifer may contribute to filtration and disinfection log reduction credits as defined by regulatory agencies.

Additional inactivation of microbial indicators because of the secondary physiological stress of culture media and incubation conditions may reduce recovery rates even further. At low concentrations

Table 10. The estimated storage time to achieve 1.0 CFU in the recovered water at the six sampling sites.

[f, decimel fraction of total bacterial counts]

Bacterium	Media	Population	Time	Well designation					
				42U	42L	15U	15M	MZ1	MZ3
Escherichia coli	mTEC	f	days	3.3	1.4	4.5	1.8	1.5	1.7
		1-f	months	3.1	1.5	3.7	1.9	2.4	2.1
	R2A	f	days	5.3	5.6	4.8	5.0	1.6	3.8
		1-f	months	4.1	84.8	> 247.5	9.5	3.1	6.7
Pseudomonas aeruginosa	PIA	f	days	1.2	1.4	6.7	6.1	2.5	1.3
		1-f	months	6.4	6.9	7.9	5.3	3.4	5.7
	R2A	f	days	3.3	20.2	2.1	1.4	1.6	1.4
		1-f	months	7.2	7.3	12.1	6.1	2.9	3.7

of bacteria such as *E. coli*, these additional reductions in recovery rates may provide data below the regulatory maximum contaminant level, thereby promoting a false sense of confidence in the microbiological quality of the tested waters.

Dissolved Organic Carbon Characterization

The dissolved organic carbon (DOC) concentrations in the groundwater samples were similar, ranging from 1.1 to 1.9 mg L^{-1} (table 11). These data are similar in magnitude to the DOC concentrations found in the Upper Floridan aquifer (UFA) in the Miami area (Lisle, 2005), which is also considered an isolated aquifer like that sampled during this study (table 11). The fluorescence index (FI) values were also similar between groundwater samples and with the UFA sample previously cited, ranging from 1.70 to 1.77 (table 11). When compared to FI data from the Biscayne aquifer (Lisle, 2005), which is a mix of terrestrial and microbially derived carbon, and Lake Okeechobee water, where the source of DOC is predominantly terrestrial, the DOC in the groundwater sampled during this study is classified as microbially derived. These data support the contention that the aquifer zones sampled during this study are isolated from surface-water intrusion that would carry DOC from terrestrial sources.

Volatile fatty acids (VFA) (for example, acetate, lactate, propionate, and pyruvate) (table 2) are components of DOC. Most microbial cells in anaerobic and reduced aquatic ecosystems readily metabolize volatile fatty acids. The total VFA (VFA_t) concentrations in the respective groundwater samples ranged from 70 micrograms per liter (µg L^{-1}) to 3.87 mg L^{-1} (table 2) and accounted for 7.1 to 21.5 percent of the measured DOC (table 11). The 351.8 percent value for MZ3 is due to the extremely high concentration of lactate (table 2). A simple explanation for such an elevated lactate concentration in one sample is unlikely and this could only be resolved after completing additional sampling and analyses.

In regard to carbon concentrations in recharge water, the DOC concentration in Lake Okeechobee water is approximately 20 times higher than in any of the sampled groundwater (table 11). Any treatment process that does not remove DOC from this surface-water source, or any other source, prior to injection will introduce carbon substrates into these subsurface ecosystems at concentrations that have not been available since the initial recharge event approximately 20,000–25,000 years before present (Meyer, 1989; Plummer and Sprinkle, 2001). This sudden increase in carbon would initiate a dramatic shift of the native geochemical signature in the receiving aquifer because of biogeochemical responses of the native and introduced microbial communities.

Table 11. Dissolved organic carbon and carbon fluorescent index data for the six sampling sites.

[DOC, dissolved organic carbon; FI, flourescent index; VFA, volitile fatty acids; mg mL^{-1}, milligrams per milliliter; %, percent; ND, not determined]

Well designation	DOC (mg mL^{-1})	FI	VFA (% of DOC)
42U	1.1	1.71	8.6
42L	1.2	1.70	5.8
15U	1.7	ND	7.1
15M	1.9	ND	13.7
MZ1	1.2	1.73	21.5
MZ3	1.1	1.73	351.8
Upper Floridan Aquifer (Miami)	1.2	1.77	
Biscayne Aquifer (Miami)	3.1	1.49	
Lake Okeechobee	19.7	1.32	

Bacterial Utilization and Turnover of Native Carbon

Access to, and utilization of, organic and inorganic carbon by native microbial communities that persist in ecosystems like this region of the Upper Floridan aquifer is required for maintaining viability. Because of the extended period of time since this region of the Upper Floridan aquifer has been impacted by the introduction of surface waters and photosynthetically fixed carbon, the organic carbon concentrations are very low and their source is predominantly from microbial recycling of organic carbon and autotrophic inorganic carbon fixation. A commonly found carbon substrate in anaerobic groundwater is acetate, a volatile fatty acid. Acetate was detected in all groundwater sampled during this study, making it well suited for assessing the total carbon utilization rates in the native microbial communities, which includes mineralization (production of CO_2) and assimilation (incorporation into biomass).

Table 12 summarizes the acetate utilization rates in each of the groundwater sources sampled during this study. The respiration-associated rates are similar and lowest for 15M and MZ1 and moderately greater for 42U, 42L, and MZ3. The native microbial community in 15U had the highest utilization rate (5.8 nanomoles per hour (nM h^{-1})), being between 1.5 to 2 times greater than those for the other sites. The rates of incorporating acetate into the microbial biomass (range: 3.3–9.0 nM h^{-1}) were similar to those for respiration at 42L and 15U, approximately 1.5 times greater at 42U and 15M and 2.5 times greater at MZ3. The biomass production rates being approximately equal or greater than respiration rates indicate the native microbial populations in these zones of the Upper Floridan aquifer are capable of producing low levels of new biomass (that is, cells) in the native conditions of strict anaerobiosis, extremely low redox potentials, and low carbon concentrations.

When taking the sum of the acetate respiration and production rates, the total acetate utilization and turnover rates can be calculated (table 12). The collective utilization rates (range: 6.9–12.2 nM h^{-1}) for 42L, 15M, and MZ1 are similar and the lowest of the sampling sites, whereas the rates for 15U and MZ3 are highest. The acetate turnover rates, which estimate the times required to utilize all of the acetate in sampled groundwater assuming no replenishment of acetate during the time interval, range from 4.1 days (MZ3) to 12.1 days (MZ1) (table 12).

Another method of estimating bacterial production is the use of ^{3}H-leucine, an amino acid. The rates of incorporation of this amino acid into cellular proteins have been correlated with carbon content in bacterial cells (Kirchman, 2001). The derivation of the relationship between incorporated leucine rates and bacterial biomass production rates is dependent on a set of empirical factors, as described previously. Biomass production, in units of carbon (nanomoles carbon per hour), can then be related to the number of bacterial cells produced per unit time using the relationship of an average carbon content per bacterial cell of 20 femtograms carbon per cell (fg C $cell^{-1}$) (Lee and Fuhrman, 1987). The ^{3}H-leucine based biomass production rates ranged from 0.03 to 0.91 nanomoles carbon per liter per hour (nM C L^{-1} h^{-1}), which will support the production of between 4.25×10^{5} to 1.31×10^{7} cells per liter per day (L^{-1} d^{-1}) (table 13). These cell production rates account for only 0.06 to 3.17 percent (table 13) of the respective native cell abundances (table 7).

Bacterial growth efficiency (BGE) is the quantity of bacterial biomass produced per unit of substrate assimilated, which in this study was acetate. The substrate can be utilized at some ratio of energy production (that is, respiration) and biomass production, which varies considerably across ecosystems and their respective nutritional gradients. Traditionally, BGE is calculated using ^{3}H-leucine data for productivity and ^{14}C-labelled substrate data for respiration.

The BGE values for the bacterial communities in this study ranged from 0.002 to 0.116 (table 14). Published BGE values from marine and freshwater systems range from 0.02 to 0.23 for the

Table 12. ^{14}C-acetate turnover and utilization rate data for the native bacterial community at the six sampling sites.

[CO_2, carbon dioxide; V_n, acetate utilization rate; T_n, acetate turnover rate; nM h^{-1}, nanomoles per hour; d, days]

Well designation	Respiration (CO_2)	Production (biomass)	Carbon demand (respiration + production)	
	Acetate utilization rate (v_n) (nM h^{-1})	Acetate utilization rate (v_n) (nM h^{-1})	Acetate utilization rate (v_n) (nM h^{-1})	Acetate turnover rate (T_n) (d)
42U	3.6	5.1	8.7	7.7
42L	3.7	3.3	7.0	7.1
15U	5.8	6.2	12.0	7.0
15M	2.7	4.4	7.1	6.9
MZ1	2.1	4.8	6.9	12.1
MZ3	3.2	9.0	12.2	4.1

more oligotrophic marine waters and 0.04 to 0.08 for freshwater lakes. The published BGE data provide a reference point for the data obtained in this study, but direct comparisons would be inappropriate because this region of the Upper Floridan aquifer is anaerobic, extremely reduced, and oligotrophic. Similar conditions are not represented in the published data.

The low proportion of carbon being used for biomass production in the Upper Floridan aquifer indicates the majority of the carbon substrate is being used in respiratory functions, such as energy transduction, membrane energization, active transport across membranes, cellular repair, and so forth. These basal, or maintenance, energy requirements are critical for bacteria in all ecosystems because the cells die once these energetic requirements are not satisfied. Because maintenance energy requirements do not change with growth rates or nutritional conditions, these energy requirements (that is, carbon demand) account for a significant proportion of the available energy in oligotrophic and anaerobic systems like this region of the Upper Floridan aquifer. Accordingly, growth rates (that is, biomass production) would be expected to be significantly reduced (Russell and Cook, 1995). The concept of lower BGE values indicating lower biomass production rates is supported by the calculated BP rates in this study, which represent only 0.06 to 3.17 percent of the native bacterial concentrations of the respective groundwater sources (table 13).

Collectively, the organic carbon cycling data show the native microbial communities are viable and active but have very slow rates of metabolism. The majority of the utilized organic carbon is used to maintain vital cellular functions, with a minor proportion diverted to producing new biomass. The organic carbon turnover rates, however, present a quandary in that the rates are on the order of days to

Table 13. ^{3}H-leucine-based bacterial production rates at the six sampling sites.

[nM C L^{-1} h^{-1}, nanomoles of carbon per liter per hour; cells L^{-1} d^{-1}, cells per liter per day; %, percent]

Well designation	Biomass production (nM C L^{-1} h^{-1})	Bacterial cell production (cells L^{-1} d^{-1})	Percent of native biomass (%)
42U	0.19	2.69×10^{6}	0.65
42L	0.09	1.24×10^{6}	3.17
15U	0.03	4.25×10^{5}	0.06
15M	0.06	8.30×10^{5}	0.11
MZ1	0.91	1.31×10^{7}	1.64
MZ3	0.1	1.50×10^{6}	0.22

Table 14. Bacterial growth efficiency data for the six sampling sites.

[BP, bacterial production; BR, bacterial respiration; BGE, bacterial growth efficiency; ^{3}H-leucine, tritium labled leucine; ^{14}C-leucine, carbon-14 labeled leucine; ng C L^{-1} h^{-1}, nanograms of carbon per liter per hour]

Well designation	BP ^{3}H-leucine ng C L^{-1} h^{-1}	BR ^{14}C-acetate ng C L^{-1} h^{-1}	BGE
42U	1.35	86.8	0.015
42L	0.62	88.0	0.007
15U	0.21	139.6	0.002
15M	0.42	63.6	0.007
MZ1	6.59	50.4	0.116
MZ3	0.75	77.2	0.010

weeks and additional carbon has not been transported from a source outside the Upper Floridan aquifer for over 20,000 years (Meyer, 1989; Plummer and Sprinkle, 2001). Possible explanations as to where the organic carbon originates include the following: (1) the non-acetate proportion of the DOC could be leaching from the geologic matrix of the karst aquifer; (2) lithoautotrophic bacteria are fixing inorganic carbon (for example, HCO_3^-, CO_2) into cellular biomass; and (3) upon bacterial lysis (for example, bacteriophage infection, predatory bacteria) the cellular debris becomes DOC (Mathias and others, 2003; Middelboe and Jørgensen, 2006). This cycling of organic and inorganic carbon into and from bacterial biomass has been shown to be a central process in carbon cycling in surface-water ecosystems and is commonly referred to as the microbial loop (Jiao and others, 2011).

Microbial Energetics and Sustainability in the Upper Floridan Aquifer

The previous section describes viable and physiologically active native microbial communities in all of the groundwater sampling sites. As shown by the BGE values (table 14), the majority of the carbon being metabolized by these communities is used in the production of energy for cellular processes. These dissimilatory reactions rely on the presence of a variety of extracellular electron donors and acceptors to generate this energy. As these reactions proceed and organic and inorganic substrates and terminal electron acceptors are respectively oxidized and reduced, the products of these reactions alter groundwater chemistry. The applicability of, for example, reactive transport models for predicting changes in groundwater geochemistry would therefore improve with the inclusion of variables that constrain these biogeochemical reactions and their rates.

The most direct method for characterizing biogeochemical reactions that alter groundwater chemistry is to sample the native microbial communities and determine the types and rates of reactions that members of these communities perform under in situ conditions. Unfortunately, there are several obstacles that make this approach impractical. Having culturable representative isolates of each microbial group that performs a specific biogeochemical reaction would be ideal. However, the low culturability rates of native groundwater microorganisms make this practically impossible. For example, an average 13 CFU mL^{-1} of the native microbial community were recovered from the six groundwater sites during this study using R2A agar (data not shown). This average value represents only 0.002 to 0.03 percent of the total cells counted in each groundwater source (table 7). These percent recoveries can be increased by using recovery media and incubation conditions specifically formulated and maintained to enhance the likelihood of recovery, but expected percentage recoveries would not be predicted to be much greater than 1.0 percent of the total population (Amann and others, 1995). Another obstacle related to culturability is the difficulty of co-culturing two or more species that must be present for the biogeochemical reactions of interest to proceed (for example, syntrophic metabolism). In addition, the slow growth and metabolic rates (tables 12–14) in anaerobic and reduced groundwater systems like this region of the Upper Floridan aquifer would require experiments to proceed for weeks-to-decades.

Free Energy Yields for Energetically Favorable Biogeochemical Reactions

One approach to circumvent the issues just described is to determine which biogeochemical reactions are most likely to proceed using thermodynamically based energetic analyses (that is, Gibbs free energy of reaction yields) and the geochemistry of the respective groundwaters. Regardless of the growth conditions (that is, high nutrients and energy in laboratory cultures versus low nutrients and extremely low energy in the Upper Floridan aquifer), the same thermodynamic principles apply. Therefore, free energy yields of microbially driven redox reactions can be applied to constrain the list of most probable biogeochemical reactions. This approach is especially applicable to low energy ecosystems like this region of the Upper Floridan aquifer, where microbial life persist close to thermodynamic equilibria.

Amend and Shock (2001) describe free energy yields for 370 reactions that have been shown to be directly or indirectly involved in microbial metabolism. Approximately 200 of these reactions were redox reactions known to be mediated by microorganisms for the acquisition of energy for cellular metabolism. The geochemical data from this study (table 2) were used to determine which subsets of these biogeochemical reactions (table 3) were applicable to the groundwater in this study. A subset of five reactions were determined to be thermodynamically feasible in this region of the Upper Floridan aquifer, using -20 kJ mol^{-1} of the limiting substrate as the minimum free energy of reaction yield required to maintain cell viability. Detailed geochemical modeling was not part of this project; therefore, mineral phases are not included in the geochemical dataset. The omission of mineral phase data and incomplete sampling of gases (for example, N_2) prevented the use of the majority of the biogeochemical reactions that rely on these data as reactants and (or) products.

Of the five favorable reactions, three reactions (reactions 1, 2, 4, and 12) were favorable in all samples, whereas reaction 3 was favorable only in the 42U and MZ1 groundwater (tables 15–17). Two of these reactions (3 and 4) are methanogenic, whereas the remaining two reactions (1 and 2) represent sulfate reductions that produce sulfides as hydrogen and acetate are oxidized, respectively. As shown in table 3, both types of reactions are dependent upon hydrogen and acetate as reactants and therefore compete for common reactants. The more interesting set of reactions is hydrogenotrophic sulfate reduction (reaction 1) and methanogenesis (reaction 3). It is commonly assumed that hydrogenotrophic and acetotrophic sulfate reduction and methanogenesis are mutually exclusive, especially in systems where sulfate is not a limiting reactant as in the Upper Floridan aquifer. This is due to sulfate reducers having a higher affinity for hydrogen (Kristjansson and others, 1982; Lovley and others, 1982; Robinson and Tiedje, 1984) and acetate (Ferry and Lessner, 2008; Schonheit and others, 1982) than methanogens, thereby maintaining hydrogen and acetate concentrations at or below a minimum threshold for methanogenesis in the presence of excess sulfate.

