INVESTIGATION OF OBSERVED DRIER CONDITIONS IN LONG-TERM DATA AT LETTUCE LAKE BY NATIONAL AUDUBON SOCIETY'S CORKSCREW SWAMP SANCTUARY

Final Report
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Executive Summary

A hydrologic modelling study was conducted to investigate the relative contribution of three potential drivers to the shortened hydroperiod observed at Audubon's Corkscrew Swamp Sanctuary in recent decades: groundwater withdrawals, increased coverage of high-ET (evapotranspiration) woody vegetation, and downstream drainage. Model simulations indicated reduction of downstream drainage has the greatest potential for reversing observed hydrologic alteration, with models suggesting that complete elimination of downstream drainage could return the Sanctuary to near 1960s hydrologic conditions. Notably, conveyance improvements downstream of the Sanctuary were implemented in the mid-2000s, roughly corresponding with the time period within which hydrologic changes were observed within the Sanctuary. While complete elimination of downstream drainage is not feasible due to residential and commercial development downstream of the Sanctuary, this study demonstrated that engineering and operations changes south of the Sanctuary have the potential to allow for significant hydrologic improvement while maintaining adequate flood protection. This study also revealed negative hydrologic impacts on the Sanctuary from agricultural and public water supply withdrawals, as well as hydrologic benefits of restoration projects to remove large stands of Carolina willow. We describe the ecological impacts of over-drying on the Sanctuary's ecology and provide recommendations on additional data collection that is critical for developing a mitigation plan. While an initial exploration of mitigation strategies was conducted, development of comprehensive mitigation strategies or solutions (which may include a combination of actions) was beyond the scope of this project. Further modelling is needed to develop a sound mitigation plan for restoration of Corkscrew Swamp Sanctuary's hydrology.

Background and Objectives

Audubon's Corkscrew Swamp Sanctuary is located in northern Collier County and protects the largest remaining old-growth bald cypress swamp in the world. The Sanctuary is a rare, remnant of Old Florida and is recognized as a Wetland of Distinction (Society of Wetlands Scientists), a wetland of international importance (Ramsar Convention), a National Natural Landmark (U.S. Department of the Interior), and an Important Bird Area (BirdLife International). The old-grown bald cypress found within the Sanctuary support a nesting colony of federally-threatened Wood Storks (*Mycteria americana*) that was once the most productive Wood Stork colony in the United States, and for which Audubon has the longest-running continuous data set on Wood Stork nesting in the United States. Wood Storks, like other Everglades wading birds, are highly dependent upon wetland hydrology as it controls the magnitude and timing of concentrations of aquatic prey and because of the benefit of standing water beneath nesting trees through the nesting season.

A 60-year record of daily surface water level measurements has revealed substantial changes in Corkscrew Swamp Sanctuary's hydrology as agricultural and residential development have grown to dominate the landscape surrounding the Sanctuary. There was little change in rainfall patterns during this 60-year period and no major changes in surface water levels during the first 40 years. However, the last 20 years has seen a dramatic lowering of the dry season water table (Clem and Duever 2019). This change has resulted in markedly shortened hydroperiods (days inundated per water year) in all wetland habitats that normally hold at least some water well into the dry season (marshes, old-growth bald cypress forests and ponds).

The objective of this study was to better understand the contribution of several known changes in the region to the observed lower dry season water table elevations. A hydrologic modelling study was conducted with the following specific objectives:

1. Develop a suitable model to evaluate response of Corkscrew Swamp Sanctuary to anthropogenic and natural changes by enhancing existing model of the region. Update and expand the aerial coverage of an existing integrated surface water/ground water model of the region to enhance its ability to describe changes in dry season water levels above ground and in the water table aquifer.

2. Apply the model to determine the difference in dry season water levels between existing conditions and conditions in each of four scenarios designed to assess major kinds of landscape changes that have occurred in southwest Florida over the last 60 years.

3. Based on the model results and analyses, provide an initial assessment of the relative contribution of specific changes to the observed drying and implications for Corkscrew Swamp's long-term future condition with and without the implementation of adaptive management strategies for reducing impacts.

The project was designed to complement the flood model recently completed for the Village of Estero and Edison Farms (now known as Kiker Preserve), and to integrate existing appropriate ecological data from the Density Reduction/Groundwater Resource (DRGR) studies in Lee County and Bonita Springs, as well as complement the modeling currently underway by contractors for Lee County. This modeling was meant to be additive to other local efforts – completing the picture by filling gaps and bridging the various modeling efforts to have a regional watershed-scaled picture. While the final scenario examined the effects of a few mitigation options, the objective of this project was not to develop a comprehensive mitigation strategy or solution.

Existing Conditions Model Development, Model Calibration, and Comparison to Ecological Indicators

Audubon contracted Water Science Associates (WSA; Principal Scientists Roger Copp and W. Kirk Martin) to complete this modelling study. The full final report for the "Corkscrew Swamp Watershed Hydrologic Modelling Project" prepared by WSA follows this document, with any description of modelling methods and outcomes in this document intended only as an overview. Key elements of the model development include reducing grid spacing from 750 feet to 375 feet (providing 4 times greater resolution), model calibration (calibration period 2013-2014), model validation (simulation period 2015-2018), and comparison of validation simulation results to biological indicators of hydrology observed in the field.

Overview and Evaluation of Scenarios

Four model scenarios were developed and run for this study. The first three scenarios evaluated the relative impact of three key anthropogenic drivers on dry season water levels, with a particular focus on hydrologic changes within the old-growth bald cypress forest that is central to the Sanctuary (and where a shortened hydroperiod has been documented). Anthropogenic drivers evaluated included: (1)

groundwater extraction (agricultural irrigation and public water supply wellfields), (2) increased evapotranspiration (ET) due to changes in marsh and prairie vegetation communities, and (3) man-made drainage south of Corkscrew Swamp Sanctuary. Each of these three scenarios involved extreme changes to land cover, land use, or flood control operations in the region and was intended to be purely hypothetical. Scenarios were not prescriptive, only serving as attempts to "move the needle" to see what changes could trigger increased hydroperiods in the Sanctuary similar to those recorded by Audubon in the 1960s and 1970s. Outcomes from these three scenarios were evaluated and compared to determine what driver(s) could reasonably be altered or mitigated for in order to restore historic hydrology while minimizing or avoiding negative impacts on adjacent land owners.

- *Elimination of Agricultural Irrigation*. Scenario 1A simulated no agricultural irrigation east of I-75, primarily areas north of the Sanctuary. Elimination of agricultural irrigation resulted in increased dry season water levels in Flint Pen Strand but no hydroperiod changes throughout most of the Sanctuary. An exception to this was seen in wetlands in the northeastern portion of Sanctuary, which lie approximately 1 mile south of agricultural lands. These wetlands currently do not dry out seasonally, exhibiting a hydroperiod that is notably longer than that observed in the 1970s and 1980s (M. Duever, personal communication). Under Scenario 1A, these wetlands had lower dry season water levels (and shortened hydroperiod), more typical of what was observed historically.

- *Elimination of Public Water Supply Withdrawals*. Scenario 1B simulated no withdrawals from public water supply wellfields. Elimination of public water supply wellfields resulted in an increase in dry season water levels in Flint Pen Strand that was similar to what was seen in Scenario 1A, but no hydroperiod or water level changes were seen within the Sanctuary.

- *Elimination of Agricultural Irrigation and Public Water Supply Withdrawals*. Elimination of both of these ground water withdrawals resulted in significantly higher water levels in Flint Pen Strand. This scenario also indicated a modest increase in wetland hydroperiod near the Corkscrew Swamp Sanctuary boardwalk. This increase raised the minimum annual water level approximately 6 inches and increased the hydroperiod by a matter of weeks. While we found it instructive that groundwater withdrawals such a distance from the boardwalk had a noticeable impact, the resulting hydroperiod is still appreciably shorter than what was observed in this area prior to the 1990s.