Although methane was detected in each groundwater sample collected for this study. This apparent contradiction may be resolved if alternative substrates for methanogenesis are present in the aquifer. Recently, low-carbon-number methylated compounds (for example, methanol, methylated amines, and methylated sulfides) have been shown to be alternative reactants for methanogens while being unutilized by sulfate reducers (Liu and Whitman, 2008). The generation of methylated sulfides occur through chemical reactions between sulfides and the methyl groups within the organic matter or DOC

(Mitterer, 2010). In regard to sources of methylamines, Mitterer and others (2001) identified the matrix of carbonate sediments as the source of methylamines because of the inclusion of biogenic proteins during formation. The region of the Upper Floridan aquifer sampled during this study is karst and contains sulfides and low concentrations of organic matter. Collectively, the conditions are present in this region of the aquifer for the noncompetitive co-occurrence of sulfate reduction and methanogenesis, and both types of reactions are energetically favorable, ranging from 52 to 64 kJ mol^{-1} and 30 to 42 kJ mol^{-1} for the sulfate reduction and methanogenic reactions, respectively (tables 15–17).

Reaction 12 describes the anaerobic oxidation of methane (AOM), for which sulfate is the terminal electron acceptor (Knittel and Boetius, 2009). AOM is driven by cooperative or syntrophic consortia of methanotrophic archaea and sulfate-reducing bacteria. This reaction currently is poorly characterized from mechanistic and phylogenetic perspectives (Caldwell and others, 2008; Thauer and Shima, 2008). The efficiency of the overall process has been measured in marine sediments, however, where it was estimated to oxidize close to 90 percent of the biogenic methane. In regard to the cycling of carbon in anaerobic, reduced, and isolated regional aquifers like this region of the Upper Floridan aquifer this is an important process even though the free energy yields are equal to, or just above, the minimum threshold of 20 kJ mol^{-1}. AOM returns the reduced carbon back to a more oxidized state (that is, HCO_2^-), which can then be recycled as a reactant for methanogenesis (reaction 3), acetogenesis (reaction 6), and other reactions listed in table 3.

Chemical Affinities for Energetically Favorable Biogeochemical Reactions

The direct comparison of the most likely biogeochemical reactions within and between groundwater samples is somewhat simplified by using the respective chemical affinities as opposed to free energy yields (that is, ΔG_r). Using chemical affinities allows the ranking of biogeochemical reactions, where the values of the most likely reactions are positive and thermodynamic equilibrium is realized at a value of 0.0 (table 18). Figure 14 shows the rankings of the biogeochemical reactions from lowest-to-highest chemical affinity for each groundwater sample. The most common reactions (reactions 1–4, 12) are similar in all samples for the reasons discussed previously, with reaction 1 (sulfate reduction) having the greatest range of values. This alignment of sample sites based on energy yields from sulfate reduction (reaction 1), from least-to-greatest chemical affinity, follows the increasing concentrations of hydrogen (table 2). Hydrogen concentrations in the subsurface have been shown to have a central role in determining which biogeochemical processes dominate in anaerobic ecosystems, like this region of the Upper Floridan aquifer, that are controlled by bacterial energetics (that is, thermodynamics) (Hoehler and others, 1998; Hoehler and Jorgensen, 2013).

As an example of the impact that treated surface water injected into the Upper Floridan aquifer can have on native microbial community energetics, a representative geochemical dataset from recharge water from the Hillsboro pilot plant (table 2) was analyzed as the other groundwater samples for free energy yields and chemical affinities (tables 18 and 19). The most significant differences between the native and recharge water are the presence of dissolved oxygen, dissolved organic carbon, nitrate, and phosphate in the recharge water. The presence of dissolved oxygen and nitrates provide concentrations of high energy reactants for biogeochemical reactions performed by native bacteria. As can be seen in table 18, not only are additional biogeochemical reactions energetically favorable (reactions 10, 17, 19, 20, 25–27), their free energy yields are orders of magnitude greater than any of the favorable reactions in the native groundwater zones. The exclusion of reactions 1–4 and 12 from the list of favorable reactions in the recharge water, which were dominant in the native groundwater samples, reflects the general difference between the water types and the respective ecosystems: aerobic and oxidized versus

Table 15. Free energy flux and maximum acquition rate data for the 42U and 42L sampling sites.

[ΔG_r, free energy of the reaction; FEF, free energy flux; MAR, maximum aquitition rate; kJ mol^{-1}, kilojoules per mole; kJ $cell^{-1}$ s^{-1}, kilojoules per cell per second; µM d^{-1}, micromoles per day]

Equation number	Equation	42U			42L		
		ΔG_r (kJ mol^{-1})	FEF (kJ $cell^{-1}$ s^{-1})	MAR (µM d^{-1})	ΔG_r (kJ mol^{-1})	FEF (kJ $cell^{-1}$ s^{-1})	MAR (µM d^{-1})
1	$4H_2 + H^+ + SO_4^{2-} \rightarrow HS^- + 4H_2O$	-63	-8.3	4.5	-39	-3.5×10^{-18}	3.2
2	$CH_3COO^- + SO_4^{2-} \rightarrow 2HCO_3^- + HS^-$	-52	-2.7	20.0	-53	-1.8×10^{-16}	146.9
3	$4H_2 + H^+ + HCO_3^- \rightarrow CH_4 + 3H_2O$	-42	-5.7	4.5			
4	$CH_3COO^- + H_2O \rightarrow CH_4 + HCO_3^-$	-31	-1.6	20.0	-32	-1.0×10^{-16}	146.9
12	$CH_4 + SO_4^{2-} \rightarrow H_2O + HCO_2^- + HS^-$	-21	-6.6	11.2	-22	-5.5×10^{-17}	86.4

Table 16. Free energy flux and maximum acquition rate data for the 15U and 15M sampling sites.

[ΔG_r, free energy of the reaction; FEF, free energy flux; MAR, maximum aquitition rate; kJ mol^{-1}, kilojoules per mole; kJ $cell^{-1}$ s^{-1}, kilojoules per cell per second; µM d^{-1}, micromoles per day]

Equation number	Equation	15U			15M		
		ΔG_r (kJ mol^{-1})	FEF (kJ $cell^{-1}$ s^{-1})	MAR (µM d^{-1})	ΔG_r (kJ mol^{-1})	FEF (kJ $cell^{-1}$ s^{-1})	MAR (µM d^{-1})
1	$4H_2 + H^+ + SO_4^{2-} \rightarrow HS^- + 4H_2O$	-60	-5.2×10^{-17}	54.4	-53	-2.6×10^{-17}	31.1
2	$CH_3COO^- + SO_4^{2-} \rightarrow 2HCO_3^- + HS^-$	-50	-2.9×10^{-16}	440.6	-48	-1.6×10^{-16}	216.0
3	$4H_2 + H^+ + HCO_3^- \rightarrow CH_4 + 3H_2O$	-40	-3.5×10^{-17}	54.4	-34	-1.7×10^{-17}	31.1
4	$CH_3COO^- + H_2O \rightarrow CH_4 + HCO_3^-$	-30	-1.7×10^{-16}	440.6	-28	-9.7×10^{-17}	216.0
12	$CH_4 + SO_4^{2-} \rightarrow H_2O + HCO_2^- + HS^-$	-20	-9.3×10^{-17}	293.8	-20	-9.5×10^{-17}	311.0

Table 17. Free energy flux and maximum acquition rate data for the MZ1 and MZ3 sampling sites.

[ΔG_r, free energy of the reaction; FEF, free energy flux; MAR, maximum aquitition rate; kJ mol^{-1}, kilojoules per mole; kJ $cell^{-1}$ s^{-1}, kilojoules per cell per second; µM d^{-1}, micromoles per day]

Equation number	Equation	MZ1			MZ3		
		ΔG_r (kJ mol^{-1})	FEF (kJ $cell^{-1}$ s^{-1})	MAR (µM d^{-1})	ΔG_r (kJ mol^{-1})	FEF (kJ $cell^{-1}$ s^{-1})	MAR (µM d^{-1})
1	$4H_2 + H^+ + SO_4^{2-} \rightarrow HS^- + 4H_2O$	-64	-1.1×10^{-16}	121.0	-26	-4.4×10^{-19}	1.1
2	$CH_3COO^- + SO_4^{2-} \rightarrow 2HCO_3^- + HS^-$	-54	-3.3×10^{-16}	501.1	-56	-1.4×10^{-16}	216.0
3	$4H_2 + H^+ + HCO_3^- \rightarrow CH_4 + 3H_2O$	-40	-6.7×10^{-17}	121.0			
4	$CH_3COO^- + H_2O \rightarrow CH_4 + HCO_3^-$	-30	-1.8×10^{-16}	501.1	-30	-7.8×10^{-17}	216.0
12	$CH_4 + SO_4^{2-} \rightarrow H_2O + HCO_2^- + HS^-$	-24	-2.3×10^{-16}	648.0	-26	-1.2×10^{-16}	259.2

anaerobic and reduced. When comparing the geochemical data from the groundwater samples to those from the recharge water (table 2), however, the absence of data for the dissolved gases, volatile fatty acids and inorganic carbon species in the recharge water prohibits the calculation of free energy yields and chemical affinities for most of the reactions in table 3.

Adding the chemical affinity data for the favorable biogeochemical reactions in the recharge water to those from the native groundwater samples, it is apparent the recharge water has a unique and high energy profile relative to the groundwater samples (table 18). This increase in bioavailable energy plus the organic carbon (table 2) greatly changes the overall energy landscape in the recharge zone of the aquifer and the rates of biogeochemical reactions that alter geochemistry. The products of the aerobic mineralization of the carbon and nutrients in the recharge water produce preferred reactants for the anaerobic native microbial community that, in addition to energy production, promote biomass production with the concomitant reduction in the ORP to native levels.

Although the recharge water may meet regulatory criteria prior to injection and after recovery, those criteria do not provide data about the biogeochemical processes that alter the geochemistry of the native and recharged water during storage. However, the thermodynamics of biogeochemical reactions does provide a tool for developing predictive models of changes in groundwater chemistry that are driven by microbial activities.

Free Energy Flux Rates for Energetically Favorable Biogeochemical Reactions

The previous section described the most likely or favorable biogeochemical reactions based strictly on their respective energy yields within the context of equaling or exceeding a minimum threshold for bacterial viability. This approach provides a framework for developing a first-order assessment of which reactants and products present in the native or recharged water may be utilized by the microbial communities, but it does not provide any insight into the rates at which these favorable reactions proceed. The free energy flux (FEF) and maximum acquisition (MAR) rates for bacterial cells constrain the energy production and reactant acquisition rates for the respective biogeochemical reactions based on the diffusion coefficient or rate (centimeters squared per second) of the limiting substrates in those reactions. These data can then be used to estimate energy acquisition, reactant utilization, and product production rates for biogeochemical reactions.

The direct relationship between diffusion and FEF and MAR rates in bacteria is due to molecular diffusion being the dominant transport mechanism for solutes and gases at distances relevant to microbial physiology (Koch, 1990). Using oxygen as an example, which is commonly reported to

Table 18. Chemical affinities for the six sampling sites and recharge water.

[kJ mol^{-1}, kilojoules per mole]

Equation number	Equation	Well designation 42U (kJ mol^{-1})	42L (kJ mol^{-1})	MZ1 (kJ mol^{-1})	MZ3 (kJ mol^{-1})	15U (kJ mol^{-1})	15M (kJ mol^{-1})	Recharge water (kJ mol^{-1})
1	$4H_2 + H^+ + SO_4^{2-} \rightarrow HS^- + 4H_2O$	47.8	24.8	49.4	11.7	45.2	38.5	
2	$CH_3COO^- + SO_4^{2-} \rightarrow 2HCO_3^- + HS^-$	34.8	36.2	37.1	38.7	32.9	30.5	
3	$4H_2 + H^+ + HCO_3^- \rightarrow CH_4 + 3H_2O$	27.4		25.0		25.1	19.3	
4	$CH_3COO^- + H_2O \rightarrow CH_4 + HCO_3^-$	14.1	14.2	12.8	12.8	12.8	11.2	
10	$HS^- + NO_3^- + H_2O \rightarrow SO_4^{2-} + NH_3$							406.1
12	$CH_4 + SO_4^{2-} \rightarrow H_2O + HCO_2^- + HS^-$	4.1	4.9	7.5	8.9	3.0	3.0	
17	$H_2S + 4NO_3^- \rightarrow SO_4^{2-} + 4NO_2^- + 2H^+$							470.3
19	$3H_2S + 4NO_2^- + 2H^+ + 4H_2O \rightarrow 3SO_4^{2-} + 4NH_4^+$							1239.7
20	$3H_2 + NO_2^- + 2H^+ \rightarrow NH_4^+ + 2H_2O$							350.0
25	$NH_3 + 1.5O_2 \rightarrow NO_2^- + H^+ + H_2O$							287.9
26	$2NO_2^- + O_2 \rightarrow 2NO_3^-$							142.3
27	$HS^- + 2O_2 + H_2O \rightarrow SO_4^{2-} + H^+$							790.8

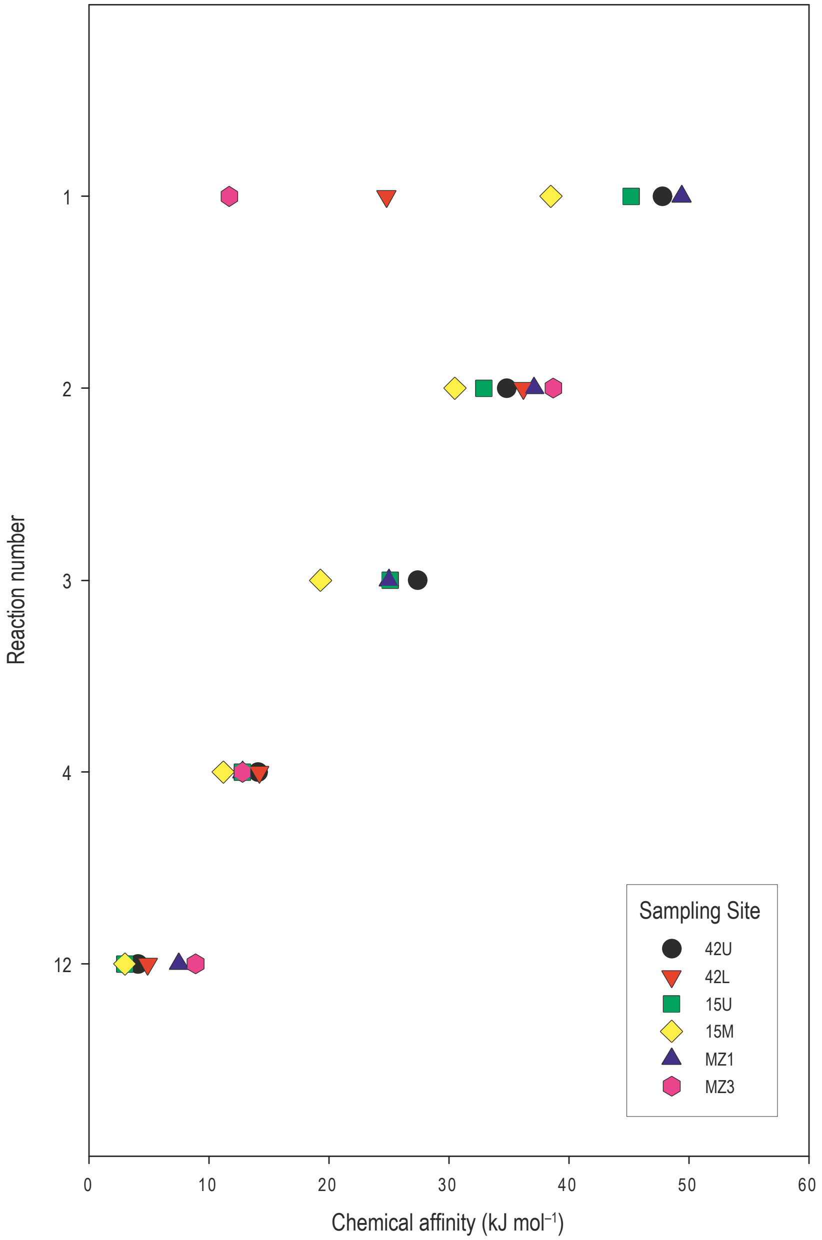


Figure 14. Graph showing chemical affinities of the thermodynamically favorable biogeochemical reactions [kJ mol^{-1}, kilojoules per mole].

diffuse at 1.0 millimeters per hour (mm h^{-1}), it would require approximately 1 day to diffuse 2.0 cm and 1,000 years to reach 10 meters (m) from its source. At the micrometer scale, however, which is relevant for bacterial processes at the intra- and extracellular levels, this same source of oxygen requires only 10^{-3} seconds to diffuse 1.0 µm. Gases and dissolved organic and inorganic substrates that serve as reactants in this study are predominantly transported across bacterial membranes by diffusion. Assuming that (1) each of the limiting reactants in the energetically favorable biogeochemical reactions are dissolved and present at the cell surfaces at the detected concentrations in the groundwater samples, and that (2) diffusion is the mechanism by which the reactants are transported into the cell, the overall FEF and MAR rates are controlled by the respective diffusion rates.