- *Elimination of Woody Marsh Vegetation and Reduction in Pine Flatwoods Density*. In Scenario 2, all willow land cover was converted to marsh and pine flatwoods density was reduced by 75%, with hydric flatwoods converted to wet prairies and mesic flatwoods converted to pastures. Elimination of willow and reduction of pine flatwood density resulted in no significant water level changes within the Sanctuary. A water budget analysis for model cells converted from willow to marsh indicated the removal of willow slightly reduced ET rates, with the reduction equivalent to >1,500 acre-feet per year in this immediate area. Despite this ET reduction, the overall water budget for Scenario 2 was similar to that of exiting conditions.

- *Reduction of Downstream Drainage*. Scenario 3 simulated reduction of downstream drainage by removing a number of canals and water control structures downstream of Corkscrew Swamp Sanctuary, and converting a large area south of the Sanctuary from urban land use to natural land cover types (see modelling report for full details). Reduction of downstream drainage resulted in significant increases in water level and hydroperiod at both the Sanctuary boardwalk and at the Bird Rookery Swamp (BRS) south hiking trail. Further, under Scenario 3, simulated water levels remained above ground 6/2013 through 12/2018, while simulations of existing conditions saw only one year (2016) that water levels failed to fall below ground. This trend aligns with the analysis of altered water levels reported by Clem and Duever (2019) that cited this area drying 1 of 5 years prior to 1999 but drying 4 of 5 years since 2000 and hydropatterns indicated in this simulation most closely match those recorded in the Sanctuary from 1959 to 1999.

- *Mitigation of Downstream Drainage*. With downstream drainage identified as the hydrologic driver with the greatest simulated deleterious impact on Corkscrew Swamp Sanctuary hydrology, in Scenario 4 our team sought to find a way to reduce drainage from the Sanctuary while maintaining existing levels of flood protection in residential areas south of BRS (see modelling report for specifics of Scenario 4). Simulated hydroperiods were increased 6% in the Sanctuary, Gordon Swamp, portions of BRS and the Mirasol Flow-way. Hydroperiods were also higher in Southern Corkscrew Regional Ecosystem Watershed (CREW). Scenario 4 also indicated slightly lower water levels than existing conditions in portions of BRS. Along the Sanctuary's boardwalk, Scenario 4 indicated dry season water levels approximately one foot higher than existing conditions during 2014-2015, while water levels still fell below the ground surface in the 2017 and 2018 dry seasons.

This study not only indicated that reduction in downstream drainage has the potential to return Corkscrew Swamp Sanctuary's hydrology to pre-1990 conditions, it demonstrated that this driver was the only examined hydrologic driver with a great enough simulated impact to allow for significant reversal of the Sanctuary's shortened hydroperiods. Notably, conveyance improvements downstream of the Sanctuary associated with the Corkscrew Canal were implemented in the mid-2000s following a study conducted by SFWMD (Ahmed and Nath 2004), roughly corresponding with the time period within which hydrologic changes were observed within the Sanctuary. While Scenario 3 included an unreasonable disruption to existing residential and commercial areas and Collier County infrastructure, the simulated hydrologic response in the Sanctuary was remarkably similar to what was observed in the 1960s and 1970s, prior to hydrologic changes, which was ultimately the desired model outcome. The challenge in developing Scenario 4 was finding a way to capture water leaving Corkscrew Swamp Sanctuary through drainage, while providing adequate flood protection for existing landowners. While the proposed engineering and operation changes in Scenario 4 were successful in reducing drainage from the Sanctuary and raising dry season water levels, a greater hydrologic improvement than Scenario 4 provided is needed. Additional modelling efforts are needed to develop a mitigation plan to further increase hydroperiods and maximize hydrologic improvement for the Sanctuary. This study demonstrated the limitations of current topography data for Corkscrew Swamp Sanctuary and Bird Rookery Swamp. Improving this data set is a critical first step in this next effort. Specific recommendations are outlined below.

This project also provided a better understanding the impacts of groundwater extraction on Sanctuary wetlands, results that likely have broad applications throughout our region and beyond. The modest hydrologic change seen along the Sanctuary boardwalk when agricultural and public water supply extractions were removed highlighted the impact these stressors can have on wetlands. These simulations also highlighted the different impacts these extraction sources can have. Public water supply extraction reduced water levels along the Sanctuary's boardwalk, which is over 5 miles from the nearest wellfield, while agricultural extraction was associated with increasing the hydroperiod of Sanctuary wetlands approximately one mile south of the source. The elongated hydroperiod indicated in the northeastern area of the Sanctuary due to upstream dry-season agricultural irrigation is also highly problematic for land management at the Sanctuary. It is likely that this extended period of inundation has encouraged the proliferation of willow (Hall et. al 2017) that Audubon restoration efforts are currently working to combat. Seasonal drying is necessary for appropriate land management activities (including controlling the spreading willow community) in this marsh habitat, as it allows for application of prescribed fire, which is essential for structuring and maintaining healthy native plant communities (Duever and Roberts 2013). This modelling result also raises concern about potential nutrient impacts from agricultural run-off, as eutrophication will further change native plant communities and can alter the aquatic food web. Additional analyses are needed to better understand and describe the magnitude and geographic extent of hydrologic changes associated with these extraction sources.

Study findings on the removal of large stands of native woody marsh vegetation (like Carolina willow (*Salix caroliniana*)) and reduced the density of hydric and mesic pinelands provided much-needed data on potential impacts of one of Audubon's current restoration efforts. This scenario was developed based on a number of observations of landscape-level plant community changes in this region. Throughout Florida, marshes and wet prairies once dominated by herbaceous vegetation have been succeeding to habitats dominated by willow, other woody shrubs, and trees (Hall et al. 2017). This succession has been documented within the Sanctuary's Central Marsh and throughout the Corkscrew Regional Ecosystem Watershed (CREW) through satellite and aerial photography (McCollom, Smith and Duver 2017). Carolina willow has a higher evapotranspiration (ET) rate than the herbaceous plant communities that it invades and creation of mature willow monocultures in marshes can result in a lower water table that promotes the proliferation of more deeply-rooted species, eventually facilitating the development of hardwood swamp communities (Hall et al. 2017). Concurrent with the spread of woody marsh vegetation, tree density in hydric and mesic pine flatwoods has increased by two orders of magnitude throughout this region (M. Duever unpublished data), thereby increasing the number of deeply-rooted trees utilizing groundwater during the dry season and further stressing groundwater resources. Simulated hydrology of the Sanctuary following removal of these woody invaders indicated that while water savings was significant within the actual restoration site, the hydrologic benefit on a landscape scale was subtle. Despite these findings, Audubon recommends continuing these types of restoration projects in our region, as willow removal improves land managers' ability to conduct prescribed fire and increases marsh openness, making aquatic prey more accessible to wading birds and other predators.

Ecological Implications of Hydrologic Alteration

Measurable ecological implications for the shortened hydroperiod are documented at Corkscrew Swamp Sanctuary, occurring most abruptly between the 1990s and 2000s (Clem and Duever 2019). These ecological changes within the Sanctuary are very likely tied to this hydrologic alteration, and without mitigation these factors will certainly continue and/or become more pronounced. A few key implications include:

> <u>Succession of plant communities and fire risk</u>. Succession of the Sanctuary's plant communities due to over-drainage has already been documented, with red maple and other upland species becoming a common sight in marshes and a general succession from herbaceous communities to shrub and hammock communities (Duever and Roberts 2013). The over-drainage presents a challenge for land management and maintenance of natural habitats using fire due to the vulnerability of the over-drained cypress forest which is naturally buffered from fire due to

inundation, but now must be protected from fire. Under current dry-season conditions, wildfire in the vicinity of the Sanctuary's cypress forest has the potential to be catastrophic.