Table 19. Free energy flux and maximum acquition rate data for the recharge water.

[ΔG_r, free energy of the reaction; kJ mol^{-1}, kilojoules per mole]

Equation number	Equation	Recharge water ΔG_r (kJ mol^{-1})
10	$HS^- + NO_3^- + H_2O \rightarrow SO_4^{2-} + NH_3$	-423
17	$H_2S + 4NO_3^- \rightarrow SO_4^{2-} + 4NO_2^- + 2H^+$	-488
19	$3H_2S + 4NO_2^- + 2H^+ + 4H_2O \rightarrow 3SO_4^{2-} + 4NH_4^+$	-1257
25	$NH_3 + 1.5O_2 \rightarrow NO_2^- + H^+ + H_2O$	-305
26	$2NO_2^- + O_2 \rightarrow 2NO_3^-$	-159
27	$HS^- + 2O_2 + H_2O \rightarrow SO_4^{2-} + H^+$	-808

The FEF rates for the energetically favorable biogeochemical reactions in the groundwater samples from this study are extremely low, ranging from -4.4×10^{-19} to -3.3×10^{-16} kilojoules per second per cell (kJ s^{-1} cell^{-1})(tables 15–17). This range of FEF rates are similar to those in deep subsurface ecosystems that are strictly chemolithotrophic and supported by hydrogeothermal processes (Lin and others, 2006). For the FEF rates to be relevant to the survival of the bacterial cell, the acquired energy must at least satisfy the basal or minimal energy requirements for performing bacterial cell maintenance and repair processes. An average maintenance energy per cell rate of -1.55×10^{-19} kilojoules per cell per second (kJ cell^{-1} s^{-1}) has been estimated from chemostat studies of mesophilic nitrifying and methanogenic bacteria (Onstott, 2005). All of the FEF values for the energetically favorable biogeochemical reactions in this study exceed this maintenance energy threshold by approximately threefold to several orders of magnitude.

The FEF data are estimates of rates for energy acquisition per bacterial cell. The MAR data provide estimates of the acquisition rates of the limiting reactant per bacterial abundance and, therefore, can also provide an estimate of product production rates from stoichiometrically balanced reactions. The MAR data for all of the energetically favorable reactions in this study range from 1.1 to 648 micromoles per day (µM d^{-1}) for the respective limiting reactants (tables 15–17). As an example of using MAR data for determining reaction rates, acetate in reaction 2 for 42U is the limiting reactant with an MAR of 20.0 µM d^{-1}; therefore, a production rate of 40.0 µM day^{-1} for HCO_3^- and 20.0 µM d^{-1} for HS^- would be predicted.

The relationships between free energy yields, FEF, and MAR for the groundwater zones are shown in figure 15. The horizontal axis indicates the free energy yield, from the least-to-greatest absolute values, for all of the favorable biogeochemical reactions. Anaerobic methane oxidation (reaction 12) and acetotrophic methanogenesis (reaction 4) group reasonably well at the lower free energy yields, whereas the other types of sulfate reduction (reactions 1 and 2) and methanogenesis (reaction 3) are more evenly distributed along the remaining range of free energy yield data. Although the there is a continual increase in the free energy yield data, the rates at which the bacterial cells generate energy for cellular processes (that is, FEF) follow an undulating pattern (fig. 15). The variability in the FEF data is due to the differences in concentrations of the limiting reactants, diffusion rates of those reactants, and the calculated free energy yields at the respective sampling sites. The differences between the free energy yield and FEF data indicate biogeochemical processes are most likely under the control of physical (for example, utilization rates of biogeochemical reactants and products) rather than strictly thermodynamic processes.

The MAR data, which are energy acquisition per cell data (kJ s^{-1} $cell^{-1}$) normalized to the total cell abundances in the respective groundwater samples, follow a trend similar to that of the FEF data (fig. 16). MAR data can be used to constrain the rate at which the limiting substrate in a biogeochemical reaction is utilized by the bacterial community in a volume of groundwater. To place the MAR data in a more relevant context to native conditions in this region of the Upper Floridan aquifer, the combined (that is, respiration+biomass production) ^{14}C-acetate utilization rate data (table 12) can be compared to the MAR data (table 15–17). The calculated MAR rates are between two and four orders of magnitude greater than those measured using the ^{14}C-acetate method (table 20). This significant discrepancy between methods for quantifying the utilization rates for acetate, and therefore product production rates, under native conditions can be partially resolved by acknowledging that 100 percent of the enumerated bacterial cells (table 7) are not acetotrophic sulfate reducers or methanogens. To estimate the number of bacterial cells in each of the groundwater samples that were potentially acetotrophic sulfate reducers and methanogens ($B_{acetotrophic}$), the following relationship was used:

$$B_{acetotrophic} = \frac{(TDC)(^{14}C - acetate)}{MAR}, \qquad 15$$

where data for *TDC* (cells per liter) and *^{14}C-acetate* (moles per day) and *MAR* (moles per day) were taken from tables 7, 12, and 15–17, respectively. Based on this relationship, between 1.33×10^{5} and 4.59×10^{5} cells L^{-1} (or <0.5 percent of the total bacterial cell abundances in table 7) would be required to be active acetotrophic sulfate reducers and methanogens in the native groundwater samples for the calculated MAR data to model the measured ^{14}C-acetate uptake rates.

Although acetate was detected in all of the groundwater samples and this carbon source was used in the example above for estimating reactant removal and product production for a specific set of biogeochemical reactions, the native source of the acetate could not be determined. There are several acetotrophic reactions that would be expected to occur in this type of ecosystem, but none of these reactions were energetically favorable and, therefore, were not included in the data analyses. The inability to identify a thermodynamically favorable acetogenic reaction is most likely the result of an inadequate geochemistry dataset for the respective groundwater samples. The collection of a more extensive set of geochemical variables (for example, gases, carbon substrates, sulfur-based compounds, and mineral phases) that includes reactants and products for a wider selection of biogeochemical reactions, such as acetogenesis, would be very beneficial.

Another example to support the collection of a more extensive geochemical data set for native, recharged, and recovered waters is that in anaerobic, extremely reduced, and chemolithotrophic systems like this region of the Upper Floridan aquifer, fermentation reactions are very important. Fermentation of various substrates is carried out by a wide variety of bacterial groups and is most probably the driver of carbon and nutrient cycling in this type of ecosystem. Figure 16 shows how fermentation supplies the reactants for chemoautotrophic and chemoheterotrophic reactions (Megonigal and others, 2003). The source of the reactants and products for these reactions are derived from the initial degradation of polymers of biological origin to monomers, which are then fermented, producing the reactants for the biogeochemical reactions like those described in this study.

The source of the polymers that the exoenzymes degrade to monomers is also unknown for this region of the Upper Floridan aquifer. The source must be autochthonous because this region of the aquifer has been isolated from terrestrial input of water containing these types of substrates for thousands of years. A possible source could be leachate from the karst matrix, as described for the noncompetitive substrates for methanogens. Another source could be the native bacterial biomass, which is lyzed by

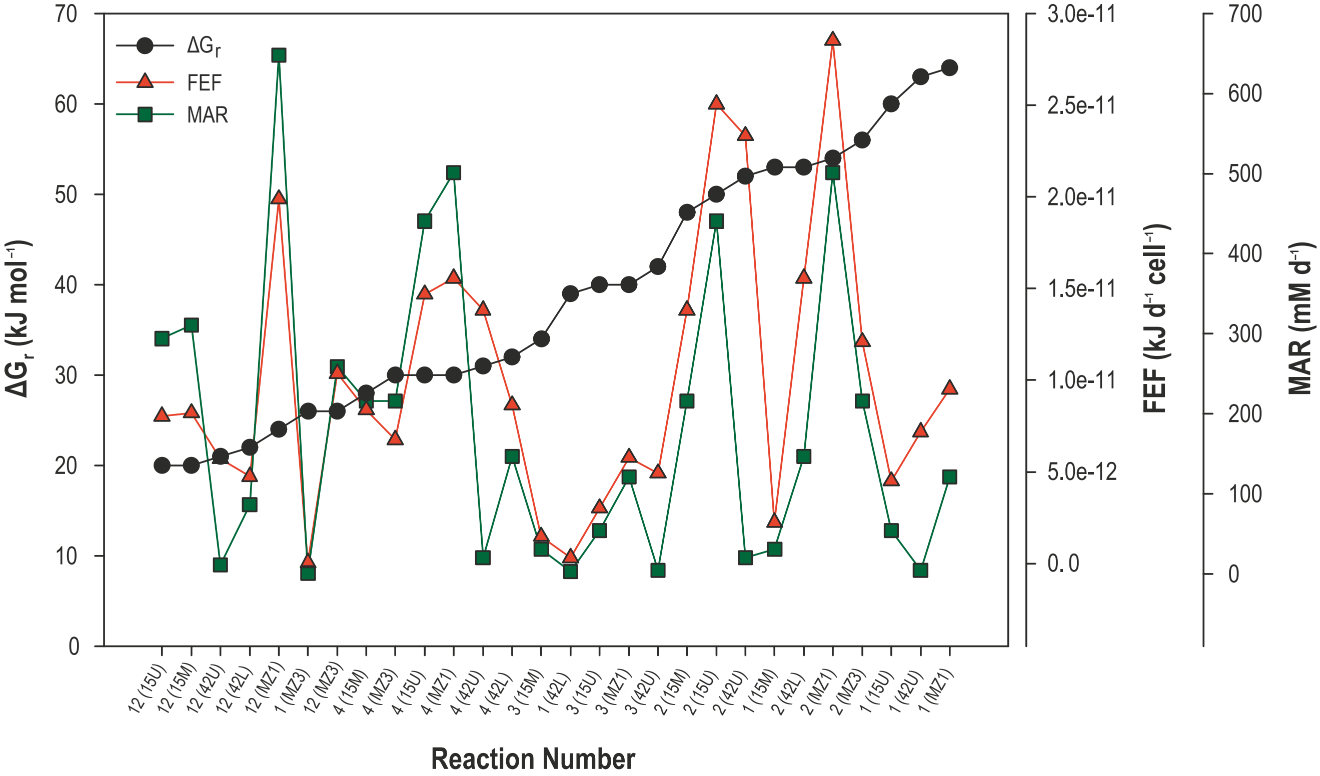


Figure 15. Comparisons between the free energy of reaction (ΔG_r), free energy flux (FEF), and maximum acquisition rate (MAR) data from the six sampling sites [kJ mol^{-1}, kilojoules per mole; kJ d^{-1} $cell^{-1}$, kilojoules per day per cell; mM d^{-1}, millimoles per day].

bacteriophage, releasing complex polymers as dissolved organic carbon that can be readily assimilated by the remaining bacterial cells (Anderson and others, 2013; Noble and Fuhrman, 1999). Either or both of these sources would provide the substrates for fermentation that subsequently produces acetate directly or the reactants for acetogenesis. This simple carbon and energetic cycling model describes a closed system that exists at the boundary of thermodynamic equilibrium but could be sustainable on geologic time scales.

Although this region of the Upper Floridan aquifer is an extreme ecosystem and isolated from terrestrial carbon and nutrient inputs, the native bacteria have sources of energy that support their survival and persistence. The use of thermodynamics to describe and quantify the energetics of this ecosystem provide a framework to constrain the effects that microbial activities have on the geochemical quality of the native groundwater, the recharged and mixed water, and the rates at which those changes proceed. The inclusion of physical principles that directly influence these activities (that is, diffusion rates of limiting reactants) allows biogeochemical data like MAR to be used in the modeling of changes to groundwater chemistry over time and distance. Using biogeochemical data derived from the same groundwater system being modeled is a preferable alternative to the common practice of using laboratory-generated data that may not be truly relevant to the native groundwater conditions being modeled.

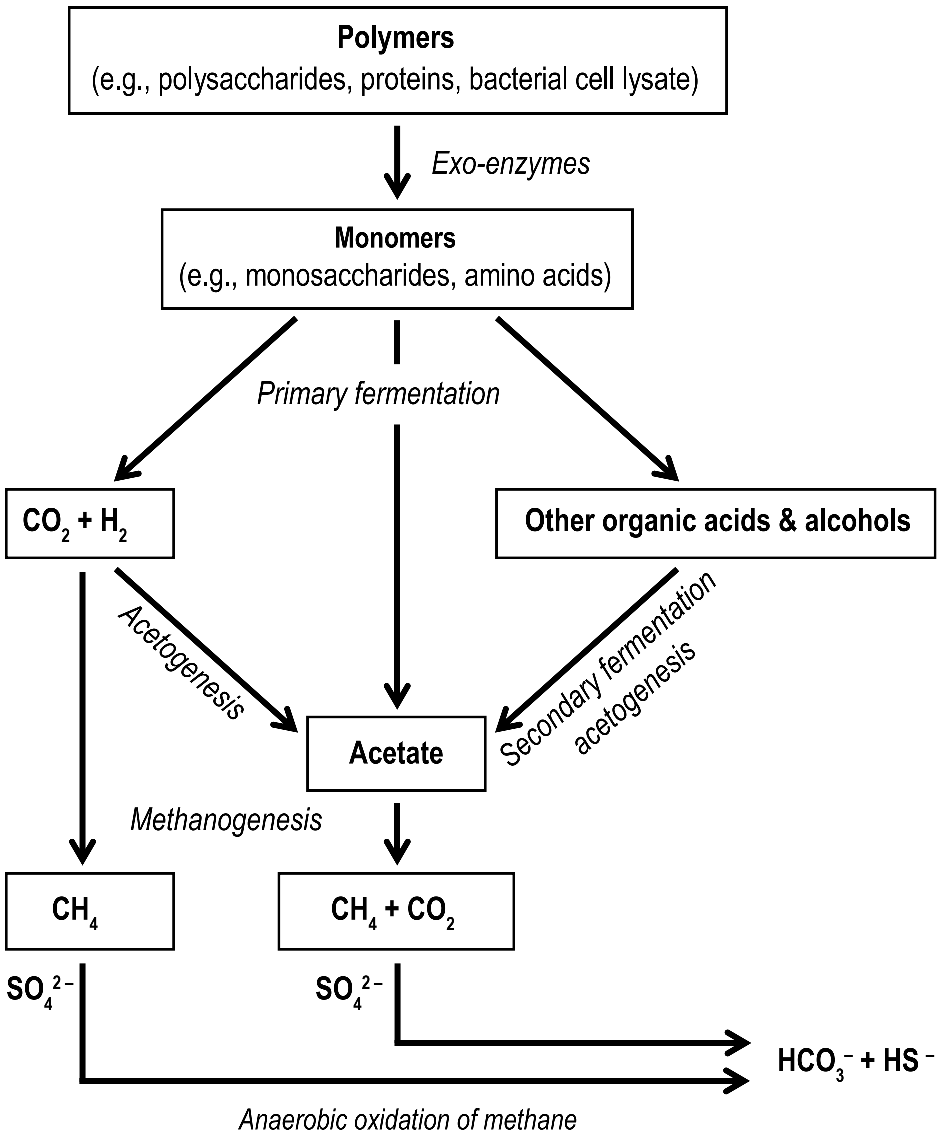


Figure 16. Biogeochemical processes that most likely dominate in the south region of the Upper Floridan aquifer.

Functional Bacterial Diversity and the Relationship to Geochemistry in the Upper Floridan Aquifer

Using thermodynamics to constrain which biogeochemical reactions, and their respective rates, are most likely to occur in the native waters of the Upper Floridan aquifer and recharge water provides a framework that can be used to supplement groundwater chemistry and reactive transport models. This approach can be applied to native groundwater prior to recharge events, recharged water prior to and during storage, and both types of water following extraction. One of the limitations to this approach is the lack of a comprehensive geochemical dataset from which the energetic calculations are performed. As previously discussed, a proportion of the complete list of biogeochemical reactions that may have been likely to proceed under the conditions of this region of the Upper Floridan aquifer could not be included in the energetics analyses because of the absence of concentration data for specific reactants and (or) products.

Table 20. Comparisons between the measured and predicted acetate turnover rates in the six sampling sites.

[^{14}C-acetate, carbon-14 labeled acetate; MAR, maximum acquistion rate; mol d^{-1}, moles per day]

Well designation	Combined ^{14}C-acetate utilization rate (mol d^{-1})	MAR (mol d^{-1})	MAR: ^{14}C-acetate ratio
42U	2.08×10^{-7}	4.00×10^{-5}	192.3
42L	1.68×10^{-7}	2.94×10^{-4}	1750.0
15U	2.89×10^{-7}	8.81×10^{-4}	3048.4
15M	1.70×10^{-7}	4.32×10^{-4}	2541.2
MZ1	1.66×10^{-7}	1.00×10^{-3}	6024.1
MZ3	2.92×10^{-7}	4.32×10^{-4}	1479.5

Another approach to characterizing the native and altered geochemistry in aquifers is to characterize the native microbial diversities and changes in those diversities, respectively. Although this phylogenetic approach will not contribute to the microbial energetics and reaction rates data, knowing which types of bacteria inhabit the aquifers can provide insight into the likelihood of specific biogeochemical processes being present in the absence of geochemical data. These types of data provide insight into the physiological capacity of microbial communities to perform these biogeochemical processes.

Some biogeochemical processes are performed by a relatively limited number of bacterial species, which if detected, allow the prediction of those reactions being present in the sampled ecosystem. Examples of these types of reactions that could proceed in anaerobic conditions like those in this region of the Upper Floridan aquifer include, but are not limited to, sulfate reduction, methanogenesis, anaerobic methane oxidation (AOM), acetogenesis, anaerobic ammonium oxidation (ANAMMOX) and other pathways in the nitrogen cycle (that is, denitrification and ammonification).

The PhyloChip G3 microarray platform was used to identify the bacterial inhabitants of this region of the Upper Floridan aquifer that have been shown to perform one or more of the previously described biogeochemical processes. This technology uses a proprietary DNA sequence binding and detection approach to identify approximately 60,000 unique operational taxonomic units (OTU), representing approximately 840 subfamilies of bacteria within the Eubacteria and Archaea kingdoms. Approximately 76 percent of the OTUs from the native bacteria in this region of the Upper Floridan aquifer were categorized as “unclassified,” however, meaning the sequence could not be definitively classified to the family, genus, or species level.

A total of 3,634 unique OTUs were detected in the groundwater samples from the six well sites (table 21), representing approximately 6.1 percent of the total OTUs on this version of the PhyloChip microarray. The bacterial diversity, used here and henceforth to collectively refer to eubacterial and archaeal OTUs, was similar between the two sampled depths for the 42 and 15 wells but significantly different at the MZ well site, with MZ3 having a more diverse community structure than that in MZ1 (table 21). The MZ3 zone of the Upper Floridan aquifer has been shown to be the more different groundwater source of the six that were sampled, based on previously discussed field, nutrient, geochemical, and energetics data.

The number of OTUs for the second sampling event increased significantly relative to the first sampling event, except for MZ3, which decreased (table 21). For all the groundwater samples, the number of OTUs that were common in the two samples was less than the number unique to the individual samples. For example, the 42U samples had a total of 647 OTUs, of which 86 were unique to the first sample,424 were unique to the second sample, and 132 were found in both samples; 2,987 OTUs were not detected in 42U but were detected in one or more of the other groundwater samples. These same relationships are similar for the other five sites as well. The Sorensen Index values in table 21 provide a direct method for comparing the similarities in bacterial diversity between groundwater sampling sites. The proximity of index values are positively related to the similarity of their diversities. Results of the adonis test for statistically significant differences between pairwise comparisons of the OTU presence/absence data indicated a significant difference in diversity between the six groundwater collection zones.

Using OTUs to characterize bacterial diversities provides an overall perspective of how many unique bacterial species are present; however, knowing which bacteria are represented by those OTUs allows a more detailed assessment of not only the overall diversity of the respective microbial communities but also the possible physiological capabilities. The PhyloChip data also include a single, most likely bacterial "species" associated with each OTU. "Species" is used as a general term to describe the closest (that is, 90-percent similar) identified bacterial DNA sequence in the National Center for Biotechnology Information (NCBI) database (*http://www.ncbi.nlm.nih.gov*). These OTU and NCBI sequence relationships can range from the family-to-species level of specificity. Figure 17 shows the OTUs from each groundwater sample organized per their proportion of the total OTUs per sample using family classifications. All of the groups in figure 17 are phylogenetic families except for Thermoprotei (class designation) and SAGMEG (South Africa Gold Mine Euarchaeotic Group) which is a nonphylogenetic grouping. Family-level classifications are used because using OTU designations from higher levels of phylogenetic classification (that is, genus and species) would significantly increase the number of graphed groups per sample, making figure 17 uninterpretable, whereas lower-level classifications do not provide adequate resolution between phylogenetic classes.

The second samples from each sampling site (denoted by "(2)") all show a significant increase in the proportion of Pseudomonadaceae (Garrity and others, 2005) (fig. 17). The other eight OTU classifications show a general decrease in their proportional contribution to each sample's diversity for the second sample. Table 22 lists the proportion that each of the nine families contributed to the groundwater samples, as shown in figure 17. The proportions of Pseudomonadaceae increased by between approximately 14 percent (42U) and 94 percent (MZ1) in the second samples. Table 22 also shows the proportion of the other families decreased between 1 and 20 percent for all sampling sites between the first and second samples, with the proportions of Peptostreptococcaceae (Schleifer, 2009) and Lachnospiraceae/Runinococcaceae (Schleifer, 2009) in MZ1 decreasing approximately 30 percent. Unlike the other sampling sites, the proportions of OTUs in 42U representing six of the nine families increased, although marginally. The Micrococcinea (Goodfellow, 2012) in 42U were not detected in the first sample but

Table 21. Bacterial diversity in the six sampling sites and between sampling events.

[OTUs, operational taxonomic units]

Well designation	OTUs				Sorensen Index
	Unique to Sample 1	Unique to Sample 2	Both Samples	Neither Sample	
42U	86	429	132	2987	0.51
42L	86	1047	118	2383	0.21
15U	232	837	242	2323	0.45
15M	215	1252	111	2056	0.15
MZ1	478	1001	75	2080	0.10
MZ3	607	187	309	2531	0.78

became a minor contributor to the community diversity in the second sample, whereas this family was never detected in 42L. Members of the Prevotellaceae (Krieg and others, 2010) followed a similar trend in 15U, 15L, MZ1, and MZ3 by becoming nondetectable in the second sample.

The significant change in the bacterial diversity between the first and second sampling events cannot be explained by the introduction of new biomass and nutrients from a surface or near-surface source into this hydrologically isolated region of the Upper Floridan aquifer. The only perturbation to this ecosystem was the relatively rapid movement of groundwater in the production zones during the flushing of each well prior to sample collection. The suspended bacterial cells would be removed from the aquifer, whereas the biofilm-associated cells would either remain or be sloughed off because of the increased hydrodynamic shear forces at the biofilm surfaces.

As discussed previously, the groundwater flow rates are low enough in this region of the Upper Floridan aquifer to make molecular diffusion the dominant transport process for dissolved constituents. The increased groundwater flow rates during the first sampling event would transport reactants for, and remove inhibitory products of, the biogeochemical reactions previously described at rates orders of magnitude higher than those under native conditions. This sudden increase in the availability of substrates for dissimilatory and biomass production reactions would favor those bacterial species best adapted to respond quickly and efficiently. The selective increase in bacterial groups that can successfully compete for the reactants and (or) products of the biogeochemical reactions will numerically dominate until the ecosystem returns to its native state. During this period, new biogeochemical processes do not necessarily have to occur, because existing processes could just proceed at different rates. The latter is most likely to have occurred in this region of the Upper Floridan aquifer because of its geochemistry and hydrologic isolation. The response of the bacterial community to ecosystem perturbations like that described here has been described for freshwater and marine ecosystems and can be divided into three phases: bacterial community resistance, resilience, and recovery (Allison and Martiny, 2008; Ho and others, 2011; Shade and others, 2011; Sjostrom and others, 2012). This may explain the significant increases in the abundances of OTUs for *Pseudomonas* species (family Pseudomonadaceae; fig. 17) (table 22), which have been shown to be the most physiologically diverse and adaptable group of bacteria in terrestrial and aquatic ecosystems (Spiers and others, 2000).

The microbial diversity data also provide a framework from which a general, but sometimes specific, assignment of physiological capabilities to specific groups within the total microbial community. Figure 16 outlines a basic energy-flow carbon-cycle model that most likely describes how microbial life is supported, and figure 17 lists the dominant bacterial groups in this region of the Upper Floridan aquifer. The biogeochemical processes and microbial diversity data can be coordinated by aligning the biogeochemical processes (fig. 16) with the bacterial groups identified in the groundwater samples (fig. 17). Table 23 lists the biogeochemical processes in figure 16, plus several biogeochemical processes for which OTUs were detected but not represented in figure 17. The additional OTU classifications include Clostridiaceae (family) (Schleifer, 2009), Planctomycetes (phylum) (Ward, 2010), Euryarchaeota (phylum) (Garrity and Holt, 2001a) and Geobacteraceae (family) (Kuever and others, 2005). The additional biogeochemical processes or physiological classes include syntrophy with methanogens and ammonification. These OTU classifications and biogeochemical processes were added because OTUs were identified whose corresponding bacterial species or group had been shown to perform one or more biogeochemical processes that are not included in figure 16 but would be important to the overall carbon cycling, energetics, and geochemistry of this ecosystem.

Because of the limited geochemical analyses, determining the presence of fermentative processes in this aquifer system could not be supported, nor refuted, using the energetics approach. However,

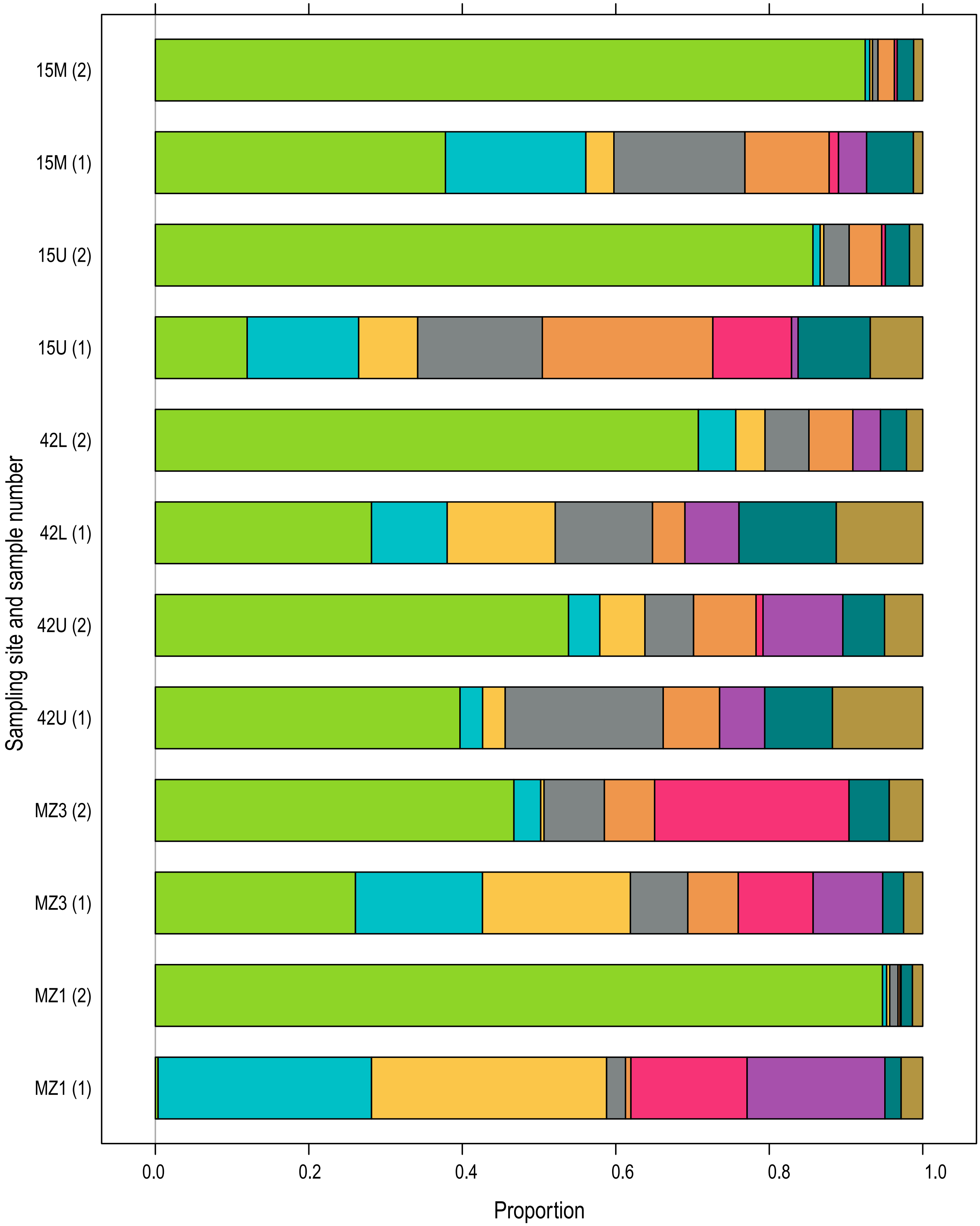


Figure 17. Bacterial diversity distributions from the six sampling sites.

	Domain	Phylum	Class	Order	Family
🟩	Bacteria	Proteobacteria	Gammaproteobacteria	Pseudomonadales	Pseudomonadaceae
🟦	Bacteria	Firmicutes	Clostridia	Clostridiales	Peptostreptococcaceae
🟨	Bacteria	Firmicutes	Clostridia	Clostridiales	Lachnospiraceae / Ruminococcaceae
⬛	Bacteria	Chloroflexi	Anaerolineae	Anaerolineales	Anaerolineaceae
🟧	Bacteria	Proteobacteria	Deltaproteobacteria	Desulfobacterales	Desulfobacteraceae
🟥	Bacteria	Actinobacteria	Actinobacteria	Actinomycetales	Micrococcineae
🟪	Bacteria	Bacteroidetes	Bacteroidia	Bacteroidales	Prevotellaceae
🟩	Archaea	Crenarchaeota	Thermoprotei	unclassified	unclassified
🟫	Archaea	Euryarchaeota	Thermoplasmata	SAGMEG	unclassified

Figure 17. Bacterial diversity distributions from the six sampling sites.—Continued.

the presence of bacteria capable of performing primary and secondary fermentations being in this region of the Upper Floridan aquifer is critical to explaining the concentrations of acetate in all of the groundwater samples. Acetogenesis was not energetically favorable and homoacetogens were not detected in the microbial diversity analyses. However, all but one of the OTU classifications represent one or more bacterial species that produce extracellular enzymes that degrade complex polymers into monomers that primary fermenters can utilize to produce acetate, CO_2, H_2 and simple organic acids and alcohols that can be fermented to produce acetate (table 23). Additionally, members of the Peptostreptococcaceae (Schleifer, 2009), Lachnospiraceae/Ruminococcaceae (Schleifer, 2009), Clostridiaceae (Schleifer, 2009), Desulfobacteraceae (Kuever and others, 2005), and Thermoprotei (Garrity and Holt, 2001b) produce and release acetate as a byproduct of fermentative or heterotrophic metabolism. Collectively, these groups of bacteria provide the reactants that drive dissimilatory biogeochemical reactions (energy production) and substrates for biomass production. Members of the Euryarchaeota are efficient methanogens (table 3, reactions 3, 4 and 5) (*Methanopyri*, *Methanobacteria*, *Methanococci* and *Thermoplasmata*) and anaerobic methane oxidizers (table 3, reaction 12) (*Methanomicrobia*: ANME–1 and ANME–3) (Garrity and Holt, 2001a). However, OTUs were also identified that represent methanogenic syntrophic bacteria, which enable methanogenesis to proceed in the presence of sulfate reducing bacteria by removing H_2 from the system. Members of the SAGMEG group have not been characterized or cultured to date. OTUs similar to sequences in this group have been recovered from the sulfate-methane transition zone in anaerobic and stratified ecosystems (Teske and Sørensen, 2007).