Decreased Wood Stork nest success. Over the past 60 years Audubon has documented a decline in Wood Stork nesting and a reduction in nesting success concurrent with regional development and loss of shallow foraging habitat (S. Clem, unpublished data). The Corkscrew colony was once the most productive Wood Stork colony in the country, the single colony producing supporting over half of Florida's Wood Storks in the late 1950s and early 1960s (USFWS). Concurrent with the timing of Corkscrew's hydrologic disruption, however, successful Wood Stork nesting in the Sanctuary has become infrequent, with Wood Storks failing to even initiate nesting in the Sanctuary nine of the past fourteen years (S. Clem, unpublished data). In the 2017 nesting season, raccoon predation was presumed as the cause of colony failure (Lauritsen 2018), predation that is only likely when nesting trees lose the standing water beneath them due to the is protection that alligators provide from mammalian predators (Frederick and Collopy 1989, Nell et al. 2016).

Altered food web. In addition to direct impact on nesting, reducing the Sanctuary's hydroperiods will change the structure of fish communities and reduce the standing stock of large and small fishes and freshwater crustaceans (e.g., Trexler et al. 2005, Chick et al. 2004, Loftus and Eklund 1994) that serve as a critical food web base in this system (Duever 2005). Reduced aquatic prey production decreases wading bird productivity in the Everglades (Frederick et al. 2009) and is likely associated with the decreased nesting effort that has been observed at the Corkscrew colony in recent decades. Further, it is unknown how the unusually high dry season water level recession rates that the Sanctuary now experiences may influence the creation of the high-density prey patches that wading birds, particularly tactile-feeding Wood Storks, rely on (Botson et al. 2016).

Altered understory microclimate. High relative humidity levels under the cypress forest canopy insulate temperature-sensitive orchids, bromeliads, and other epiphytes during occasional South Florida cold spells (Luer 1972). Loss of standing water in the Sanctuary's cypress forest has the potential to alter the understory microclimate, further stressing many species that are already at risk due to habitat loss, poaching, and pests (Langdon 1979, Coile and Garland 2003).

Research Recommendations

The following recommendations will support the hydrologic restoration of Corkscrew Swamp Sanctuary, as well as, conservation of wetlands and water resource protection throughout the Corkscrew watershed:

Further refinement of a mitigation strategy. This study highlighted several datasets and actions that are needed to better prescribe mitigation efforts for Corkscrew Swamp Sanctuary.

- *Improved hydrologic monitoring*. Concurrent with this study, Audubon installed two telemetered water level recording stations along the Sanctuary's Central Marsh Transect. With the majority of existing water level recorders in this region associated with man-made structures, Audubon recommends creating a network of water level recording stations in natural areas throughout

CREW to allow for better monitoring of these critical conservation lands. Audubon supports the specific monitoring well locations prescribed in the modelling report.

- *Improvements to topographic data*. This project highlighted the need for improved topography data for Corkscrew Swamp Sanctuary and BRS, data that are critical for further refinement of the model and developing a mitigation plan to restore Corkscrew Swamp Sanctuary's hydrology. We recommend conducting five transect surveys running roughly east-west across the Sanctuary and BRS (see modelling report for specific map locations). These topography data must be collected prior to further model improvements.

- *Additional modelling of mitigation options*. Following implementation of additional monitoring and improving the accuracy of topographic data, we recommend additional modelling efforts to develop a mitigation strategy that will maximize hydrologic restoration of Corkscrew Swamp Sanctuary.

Policy Recommendations

The findings of this regional hydrologic modelling project have implications for water resource policies in the greater watershed of Corkscrew Swamp Sanctuary. Audubon, as the private landowner and manager of a 13,000-acre environmental sanctuary in the heart of the Western Everglades, is greatly affected by the policies, permits, and land uses that surround our sanctuary. In complement to science and land management recommendations based on findings of the Corkscrew Swamp Watershed Hydrologic Modeling Project, the following policy recommendations are offered:

<u>Non-Legislative Policy Recommendations:</u>

1. **Address Properties with Excessive Flooding**: Support buyouts of properties in 100-year floodplains that have repeated flood damage claims. Funding could come from FEMA, or other insurance risk minimization program.
    - ➢ Model nexus: Scenario 3 showed the largest impact to dry season hydrology at Corkscrew Swamp Sanctuary came from overdrainage south of the Sanctuary. Reducing flood protection demands by removing existing structures in flood plains is a strategic response.