Nitrogen is a critical nutrient for bacterial cell maintenance and production because of its being an integral component of amino acids and proteins (for example, enzymes and membranes). Accordingly, nitrogen cycling is extremely important in this type of ecosystem, because allochthonous introductions of nitrogen (that is, nitrates and nitrites) and aerobic nitrogen fixation do not occur. Additionally, the absence of nitrates and nitrites in this region of the Upper Floridan aquifer prevents denitrification and anaerobic ammonia oxidation (ANAMMOX) processes from proceeding. Ammonia was present in all of the groundwater samples analyzed during this study. This form of nitrogen is required by all bacterial species and is the form of nitrogen most easily metabolized by bacterial cells. The source of ammonia cannot be explained by terrestrial inputs or in situ chemolithotrophic reactions that rely on nitrates or nitrites being present. The most likely source is the ammonification of bacterial cell lysates that originate from cell death or viral lysis. Representatives in four of the classifications in table 23 are capable of ammonification.

Table 22. Bacterial diversity based on the family classifications.

[%, percent; ND, not determined; NA, not applicable]

Bacterial family classification	Sample 1	Sample 2	Percent change	Sample 1	Sample 2	Percent change
		42U			42L	
Pseudomonadaceae	39.71%	53.85%	14.14%	28.17%	70.76%	42.59%
Peptostreptococcaceae	2.94%	4.07%	1.13%	9.86%	4.87%	-4.99%
Lachnospiraceae/Runinococcaceae	2.94%	5.88%	2.94%	14.08%	3.81%	-10.27%
Anaerolineaceae	20.59%	6.33%	-14.25%	12.68%	5.72%	-6.96%
Desulfobacteraceae	7.35%	8.14%	0.79%	4.23%	5.72%	1.49%
Micrococcinea	ND	0.90%	0.90%	ND	ND	NA
Prevotellaceae	5.88%	10.41%	4.52%	7.04%	3.60%	-3.44%
Thermoprotei	8.82%	5.43%	-3.39%	12.68%	3.39%	-9.29%
SAGMEG	11.76%	4.98%	-6.79%	11.27%	2.12%	-9.15%
		15U			15M	
Pseudomonadaceae	11.97%	85.69%	73.73%	37.80%	92.50%	54.70%
Peptostreptococcaceae	14.53%	0.94%	-13.59%	18.29%	0.60%	-17.70%
Lachnospiraceae/Runinococcaceae	7.69%	0.47%	-7.22%	3.66%	0.36%	-3.30%
Anaerolineaceae	16.24%	3.30%	-12.94%	17.07%	0.71%	-16.36%
Desulfobacteraceae	22.22%	4.25%	-17.98%	10.98%	2.14%	-8.83%
Micrococcinea	10.26%	0.47%	-9.78%	1.22%	0.36%	-0.86%
Prevotellaceae	0.85%	ND	-0.85%	3.66%	ND	-3.66%
Thermoprotei	9.40%	3.14%	-6.26%	6.10%	2.14%	-3.95%
SAGMEG	6.84%	1.73%	-5.11%	1.22%	1.19%	-0.03%
		MZ1			MZ3	
Pseudomonadaceae	0.35%	94.76%	94.41%	26.08%	46.72%	20.65%
Peptostreptococcaceae	27.82%	0.54%	-27.28%	16.55%	3.49%	-13.06%
Lachnospiraceae/Runinococcaceae	30.63%	0.40%	-30.23%	19.27%	0.44%	-18.84%
Anaerolineaceae	2.46%	1.08%	-1.39%	7.48%	7.86%	0.38%
Desulfobacteraceae	0.70%	0.27%	-0.44%	6.58%	6.55%	-0.03%
Micrococcinea	15.14%	0.13%	-15.01%	9.75%	25.33%	15.58%
Prevotellaceae	17.96%	ND	-17.96%	9.07%	ND	-9.07%
Thermoprotei	2.11%	1.48%	-0.63%	2.72%	5.24%	2.52%
SAGMEG	2.82%	1.34%	-1.47%	2.49%	4.37%	1.87%

Sulfate reduction (reactions 1 and 2), which is the most energetically favorable biogeochemical process in this region of the Upper Floridan aquifer (fig. 14), is well represented by members of the Desulfobacteraceae, Thermoprotei, and Euryarchaeota (fig. 17, table 23). The sulfate concentrations measured in the groundwater sampled during this study are not limiting and sulfate reduction proceeds in the presence of methanogenesis. Sulfate reduction and methanogenesis are commonly considered mutually exclusive, with methane being absent or in very low concentrations in ecosystems until sulfate has been reduced to sulfide (Mitterer, 2010). Recent studies have shown, however, that both processes can co-occur in carbonate sediment systems, similar to the Upper Floridan aquifer, if the methanogens

Table 23. Likely biogeochemical processes based on bacterial diversity in all of the sampling sites.
[OTU, operational taxonomic unit]

OTU Classification	Physiological classification								
	Extracellular Enzymes	Primary Fermentation	Secondary Fermentation	Acetate Production	Methanogenesis	Methane Oxidation	Syntrophy with Methanogens	Ammonification	Sulfate Reduction
Pseudomonadaceae	x	x						x	
Peptostreptococcaceae	x			x				x	
Lachnospiraceae/Ruminococcaceae	x	x	x	x				x	
Clostridiaceae	x	x	x	x			x		
Anaerolineaceae	x	x					x		
Desulfobacteraceae	x	x	x	x			x		x
Micrococcineae	x	x	x					x	
Prevotellaceae	x	x							
Thermoprotei	x	x	x	x					x
SAGMEG		(Bacteria belonging to this group are currently uncharacterized)							
Geobacteraceae							x		
Planctomycetes	x								
Euryarchaeota	x	x			x	x			x

utilize noncompetitive substrates. Additionally, geochemical conditions similar to those in this region of the Upper Floridan aquifer have been modeled and a new concept for the co-occurrence of sulfate reduction and methanogenesis has been put forth that relies on the physical isolation of sulfate reducers from methanogens in the fractures and pore spaces of the rock matrix (Jakobsen, 2007). Sulfide and methane were detected in all of the groundwater samples; the energetics analyses found both type of reactions were energetically favorable, and the bacterial diversity analyses identified sulfate reducers and methanogens in all of the samples. These two biogeochemical reactions are co-occurring in the Upper Floridan aquifer and are critical for energy production and carbon cycling in this ecosystem.

Many groups of bacteria have physiological capabilities for performing biogeochemical reactions, even though the environmental conditions (such as the absence of chemical reactants) are not appropriate for those reactions to be initiated. The bacterial diversity analyses detected OTUs in this region of the Upper Floridan aquifer that have been shown to perform the following biogeochemical reactions or processes under nonphototrophic and anaerobic conditions: denitrification, ANAMMOX, nitrogen fixation, Fe(III) reduction, Fe(II) oxidation (nitrate dependent), elemental sulfur respiration, arsenite oxidation, arsenate reduction, chlorinated hydrocarbon degradation, and hydrocarbon (crude oil) degradation. Although this is not an exhaustive list from the PhyloChip data, those reactions and processes listed may of interest to groundwater resource managers responsible for (1) designing and monitoring managed recharge/recovery facilities, (2) remediating accidental contamination events, and (3) geochemical modeling.

Future Research Directions

1. Although a representative of the total coliform group was chosen as the model microbial indicator for this study, pathogenic bacteria, protozoan parasites, and viruses are of equal or greater public health concern. The aboveground, flowthrough mesocosms used during this study can also be adapted to retain and study these microorganisms. Because the native conditions in the UFA and APPZ were shown to have a negative effect on the survival of *E. coli*, relative to the conditions analyzed in other groundwater studies, characterizing the inactivation rates of these other microbial indicators and pathogens in these zones would be of interest to public health, regulatory, and resource-management officials.

2. This study focused on the suspended bacterial communities in the Upper Floridan aquifer; however, it is generally accepted that the majority of the microbial biomass in any subsurface ecosystem is associated with the attached or biofilm communities (Pedersen, 2012; Whitman and others, 1998). Using the same approaches described in this study to characterize the functional diversity and rates of biogeochemical reactions associated with biofilms in the UFA and APPZ would provide a significant contribution to the understanding of how these zones respond to native conditions and recharge events.

1. The inactivation of microbial indicators to satisfy primary drinking-water standards is required for some groundwater recharge methods. Although oxidizing disinfectants (such as chlorine and chloramines) are routinely used in potable-water treatment facilities prior to distribution, their use for treating recharge water prior to injection is discouraged because of the formation of disinfection byproducts. Alternative types of disinfectants, such as UV irradiation, are commonly used for treating these types of recharge water. The efficacy of UV irradiation can be compromised, however, by dissolved constituents, leading to injured microbial indicators that appear to be inactivated when using required water-quality monitoring methods (Blatchley and others, 2007; Lisle and others, 1998, 1999). Because UV irradiation is a commonly used disinfectant for recharge water in Florida, assessing the inactivation and recovery rates of bacterial, protozoan, and viral contaminants during and following treatment and during storage would assist public health and regulatory officials in determining appropriate disinfectants and dosages to maintain a product that satisfies regulatory standards.

References Cited

Aiken, G.R., 1992, Chloride interference in the analysis of dissolved organic carbon by the wet oxidation method: Environmental Science & Technology, v. 26, p. 2435–2439.

Aiken, G.R., McKnight, D.M., Thorn, K.A., and Thurman, E.M., 1992, Isolation of hydrophilic organic acids from water using nonionic macroporous resins: Organic Geochemistry, v. 18, p. 567–573.

Allison, S., and Martiny, J., 2008, Resistance, resilience, and redundancy in microbial communities: Proceedings of the National Academy of Sciences, v. 105, p. 11512–11519.

Amann, R.I., Ludwig, W., and Schleifer, K.H., 1995, Phylogenetic identification and in situ detection of individual microbial cells without cultivation: Microbiology and Molecular Biology Reviews, v. 59, p. 143–169.

Amend, J., and Shock, E., 2001, Energetics of overall metabolic reactions of thermophilic and hyperthermophilic Archaea and Bacteria: FEMS Microbiology Reviews, v. 25, p. 175–243.

Anderson, R., Brazelton, W., and Baross, J., 2013, The deep viriosphere—Assessing the viral impact on microbial community dynamics in the deep subsurface: Reviews in Mineralogy and Geochemistry, v. 75, p. 649–675.

Anonymous, 1989, National Primary Drinking Water Regulations; Total Coliforms: Federal Register, v. 54, no. 124, p. 27544–27568.

Anonymous, 2012, Sewage disposal facilities; advanced and secondary waste treatment: v. Title XXIX (Public Health), Chapter 403 (Environmental Control), Part I (Pollution Control), Section 403.086 (9)(g).

Anonymous, 2013a, Drinking water standards, monitoring, and reporting: v. Floridan Administrative Code 62–550, p. 102–828.

Anonymous, 2013b, Ground water classes, standards, and exemptions: v. Floridan Administrative Code 62–520, p. 200–900.

Anonymous, 2013c, Underground injection control: v. Floridan Administrative Code 62–528, p. 100–900.

Barer, M., Gribbon, L., Harwood, C., and Nwoguh, C., 1993, The viable but non-culturable hypothesis and medical bacteriology: Reviews in Medical Microbiology, v. 4, p. 183–191.

Barer, M. and Harwood, C., 1999, Bacterial viability and culturability: Advances in Microbial Physiology, v. 41, p. 94–137.

Bastviken, D., and Tranvik, L., 2001, The leucine incorporation method estimates bacterial growth equally well in both oxic and anoxic lake waters: Applied and Environmental Microbiology, v. 67, p. 2916–2921.

Bissonnette, G., Jezeski, J., McFeters, G., and Stuart, D., 1975, Influence of environmental stress on enumeration of indicator bacteria from natural waters: Applied Microbiology, v. 29, p. 186–194.

Blatchley, E., Gong, W., Alleman, J., Rose, J., Huffman, D., Otaki, M., and Lisle, J., 2007, Effects of wastewater disinfection on waterborne bacteria and viruses: Water Environmental Research, v. 79, p. 81–92.

Bradner, L., 1991, Water quality in the Upper Floridan aquifer in the vicinity of drainage wells, Orlando, Florida: U.S. Geological Survey Water-Resources Investigations Report, 90–4175, 57 p.

Buesing, N., and Marxsen, J., 2005, Theroretical and empirical conversion factors for determining bacterial production in freshwater sediments via leucine incorporation: Limnology and Oceanography Methods, v. 3, p. 101–107.

Bush, P., and Johnston, R., 1988, Ground-water hydraulics, regional flow, and ground-water development of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Professional Paper, 1403–C, 80 p.

Caldwell, S., Laidler, J., Brewer, E., Eberly, J., Sandborgh, S., and Colwell, F., 2008, Anaerobic oxidation of methane—Mechanisms, bioenergetics, and the ecology of associated microorganisms: Environmental Science & Technology, v. 42, p. 6791–6799.

Cerf, O., 1977, A review—Tailing of survival curves of bacterial spores: Journal of Applied Microbiology, v. 42, p. 1–19.

Chapelle, F., 2000, The significance of microbial processes in hydrogeology and geochemistry: Hydrogeology Journal, v. 8, p. 41–46.

Chapelle, F., Vroblesky, D., Woodward, J., and Lovley, D., 1997, Practical considerations for measuring hydrogen concentrations in groundwater: Environmental Science & Technology, v. 31, p. 2873–2877.

Crane, S., and Moore, J., 1986, Modeling enteric bacterial die-off—A review: Water Air Soil Pollution, v. 27, p. 411–439.

Davidson, M., Silver, B., Onstott, T., Moser, D., Gihring, T., Pratt, L., Boice, E., Lollar, B., Lippmann-Pipke, J., Pfiffner, S., Kieft, T., Seymore, W., and Ralston, C., 2011, Capture of planktonic microbial diversity in fractures by long-term monitoring of flowing boreholes, Evander Basin, South Africa: Geomicrobiology Journal, v. 28, p. 275–300.

DeAngelis, K.M., Allgaier, M., Chavarria, Y., Fortney, J.L., Hugenholtz, P., Simmons, B., Sublette, K., Silver, W.L., and Hazen, T.C., 2011, Characterization of trapped lignin-degrading microbes in tropical forest soil: PLoS ONE, v. 6, p. e19306.

del Giorgio, P., and Cole, J., 1998, Bacterial growth efficiency in natural aquatic systems: Annual Review of Ecology and Systematics, v. 29, p. 503–541.

DeSantis, T., Brodie, E., Moberg, J., Zubieta, I., Piceno, Y., and Andersen, G., 2007, High-Density universal 16S rRNA microarray analysis reveals broader diversity than typical clone library when sampling the environment: Microbial Ecology, v. 53, p. 371–383.

Dick, J., 2008, Calculation of the relative metastabilities of proteins using the CHNOSZ software package: Geochemical Transactions, v. 9, p. 1–17.

Ferry, J., and Lessner, D., 2008, Methanogenesis in marine sediments: Annals of the New York Academy of Sciences, v. 1125, p. 147–157.

Finkel, S., Zinser, E., and Kolter, R., 2000, Long-term survival and evolution in the stationary phase, *in* Storz, G., and Hengge-Aronis, R., eds., Bacterial Stress Responses: ASM Press, p. 231–238.

Fredrickson, J., and Balkwill, D., 2006, Geomicrobial processes and biodiversity in the deep terrestrial subsurface: Geomicrobiology Journal, v. 23, p. 345–356.

Garrity, G., Bell, J., and Lilburn, T., 2005, Pseudomonadales Orla-Jensen 1921, 270, *in* Brenner, D.J., Krieg, N.R., and Staley, J.T., eds., Bergey's manual of systematic bacteriology (2d ed), v. 2, The Proteobacteria: part B, The Gammaproteobacteria: Springer, p. 323–442.

Garrity, G., and Holt, D., 2001a, Phylum AII. Euryarchaeota *phy. nov*., *in*, Boone, D.R. and Castenholz, R.W., eds., Bergey's manual of systematic bacteriology (2d ed), v. 1., The Archaea and the deeply branching and phototrophic Bacteria: New York, Springer p. 211–355.

Garrity, G., and Holt, J., 2001b, Phylum AI. Crenarchaeota *phy. nov.*, *in* Boone, D.R., and Castenholz, R.W., eds., Bergey's manual of systematic bacteriology (2d ed), v. 1, The Archaea and the deeply branching and phototrophic Bacteria: New York, Springer, p. 169–210.

Goodfellow, M., 2012, Phylum XXVI. Actinobacteria *phy. nov*, *in* Whitman, W.B., Goodfellow, M., Kämpfer, P., Busse, H.J., Trujillo, M.E., Ludwig, W., Suzuki, K., and Parte, A., eds., Bergey's manual of systematic bacteriology (2d ed), v. 5, The Actinobacteria: Springer, p. 33–2028.

Hazen, T., Dubinsky, E., DeSantis, T., Andersen, G., Piceno, Y., Singh, N., Jansson, J., Probst, A., Borglin, S., Fortney, J., Stringfellow, W., Bill, M., Conrad, M., Tom, M., Chavarria, K., Alusi, T., Lamendella, R., Joyner, D., Spier, C., Baelum, J., Auer, M., Zemla, M., Chakraborty, R., Sonnenthal, E., D'haeseleer, P., Holman, H., Osman, S., Lu, Z., Van Nostrand, J., Deng, Y., Zhou, J., and Mason, O., 2010, Deep-sea oil plume enriches indigenous oil-degrading bacteria: Science, v. 330, p. 204–208.

Ho, A., Luke, C., and Frenzel, P., 2011, Recovery of methanotrophs from disturbance—Population dynamics, evenness and functioning: International Society for Microbial Ecology Journal, v. 5, p. 750–758.

Hobbie, J., 1973, Using kinetic analyses of uptake of carbon-14 to measure rates of movement of individual organic compounds into aquatic bacteria: Bulletins from the Ecological Research Committee, p. 207–214.

Hoben, H.J., and Somasegaran, P., 1982, Comparison of the pour, spread, and drop plate methods for enumeration of *Rhizobium* spp. in inoculants made from presterilized peat: Applied and Environmental Microbiology, v. 44, p. 1246–1247.

Hoehler, T., Alperin, M., Albert, D., and Martens, C., 1998, Thermodynamic control on hydrogen concentrations in anoxic sediments: Geochimica et Cosmochimica Acta, v. 62, p. 1745–1756.

Hoehler, T., and Jorgensen, B., 2013, Microbial life under extreme energy limitation: Nature Reviews Microbiology, v. 11, p. 83–94.

Jakobsen, R., 2007, Redox microniches in groundwater: a model study on the geometric and kinetic conditions required for concomitant Fe oxide reduction, sulfate reduction, and methanogenesis: Water Resources Research, v. 43, p. 1–11.

Jiao, N., Azam, F., and Sanders, S., 2011, The microbial carbon pump in the ocean: American Association for the Advancement of Science, Washington, D.C. 68 p.

John, D., 2003, Transport and survival of water quality indicator microorganisms in the ground water environment of Florida—Implications for aquifer storage and waste disposal: University of South Florida, Tampa, Ph.D. dissertation, 322 p.

John, D., and Rose, J., 2005, Review of factors affecting microbial survival in groundwater: Environmental Science & Technology, v. 39, p. 7345–7356.

Johnston, R., and Bush, P., 1988, Summary of the hydrology of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Professional Paper, 1403–A, 32 p.

Kell, D., Kaprelyants, A., Weichart, D., Harwood, C., and Barer, M., 1998, Viability and activity in readily culturable bacteria—A review and discussion of the practical issues: Antonie van Leeuwenhoek, v. 73, p. 169–187.

Kenny, J., Barber, N., Hutson, S., Linsey, K., Lovelace, J., and Maupin, M., 2005, Estimated use of water in the United States in 2005: U.S. Geological Survey Circular 1344, 52 p.

Keswick, B., Gerba, C., Secor, S., and Cech, I., 1982, Survival of enteric viruses and indicator bacteria in groundwater: Journal of Environmental Science and Health. Part A: Environmental Science and Engineering, v. 17, p. 903–912.

Kirchman, D., 1993, Leucine incorporation as a measure of biomass production by heterotrophic bacteria, *in* Kemp, P., Sherr, B., Sherr, E., Cole, J., eds., Handbook of methods in aquatic microbial ecology: CRC Press, p. 509–512.

Kirchman, D., 2001, Measuring bacterial biomass production and growth rates from leucine incorporation in natural aquatic environments, chap. 12 *in* Paul J., ed., Marine microbiology: Academic Press, Methods in Microbiology, v. 30, p. 227–237.

Kirchman, D., and Ducklow, H., 1993, Estimating conversion factors for the thymidine and leucine methods for measuring bacterial production, *in* Kemp, P., Sherr, B., Sherr, E., Cole, J., eds., Handbook of methods in aquatic microbial ecology: CRC Press, p. 513–517.

Knittel, K., and Boetius, A., 2009, Anaerobic oxidation of methane: progress with an unknown process: Annual Review of Microbiology, v. 63, p. 311–334.

Koch, A., 1990, Diffusion: the crucial process in many aspects of the biology of bacteria: Advances in Microbial Ecology, v. 11, p. 37–70.

Krause, R., and Randolph, R., 1989, Hydrology of the Floridan aquifer system in southeast Georgia and adjacent parts of Florida and South Carolina: U.S. Geological Survey Professional Paper, 1403–D, 65 p.

Krieg, N., Ludwig, W., and Euzeby, J., Whitman, W., 2010, Phylum XIV. Bacteroidetes *phy. nov.*, in Krieg, N.R., Ludwig, W., Whitman, W.B., Hedlund, B.P., Paster, B.J., Staley, J.T., Ward, N., Brown, D., and Parte, A., eds., Bergey's manual of systematic bacteriology (2d ed), v. 4: The Bacteroidetes, Spirochaetes, Tenericutes (Mollicutes), Acidobacteria, Fibrobacteres, Fusobacteria, Dictyoglomi, Gemmatimonadetes, Lentisphaerae, Verrucomicrobia, Chlamydiae, and Planctomycetes : New York, Springer, p. 25–469.

Kristjansson, J., Schonheit, P., and Thauer, R., 1982, Different K_s values for hydrogen of methanogenic bacteria and sulfate reducing bacteria: an explanation for the apparent inhibition of methanogenesis by sulfate: Archives of Microbiology, v. 131, p. 278–282.

Kuever, J., Rainey, F., and Widdel, F., 2005, Class IV. Deltaproteobacteria *class nov.*, *in* Brenner, D.J., Krieg, N.R., and Staley, J.T., eds., Bergey's manual of systematic bacteriology (2d ed), v. 2, The Proteobacteria, part C, The Alpha-, Beta-, Delta, and Epsilonproteobacteria: Springer, p. 922–1144.

LeChevallier, M., Cameron, S., and McFeters, G., 1983, New medium for improved recovery of coliform bacteria from drinking water: Applied and Environmental Microbiology, v. 45, p. 484–492.

Lee, S., and Fuhrman, J., 1987, Relationships between biovolume and biomass of naturally derived marine bacterioplankton: Applied and Environmental Microbiology, v. 53, p. 1298–1303.

Lin, L., Wang, P., Rumble, D., Lippmann-Pipke, J., Boice, E., Pratt, L., Lollar, B., Brodie, E., Hazen, T., Andersen, G., DeSantis, T., Moser, D., Kershaw, D., and Onstott, T., 2006, Long-term sustainability of a high-energy, low-diversity crustal biome: Science, v. 314, p. 479–482.

Lisle, J., 2005, Characterization of the native microbial communities in Floridan aquifer waters targeted for aquifer storage and recovery (ASR) applications, south central Florida: U.S. Geological Survey Open-File Report 2005–1036, 24 p.

Lisle, J., Broadaway, S., Prescott, A., Pyle, B., Fricker, C., and McFeters, G., 1998, Effects of starvation on physiological activity and chlorine disinfection resistance in *Escherichia coli* O157:H7: Applied and Environmental Microbiology, v. 64, p. 4658–4662.

Lisle, J., and Priscu, J., 2004, The occurrence of lysogenic bacteria and microbial aggregates in the lakes of the McMurdo Dry Valleys, Antarctica: Microbial Ecology, v. 47, p. 427–439.

Lisle, J., Pyle, B., and McFeters, G., 1999, The use of multiple indices of physiological activity to access viability in chlorine disinfected *Escherichia coli* O157:H7: Letters in Applied Microbiology, v. 29, p. 42–47.

Liu, Y., and Whitman, W., 2008, Metabolic, phylogenetic, and ecological diversity of the methanogenic archaea: Annals of the New York Academy of Sciences, v. 1125, p. 171–189.

Lovley, D., Dwyer, D., and Klug, M., 1982, Kinetic analysis of competition between sulfate reducers and methanogens for hydrogen in sediments: Applied and Environmental Microbiology, v. 43, p. 1373–1379.

Maslia, M., and Hayes, L., 1988, Hydrogeology and simulated effects of ground-water development of the Floridan aquifer system, southwest Georgia, northwest Floridan and southwest Alabama: U.S. Geological Survey Professional Paper 1403–H, 71 p.

Mathias, M., Lasse, R., Grieg, F., Vinni, H., and Ole, N., 2003, Virus-induced transfer of organic carbon between marine bacteria in a model community: Aquatic Microbial Ecology, v. 33, p. 1–10.

McDougald, D., Rice, S., Weichart, D., and Kjelleberg, S., 1998, Nonculturability—Adaptation or debilitation?: FEMS Microbiology Ecology, v. 25, p. 1–9.

McFeters, G., 1990, Enumeration, occurrence, and significance of injured indicator bacteria in drinking water, *in* McFeters, Gordon, ed., Drinking water microbiology: New York, Springer, p. 478–492.

McFeters, G., Bissonnette, G., Jezeski, J., Thomson, C., and Stuart, D., 1974, Comparative survival of indicator bacteria and enteric pathogens in well water: Applied Microbiology, v. 27, p. 823–829.

McFeters, G., and Stuart, D., 1972, Survival of coliform bacteria in natural waters—Field and laboratory studies with membrane-filter chambers: Applied Microbiology, v. 24, p. 805–811.

McFeters, G., and Terzieva, S., 1991, Survival of *Escherichia coli* and *Yersinia enterocolitica* in stream water—Comparison and field and laboratory exposure: Microbial Ecology, v. 22, p. 65–74.

McKnight, D.M., Boyer, E.W., Westerhoff, P.K., Doran, P.T., Kulbe, T., and Andersen, D.T., 2001, Spectrofluorometric characterization of dissolved organic matter for indication of precursor organic material and aromaticity: Limnology and Oceanography, v. 46, p. 38–48.

Megonigal, J., Hines, M., and Visscher, P., 2003, Anaerobic metabolism—Linkages to trace gases and aerobic processes: Treatise on Geochemistry, v. 8, p. 317–424.

Meyer, F., 1989, Hydrogeology, ground-water movement, and subsurface storage in the Floridan aquifer system in southern Florida: U.S. Geological Survey Professional Paper, 1403–G, 64 p.

Middelboe, M., and Jørgensen, N., 2006, Viral lysis of bacteria—An important source of dissolved amino acids and cell wall compounds: Journal of the Marine Biological Association of the United Kingdom, v. 86, p. 605–612.

Miller, J., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper, 1403–B, 98 p.

Miller, L., 1990, Ground water atlas of the United States: Alabama, Florida, Georgia, and South Carolina: U.S. Geological Survey Hydrologic Atlas, Section 730–G, 30 p.

Mirecki, J., 2006, Geochemical models of water-quality changes during aquifer storage recovery (ASR) cycle tests, phase I—Geochemical models using existing data:, U.S. Army Engineer Research & Development Center, Vicksburg, Miss., ERDC/EL–TR–06–8, 64 p.

Mirecki, J., 2013, Lake Okeechobee ASR pilot project technical data report:, U.S. Army Corp of Engineers, Jacksonville, Fla., 300 p.

Mitterer, R., 2010, Methanogenesis and sulfate reduction in marine sediments—A new model: Earth and Planetary Science Letters, v. 295, p. 358–366.

Mitterer, R., Malone, M., Goodfriend, G., Swart, P., Wortmann, U., Logan, G., Feary, D., and Hine, A., 2001, Co-generation of hydrogen sulfide and methane in marine carbonate sediments: Geophysical Research Letters, v. 28, p. 3931–3934.

Noble, R., and Fuhrman, J., 1999, Breakdown and microbial uptake of marine viruses and other lysis products: Aquatic Microbial Ecology, v. 20, p. 1–11.

Nystrom, T., 2004, Stationary-phase physiology: Annual Review of Microbiology, v. 58, p. 161–181.

Onstott, T., 2005, Impact of CO_2 injections on deep subsurface microbial ecosystems and potential ramifications for the surface biosphere, *in* Benson, S., Oldenburg, C., Hoversten, M., Imbus, S., eds., Carbon Dioxide Capture for Storage in Deep Geologic Formations—Results from the CO_2 Capture Project: Elsevier, p. 1207–1239.

Onstott, T., Lin, L., Davidson, M., Mislowack, B., Borcsik, M., Hall, J., Slater, G., Ward, J., Lollar, B., Lippmann-Pipke, J., Boice, E., Pratt, L.M., Pfiffner, S., Moser, D., Gihring, T., Kieft, T., Phelps, T., Vanheerden, E., Litthaur, D., DeFlaun, M., Rothmel, R., Wanger, G., and Southam, G., 2006, The origin and age of biogeochemical trends in deep fracture water of the Witwatersrand Basin, South Africa: Geomicrobiology Journal, v. 23, p. 369–414.

Pedersen, K., 2012, Subterranean microbial populations metabolize hydrogen and acetate under *in situ* conditions in granitic groundwater at 450 m depth in the Äspö Hard Rock Laboratory, Sweden: FEMS Microbiology Ecology, v. 81, p. 217–229.

Phelps, T., Murphy, E., Pfiffner, S., and White, D., 1994, Comparison between geochemical and biological estimates of subsurface microbial activities: Microbial Ecology, v. 28, p. 335–349.

Plummer, N., and Sprinkle, C., 2001, Radiocarbon dating of dissolved inorganic carbon in groundwater from confined parts of the Upper Floridan aquifer, Florida, USA: Hydrogeology Journal, v. 9, p. 127–150.

Poiencot, B., and Brown, C., 2011, An optimal centralized carbon dioxide repository for Florida, USA: International Journal of Environmental Research and Public Health, v. 8, p. 955–975.

Reasoner, D., and Geldreich, E., 1985, A new medium for the enumeration and subculture of bacteria from potable water: Applied and Environmental Microbiology, v. 49, p. 1–7.

Reese, R., and Alvarez-Zarikian, C., 2006, Hydrogeology and aquifer storage and recovery performance in the Upper Floridan aquifer, southern Florida: U.S. Geological Survey Scientific Investigations Report 2006–5239, 74 p.

Reese, R., and Richardson, E., 2008, Synthesis of the hydrogeological framework of the Floridan aquifer system and delineation of a major Avon Park permeable zone in central and southern Florida: U.S. Geological Survey Scientific Investigations Report 2007–5207, 60 p.

Renken, R., Cunningham, K., Zygnerski, M., Wacher, M., Shapiro, A.M., Harvey, R.W., Metge, D.W., Osborn, C., and Ryan, J.N., 2005, Assessing the vulnerability of a municipal well field to contamination in a karst aquifer: Environmental and Engineering Geoscience, v. 11, p. 319–331.

Robbins, L., Hansen, M., Kleypas, A., and Meylan, S., 2010, CO2calc—A user-friendly seawater carbon calculator for Windows, Max OS X, and iOS (iPhone): U.S. Geological Survey Open-File Report 2010–1280, 17 p.

Robinson, J., and Tiedje, J., 1984, Competition between sulfate-reducing and methanogenic bacteria for H_2 under resting and growing conditions: Archives of Microbiology, v. 137, p. 26–32.

Roszak, D.B., and Colwell, R.R., 1987, Survival strategies of bacteria in the natural environment: Microbiological Reviews, v. 51, p. 365–379.

Russell, J.B., and Cook, G.M., 1995, Energetics of bacterial growth: balance of anabolic and catabolic reactions: Microbiological Reviews, v. 59, p. 48–62.

Ryder, P., 1985, Hydrology of the Floridan aquifer system in west-central Florida: U.S. Geological Survey Professional Paper 1403–F, 72 p.

Schink, B., 1997, Energetics of syntrophic cooperation in methanogenic degradation: Microbiology and Molecular Biology Reviews, v. 61, p. 262–280.

Schleifer, K., 2009, Phylum XIII. *Firmicutes* Gibbons and Murray 1978, 5 (Firmacutes [sic] Gibbons and Murray 1978, 5), *in* Vos, P., Garrity, G., Jones, D., Krieg, N.R., Ludwig, W., Rainey, F.A., Schleifer, K.-H., and Whitman, W.B., eds., Bergey's manual of systematic bacteriology (2d ed), v. 3, The Firmicutes: New York, Springer, p. 19–1317.

Schonheit, P., Kristjansson, J., and Thauer, R., 1982, Kinetic mechanism for the ability of sulfate reducers to out-compete methanogens for acetate: Archives of Microbiology, v. 132, p. 285–288.

Schulz, H., and Jorgensen, B., 2001, Big bacteria: Annual Review of Microbiology, v. 55, p. 105–137.

Shade, A., Read, J., Welkie, D., Kratz, T., Wu, C., and McMahon, K., 2011, Resistance, resilience and recovery—Aquatic bacterial dynamics after water column disturbance: Environmental Microbiology, v. 13, p. 2752–2767.

Sidhu, J., and Toze, S., 2012, Assessment of pathogen survival potential during managed aquifer recharge with diffusion chambers: Journal of Applied Microbiology, v. 113, p. 693–700.