2. **Reduce Stormwater Runoff with Innovative Strategies:** Whether from agricultural or urban land uses, holding more rainwater longer improves downstream water quality and upstream hydrology. Low Impact Development (LID) strategies are featured in the Collier County Watershed Management Plan (2011) and should be implemented on a regional scale.
    - ➢ Model nexus: Scenario 1 shows upstream water discharges have negative effects downstream, and Scenarios 3 and 4 document the dry season problem and solution to discharging too much stormwater during the wet season.

3. **Collaborate on wider hydrologic models, restoration projects, and flood mitigation plans**: South Florida Water Management District, Corkscrew Regional Ecosystem Watershed, and Audubon should work collaboratively with any agencies pursuing regional watershed modeling, restoration planning, and flood mitigation planning efforts in order to maximize water resource benefits, restoration outcomes and minimize impacts, especially to dry season hydrology.

- Model nexus: All scenarios identified land uses and water management practices that affected Corkscrew Swamp Sanctuary dry season hydrology. The South Lee Watershed Restoration Model and Lee County Flood Mitigation Plan and Model are two representative current wider regional plans that can lead to project outcomes that are either beneficial or harmful. These efforts need to be coordinated to take advantage of the important work in the Corkscrew Swamp Sanctuary Model and assure optimal watershed restoration outcomes.

4. **Support land acquisition and restoration of strategic water resources parcels in region:** Provide strong technical, logistical and financial support for local, state and federal land acquisition and restoration programs to target strategic parcels with greatest potential to improve dry season hydrology in the Corkscrew Regional Ecosystem Watershed (including Corkscrew Swamp Sanctuary), especially Flint Pen, Golden Gate Estates, Corkscrew Island Neighborhood, Southern CREW expansion, Corkscrew Road, CREW Headwaters, and DR/GR areas.
    - Model nexus: All scenarios identified land uses in specific locations that affect Sanctuary hydrology in particular ways. Using this information should help guide acquisition or restoration of parcels with greatest potential to effect hydrologic improvements.

<u>Legislative and Rule Change Recommendations:</u>

1. **Rule change to avoid development in indefensible flood plains**: Modify ERP and Florida 404 Programs' implementation to avoid permits for development in 25-year floodplains. The objective is to reduce flood protection demands on the regional drainage systems.
    - Model nexus: Scenario 3 identifies over-drainage south of Corkscrew Swamp Sanctuary as causing the greatest impacts to Sanctuary dry season hydrology. Wetland permits should reflect the importance of not building any more structures within flood plains that will demand increased drainage for flood protection, especially as sea level rise, climate change and storm intensity increases.

2. **Rule change to prohibit discharges which harm downstream conservation lands:** Amend Water Use Permit (WUP)/Environmental Resource Permit (ERP) Water Management Programs for Agricultural, Urban and Industrial operations to prohibit new discharges offsite if they would result in hydrology or habitat degradation downstream, or cause impacts to land management operations downstream. Additionally, require monitoring for water quality to prevent eutrophication or other harm to downstream natural aquatic ecosystems.
    - Model nexus: Scenario 1 identified hydrologic impacts to Corkscrew Swamp Sanctuary from agricultural discharges to the Sanctuary. Regulations should reflect the importance and fairness of new permits fully protecting landowners downstream of permitted activities.

3. **Retrofit existing agricultural, urban and industrial water management systems to stop demonstrated harm to downstream lands, using public investments & partnerships**: Revise all existing WUP/ERP's for Water Management of Agricultural, Urban and Industrial operations to end allowed discharges offsite, which cause hydrologic or habitat harm, or impact land management operations downstream. This will require water management system retrofits. Use public or partnership funding to implement this strategy where existing permits are in compliance with former standards.