Simon, M., and Azam, F., 1989, Protein content and protein synthesis rates of planktonic marine bacteria: Marine Ecology Progress Series, v. 51, p. 201–213.

Sjostrom, J., Koch-Schmidt, P., Pontarp, M., Canback, B., Tunlid, A., Lundberg, P., Hagstrom, A., and Riemann, L., 2012, Recruitment of members from the rare biosphere of marine bacterioplankton communities after an environmental disturbance: Applied and Environmental Microbiology, v. 78, p. 1361–1369.

Spiers, A., Buckling, A., and Rainey, P., 2000, The causes of *Pseudomonas* diversity: Microbiology, v. 146, p. 2345–2350.

Sprinkle, C., 1989, Geochemistry of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Professional Paper, 1403–I, 111 p.

Szulczewski, M., MacMinn, C., Herzog, H., and Juanes, R., 2012, Lifetime of carbon capture and storage as a climate-change mitigation technology: Proceedings of the National Academy of Sciences, v. 109, p. 5185–5189.

Terzieva, S., and McFeters, G., 1991, Survival and injury of *Escherichia coli*, *Campylobacter jejuni*, and *Yersinia enterocolitica* in stream water: Canadian Journal of Microbiology, v. 37, p. 785–790.

Teske, A., and Sørensen, K., 2007, Uncultured archaea in deep marine subsurface sediments—Have we caught them all?: International Society for Microbial Ecology Journal, v. 2, p. 3–18.

Thauer, R., Jungermann, K., and Decker, K., 1977, Energy conservation in chemotrophic anaerobic bacteria: Bacteriological Reviews, v. 41, p. 100–180.

Thauer, R., and Shima, S., 2008, Methane as fuel for anaerobic microorganisms: Annals of the New York Academy of Sciences, v. 1125, p. 158–170.

Tibbals, C., 1990, Hydrology of the Floridan aquifer system in east-central Florida: U.S. Geological Survey Professional Paper, 1403–E, 110 p.

U.S. Army Corps of Engineers and South Florida Water Management District, 1999, Central and Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report and Programmatic Environmental Impact Statement: U.S. Army Corps of Engineers, Jacksonville, Fla., and South Florida Water Management District, West Palm Beach, Fla., 4034 p.

U.S. Environmental Protection Agency, 2002, Method 1603: *Escherichia coli* (*E. coli*) in water by membrane filtration using modified membrane-thermotolerant *Escherichia coli* agar (modified mTEC): p. 1–13.

Ward, N., 2010, Phylum XXV. Planctomycetes Garrity and Holt 2001, 137 emend. Ward (this volume), *in* Krieg, N.R., Ludwig, W., Whitman, W.B., Hedlund, B.P., Paster, B.J., Staley, J.T., Ward, N., Brown, D., and Parte, A., eds., Bergey's manual of systematic bacteriology (2d ed), v. 4, The Bacteroidetes, Spirochaetes, Tenericutes (Mollicutes), Acidobacteria, Fibrobacteres, Fusobacteria, Dictyoglomi, Gemmatimonadetes, Lentisphaerae, Verrucomicrobia, Chlamydiae, and Planctomycetes: New York, Springer, p. 879–925.

Weishaar, J.L., Aiken, G.R., Bergamaschi, B.A., Fram, M.S., Fujii, R., and Mopper, K., 2003, Evaluation of specific ultraviolet absorbance as an indicator of the chemical composition and reactivity of dissolved organic carbon: Environmental Science & Technology, v. 37, p. 4702–4708.

Whitman, W., Coleman, D., and Wiebe, W., 1998, Prokaryotes—The unseen majority: Proceedings of the National Academy of Sciences, v. 95, p. 6578–6583.

Wright, R., 1978, Measurement and significance of specific activity in the heterotrophic bacteria of natural waters: Applied and Environmental Microbiology, v. 36, p. 297–305.

Wright, R., and Burnison, B., 1979, Heterotrophic activity measured with radiolabelled organic substrates, *in* Costerton, J., and Colwell, R., eds., Native aquatic Bacteria—Enumeration, activity, and ecology: ASTM Special Technical Publication 695, p. 140–155.

Wright, R., and Hobbie, J., 1966, Use of glucose and acetate by bacteria and algae in aquatic ecosystems: Ecology, v. 47, p. 447–464.

Xiong, R., Xie, G., Edmondson, A., and Sheard, M., 1999, A mathematical model for bacterial inactivation: International Journal of Food Microbiology, v. 46, p. 45–55.

Zaske, S., Dockins, W., and McFeters, G., 1980, Cell envelope damage in *Escherichia coli* caused by short-term stress in water: Applied and Environmental Microbiology, v. 40, p. 386–390.

Zimbro, M., Power, D., Miller, S., Wilson, G., and Johnson, J., 2009, Difco & BBL manual—Manual of microbiological culture media (2d ed): Sparks, Md., BD Diagnostics, p. 1–686.

Appendix

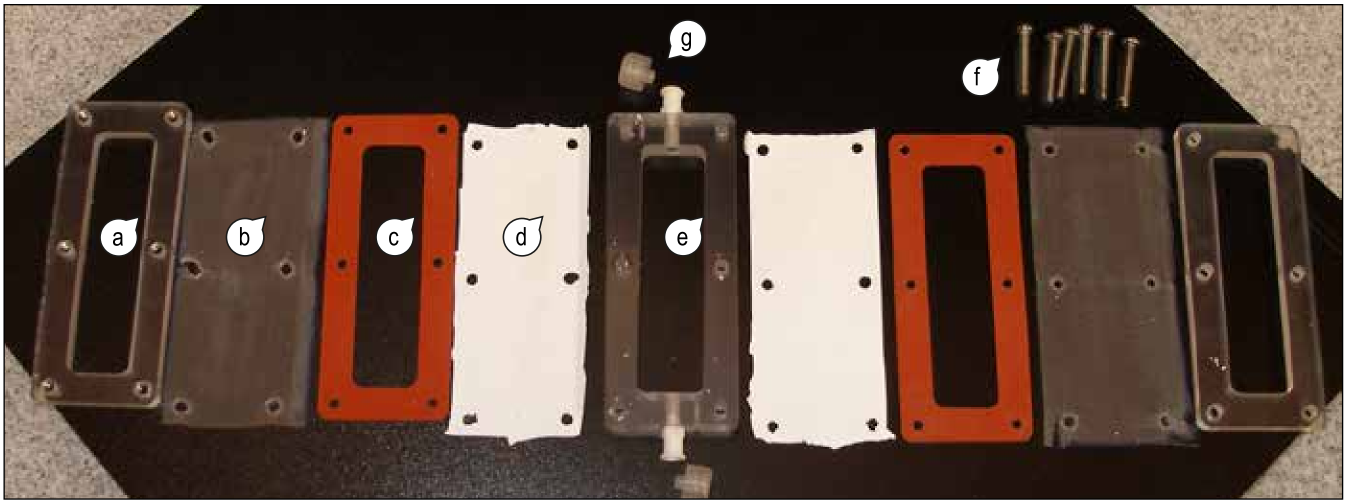
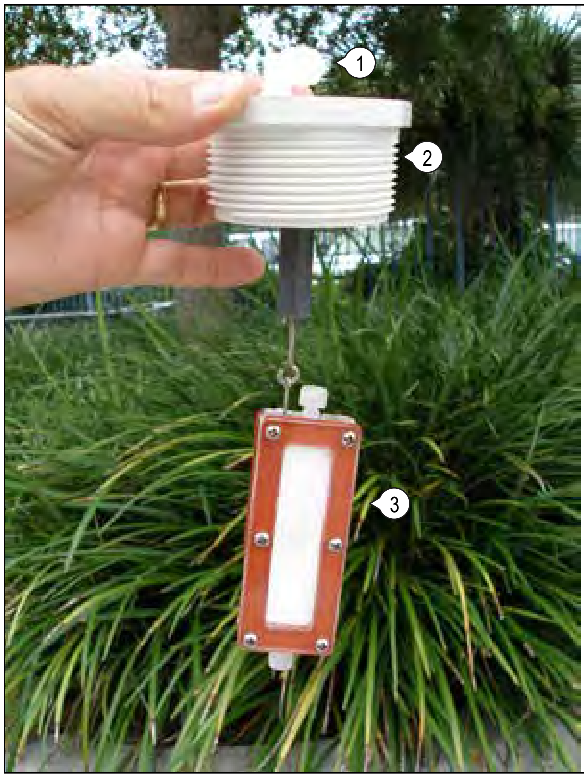


Figure 1-1. Diffusion chamber design: Each diffusion chamber was constructed by placing a membrane filter (d) on the central chamber (e), on which a silicon gasket (c) was placed. A polycarbonate screen (b) was placed on the gasket and the top chamber plate (a) placed on the screen. The same process was repeated for the other side of the central chamber and the completed chamber fastened and sealed with the six stainless steel bolts (f). The nylon syringe fittings on either end of the central chambers were closed using threaded polycarbonate caps (g).

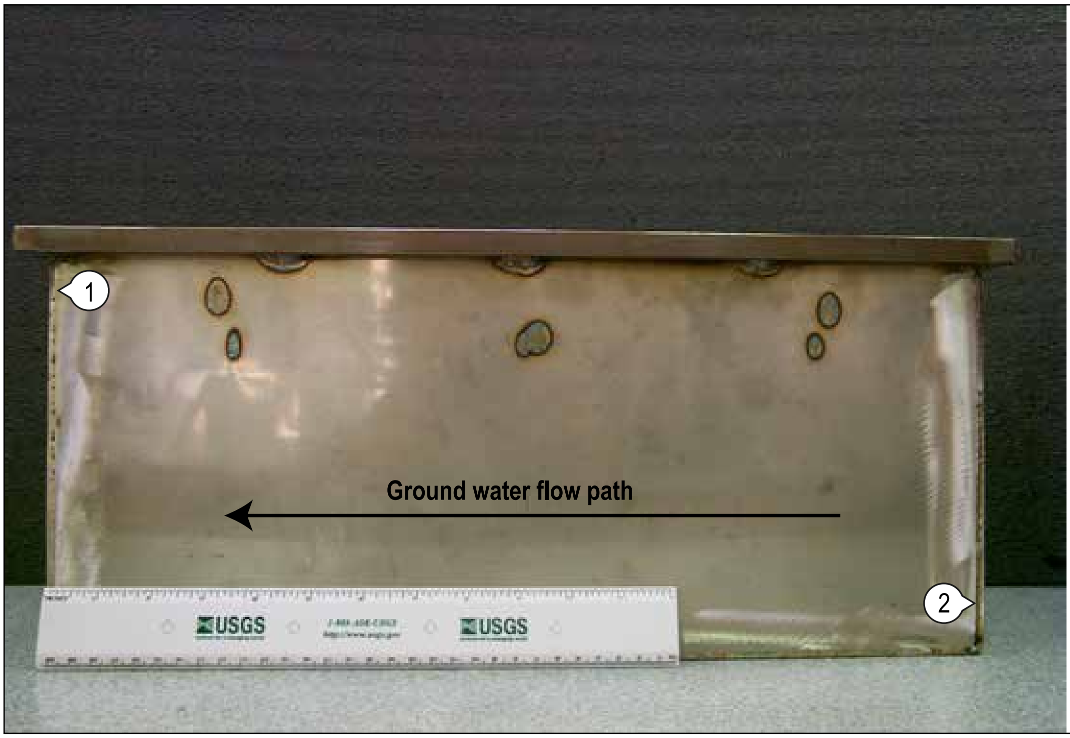
Figure 1-2. A completed diffusion chamber.

Figure 1-3. Loading a diffusion chamber with a culture of bacteria using a syringe.



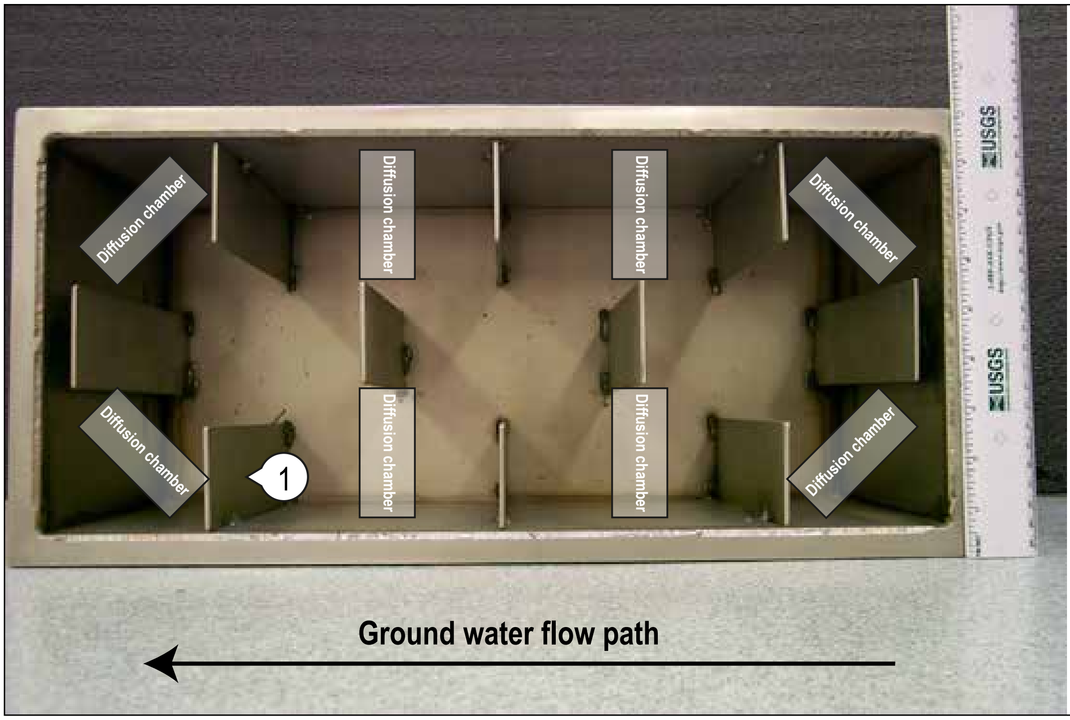
1. Off gas release fitting that allows gases released within the stainless steel (SS) flow cell due to depressurization to vent into the water jacket
2. Threaded polyvinyl chloride (PVC) cap that fits the PVC inserts in the SS flow cell's top
3. Diffusion chamber filled with bacterial suspension

Figure 1-4. A diffusion chamber containing the bacterial culture suspended from a cap from the stainless steel flow–through chamber (See Figure 1-9).



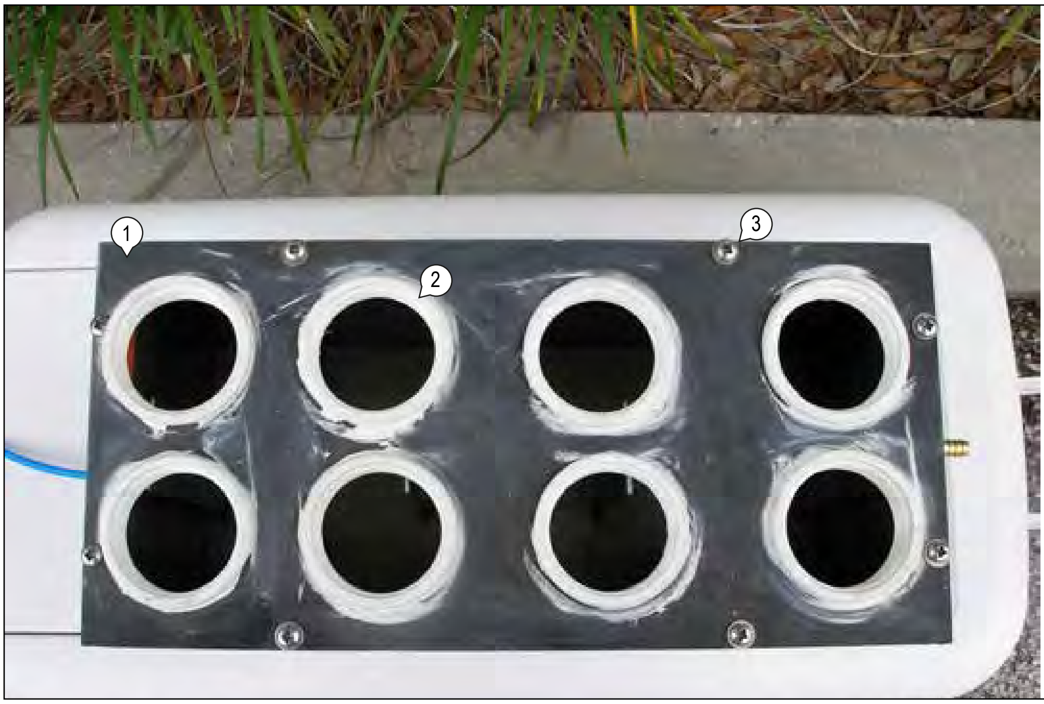
1. Discharge connection
2. Inflow connection

Figure 1-5. The stainless steel flow–through chamber (side view).