- Model nexus: Scenario 1 identifies water discharge impacts occurring currently to Corkscrew Swamp Sanctuary from agricultural irrigation and water management operations to the north. While such activities likely have permits, they should be revised and retrofitted to cure any harm to downstream private landowners, including the Sanctuary. Public or partnership investment is appropriate due to current permit-holders' compliance with grandfathered permits.

4. **Prohibit public and private water wells within 5 miles of conservation lands; reduce surficial water supply sources, and reduce turfgrass to conserve water**: Amend the WUP Program to prohibit siting of Public Water Supply (PWS) or private self-supply water wells within 5 miles of private or public conservation resources, or anywhere such a well's cone of influence is demonstrated to impact such resources. Direct all new public water supply wells to use deeper aquifers hydrologically separated by confining layers from surficial aquifers. Emphasize water conservation, including reduction of irrigated turf grasses, to reduce demand for new PWS wells.
    - Model nexus: Scenario 1 identifies water withdrawals from surficial aquifers for PWS, agricultural and industrial uses impacting Corkscrew Swamp Sanctuary hydrology. Regulations should reflect the current science in the Corkscrew model on how far these wells' effects cumulatively extend to harm wetland resources. The Lower West Coast Water Supply Plan 2017 update identifies the importance of seeking alternative water sources to avoid impacts to wetlands (over half of this region's water sources are surficial). Alternatives include deeper aquifers and conservation.

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Corkscrew Swamp Watershed Hydrologic Modeling Project

PREPARED FOR:

Audubon

Corkscrew Swamp Sanctuary

Water Science Associates

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EXECUTIVE SUMMARY

Water Science Associates was contracted by the National Audubon Society (Audubon Florida) to develop a hydrologic model to assist in the understanding of potential factors that have led to decreased wetland hydroperiods and have contributed to the changing hydrology within Corkscrew Swamp Sanctuary (hereinafter referred to as the Sanctuary). Hydroperiods in the sanctuary have been reduced by 29 percent in marshes and by 18 percent in old-growth bald cypress habitats from the 1960s to 2010s, with the most marked change occurring between the 1990s and 2000s (Clem and Duever, 2019).

The Watershed Hydrologic Modeling project includes the compilation of existing meteorological, surface and groundwater hydrologic-hydraulic data into a GIS-interfaced database specific to the model, mapping of historic land use, evaluation of ecologic conditions in wetlands, updating an integrated surface/ground water model of the project area with newly collected data, calibrating the model, and conducting model simulations of existing conditions and alternative scenarios to better understand the key factors that may be impacting wetland hydroperiods within the Sanctuary. The scenario analysis is intended to provide a direction for future analyses and formulation of restoration plans to improve wetland hydroperiods within this unique ecologic resource, which is recognized as a Wetland of Distinction (Society of Wetland Scientists) and a wetland of international importance (Ramsar Convention).

The model has been updated, calibrated, validated, and compared to vegetation indicators of ecologic condition. The updated and calibrated model was used to evaluate four scenarios, summarized below to evaluate factors that may be contributing to the decreased hydroperiods of the Sanctuary. The scenarios are not intended to necessarily represent a real proposed condition but to facilitate estimation of the level of effect each of the modeled elements is having on hydroperiods in and surrounding the Sanctuary. The four modeled scenarios included:

1. Reduction of groundwater withdrawals from agricultural and public water supply wells;
2. Elimination of willow and reduced density of mesic and hydric flatwoods;
3. Elimination of simulated downstream drainage infrastructure; and
4. Addition of weirs and clay slurry cutoff walls to reduce discharges from the Sanctuary.

The analysis of the first three model scenarios determined that elimination of downstream drainage infrastructure (Scenario 3) resulted in the greatest increase in the Sanctuary wetland hydroperiods. Scenarios 1 and 2 showed much smaller impacts that were limited in area, magnitude, and/or season. Because the application model scenarios 1 through 3 in the real world is not necessarily feasible, Scenario 4 was developed using reasonable restoration measures to reduce discharges from the Sanctuary and restore wetland hydroperiod to approach that of the 1960s. Further refinement of Scenario 4 is recommended for further consideration and analysis.