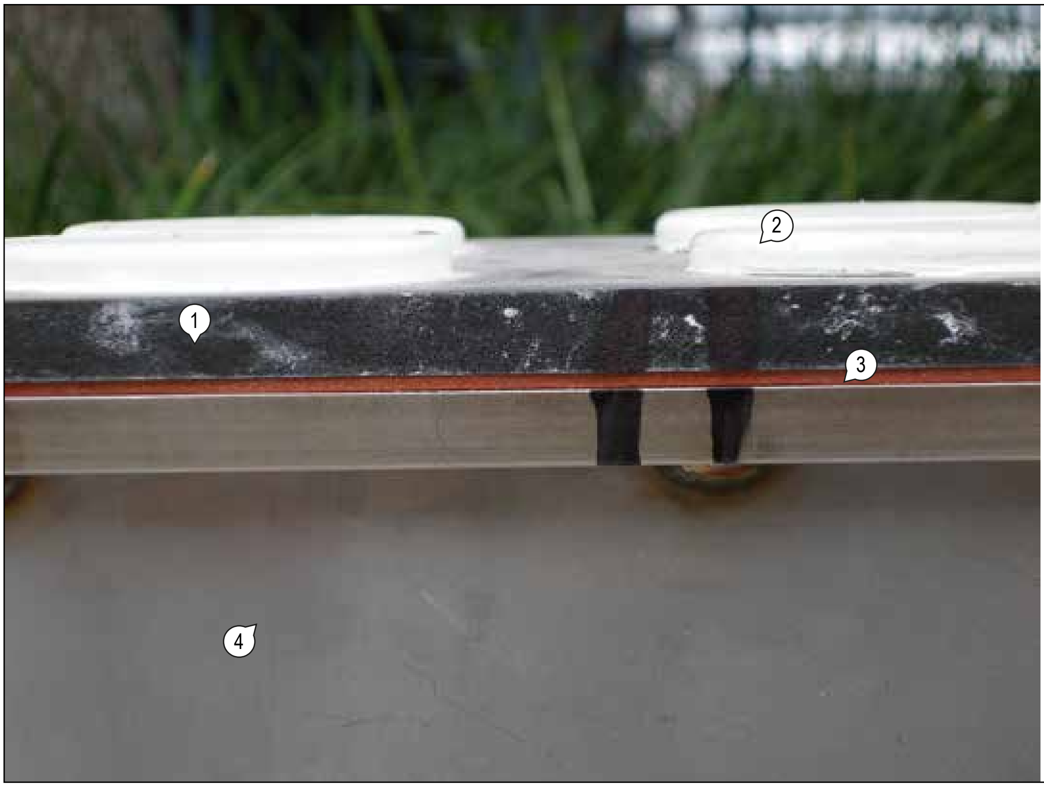
1. Flow baffles to prevent short circuiting flow paths

Figure 1-6. The stainless steel flow–through chamber showing the baffles and positions of the diffusion chambers (top view).



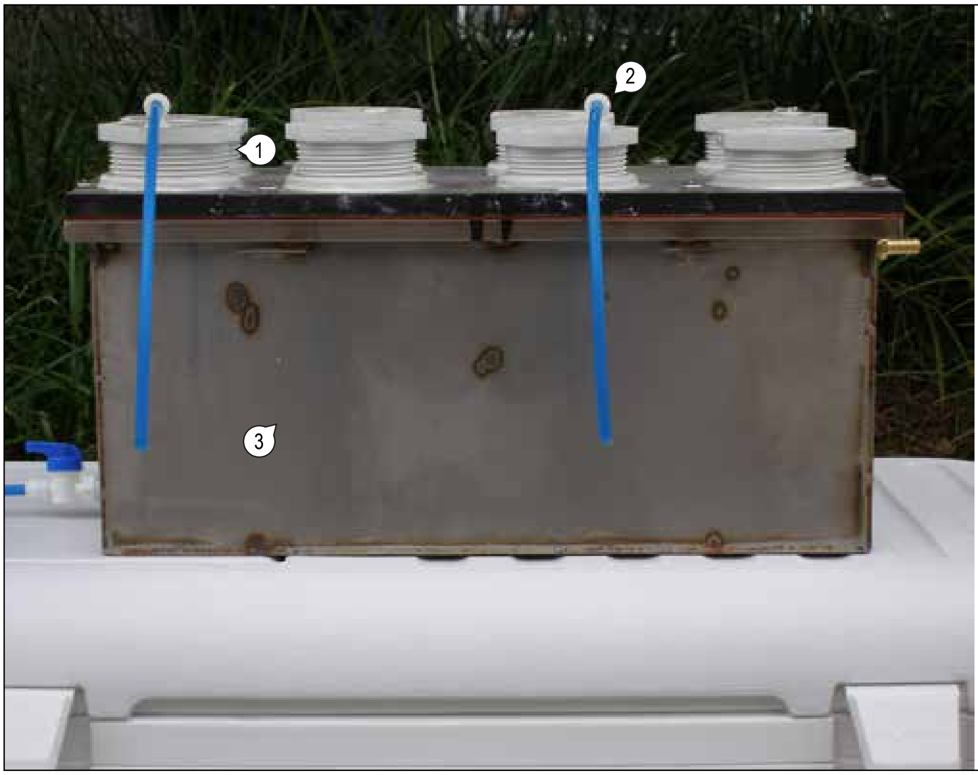
1. Inert polymer top
2. Threaded PVC insert for cap with diffusion chamber (see figure 1-4)
3. SS bolts to secure polymer top to SS flow cell

Figure 1-7. The stainless steel flow–through chamber showing the inert polymer top into which the caps that hold the diffusion chambers are inserted (top view).



1. Inert polymer top
2. Threaded PVC inserts
3. Silicone gasket to ensure water tight seal between the SS flow cell and polymer top
4. SS flow cell (side view)

Figure 1-8. The stainless steel flow–through chamber showing the silicon gasket that seals the connection between the polymer top and the stainless steel chamber (side view). This gasket prevents the source water in the outer flow–through chamber from leaking into this chamber.

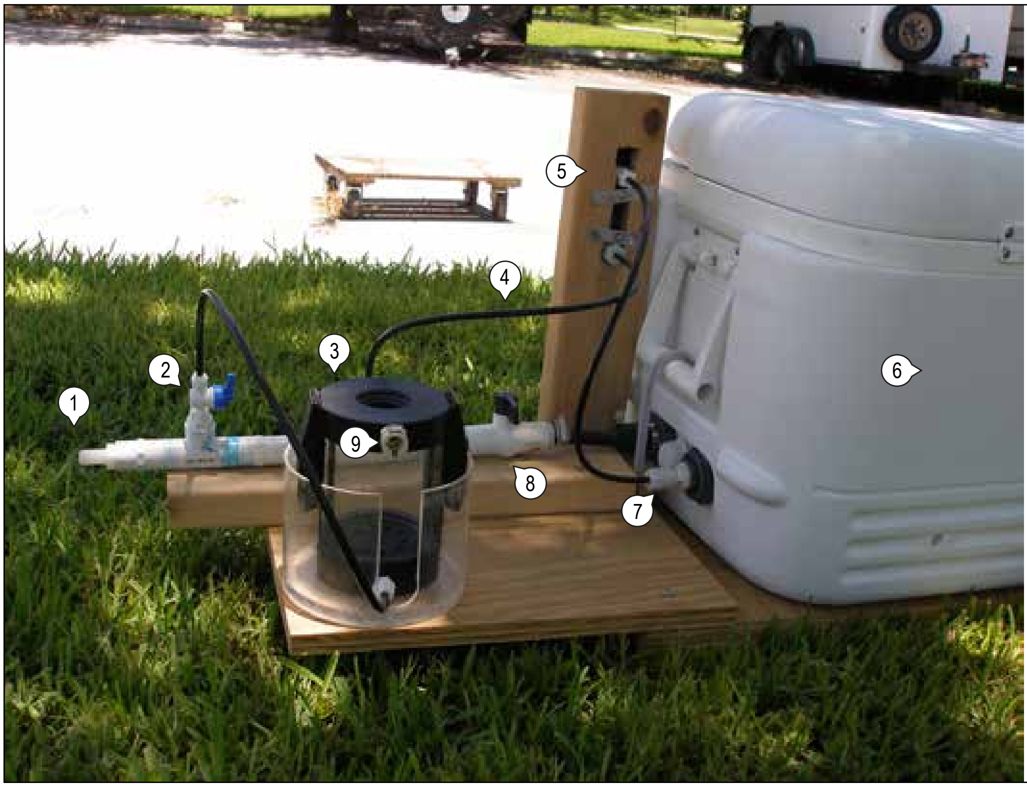


1. Threaded PVC cap that fits the PVC inserts in the SS flow cell's top
2. Off gas release fitting with tubing attached for directing gas release
3. SS flow cell (side view)

Figure 1-9. The complete stainless steel flow–through chamber with diffusion chambers inserted (side view).

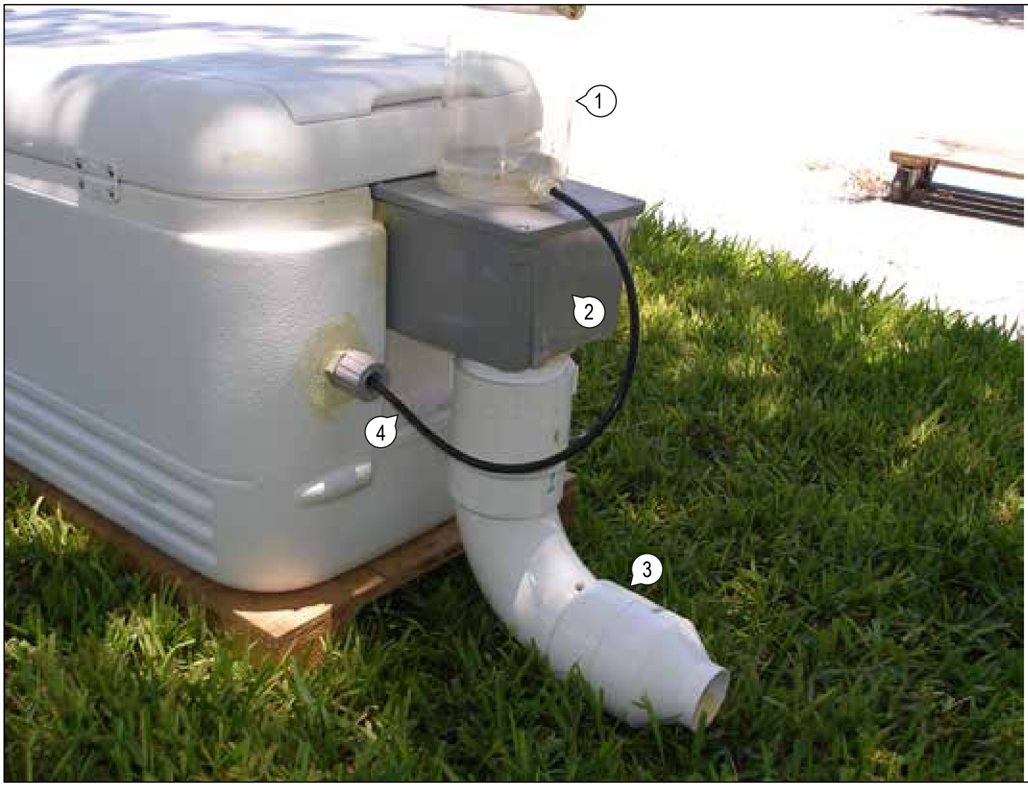
1. Multiprobe flow cell for monitoring pH, temp, oxidation/reduction potential (ORP) of ground water (GW) leaving the SS flow–through chamber
2. Outer flow–through chamber
3. Flow meter for regulating flow through the SS flow chamber
4. Multiprobe flow cell for monitoring pH, temp, ORP of GW entering the SS flow chamber
5. Flow control valve for outer flow–through chamber
6. GW source to SS flow–through chamber
7. Flow control valve for multiprobe flow cell
8. Inflow connection to GW source
9. Discharge outlet for the outer flow–through chamber

Figure 1-10. The outer flow–through chamber, flow rate controls and connections for the multiprobe attachment fittings.



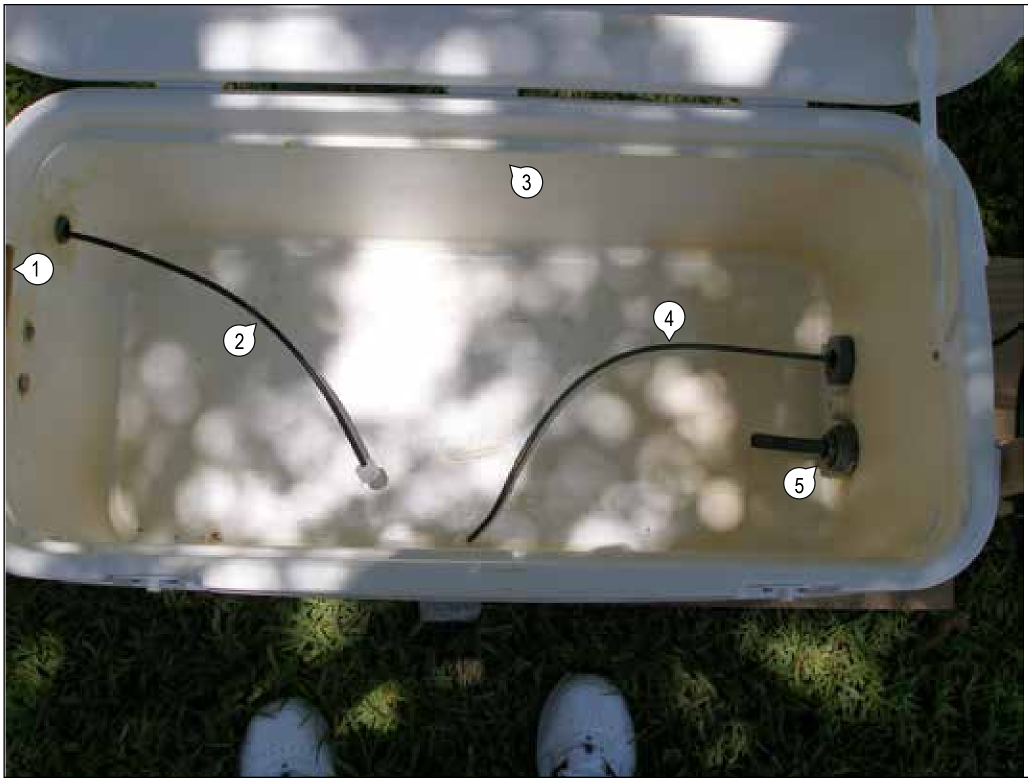
1. Inflow connection to GW source
2. Flow control valve for multiprobe flow cell
3. Multiprobe flow cell for monitoring pH, temp, ORP of GW entering the SS flow chamber
4. GW source to SS flow–through chamber via flow meter
5. Flow meter (backside) for regulating flow through the SS flow–through chamber
6. Outer flow–through chamber
7. GW source line for SS flow–through chamber
8. Flow control valve for outer flow–through chamber
9. Discharge to waste outlet for multiprobe flow cell

Figure 1-11. The outer flow–through chamber flow rate controls and multiprobe attachment fittings (rear view).



1. Multiprobe flow cell for monitoring pH, temp, ORP of GW leaving the SS flow–through chamber
2. High volume collection box for the outer flow–through chamber
3. Discharge outlet for the flow–through chamber
4. GW discharge line from the SS flow–through chamber

Figure 1-12. The outer flow–through chamber discharge and multiprobe fittings.



1. High volume discharge outlet for outer flow–through chamber over flow
2. GW discharge line from the SS flow–through chamber
3. Outer flow–through chamber
4. GW source line for SS flow–through chamber
5. GW inflow line for the outer flow–through chamber

Figure 1-13. An empty outer flow–through chamber showing the connections for the stainless steel flow–through chamber that contains the diffusion chambers.

1. High volume discharge outlet for outer flow–through chamber over flow (not shown)
2. GW discharge line from the SS flow–through chamber
3. Off gas fitting with tubing
4. Threaded PVC cap with diffusion chamber attached and suspended in the SS flow–through chamber
5. GW source line for SS flow–through chamber
6. GW inflow line for the outer flow–through chamber
7. Outer flow–through chamber

Figure 1-14. The complete aboveground flow–through microcosm.

Figure 1-15. The above ground flow through microcosm in the field.