Through this project, topographic data obtained from LiDAR sources was found to be inaccurate in the Sanctuary and Bird Rookery Swamp (located due south of the Sanctuary). Traditional survey transects are recommended to address the inaccurate topographic information. This study also recommends the installation of additional monitoring stations to assist in future model calibration efforts and long-term assessment of hydrologic trends for this wetland conservation region.

1.0 PROJECT BACKGROUND

Water Science Associates was contracted by the National Audubon Society (Audubon Florida) to develop a hydrologic model to assist Audubon in understanding factors that have led to decreased wetland hydroperiods and resultant functions of the unique ecology of the Corkscrew Swamp Sanctuary (hereinafter referred to as the Sanctuary). The Sanctuary is an ecologic relic of Old Florida and protects the largest remaining old-growth bald cypress swamp in the world. A 60-year record of daily water level measurements has revealed changes in Corkscrew Swamp's hydrology as agricultural and residential development have grown to dominate the landscape surrounding the Sanctuary. Hydroperiods in the Sanctuary have been reduced by 29 percent in marshes and by 18 percent in old-growth bald cypress habitats from the 1960s to 2010s, with the most marked change occurring between the 1990s and 2000s (Clem and Duever, 2019).

The Watershed Hydrologic Modeling project includes compilation of existing meteorological, surface and groundwater hydrologic- hydraulic data into a GIS-interfaced database specific to the model, mapping of historic land use, evaluation of ecologic conditions in wetlands, updating an integrated surface/ground water model of the project area, calibrating the model, and conducting simulations of existing conditions and various alternative scenarios to better understand the key hydrologic and land use factors in the watershed that may be impacting wetland hydroperiods in the Sanctuary. The scenario analysis is intended to provide direction for future analyses and formulation of restoration plans to improve wetland hydroperiods and resulting ecologic function within this unique ecologic resource, which is recognized as a Wetland of Distinction (Society of Wetland Scientists) and a wetland of international importance (Ramsar Convention).

This report describes Existing Conditions Model Development, Model Calibration, Comparison to Ecological Indicators, and Scenario Analysis. Details are provided on the data collected for the model, information obtained from prior modeling efforts, enhancements of model input files, existing conditions model development, and field investigations to gather ecologic and natural water level indicators. Modifications to input data used in the model during the calibration process are also discussed. Four scenarios were developed and simulation results for the four scenarios were compared to existing conditions simulation results.

2.0 DESCRIPTION OF EXISTING CONDITIONS MODEL INPUT FILES

The MIKE SHE/MIKE 11 integrated surface/ground water model (version 2020) developed for this project evolved from the earlier formulations of the Corkscrew watershed included in the regional/subregional models of the Southern Lee County, Big Cypress Basin, Village of Estero, and Edison Farms stormwater plans. A summary of the most recent information of the databases and modeling files adapted for the Corkscrew Swamp Sanctuary project utilized from those studies are listed in **Table 1**. Changes to data sources used and the modifications to various model elements made based on those data are also provided below.

Table 2.1 – Sources of Information Used for Hydrologic Modeling

Study	Project Summary
Village of Estero Stormwater Management Plan, 2017	Utilized South Lee County Watershed Plan Update Model (2008) and updated all files through 2014, and surveyed cross sections were obtained for North and South Branches of Estero River. Calibrated for 2013 – 2014 with focus on Estero River North and South Branch and Halfway Creek. Model results were compared to Hurricane Irma with minor adjustments to calibration based on Irma measurements
Edison Farms, 2019	Utilized Village of Estero Model, improved hydrogeologic representation of Bonita Springs Marl and Lower Tamiami aquifer, calibrated for 2013 – 2014, with focus on Edison Farms. Additional information was obtained for channels north and south of Edison Farms, and surveyed cross sections were obtained conveyances leaving Edison Farms. Irrigation of agricultural areas was improved by reviewing permit files and comparing simulated to reported irrigation rates. Willow was added as a vegetation class using information provided by Audubon.
Flood Protection Level of Service for Big Cypress Basin, 2017	Model files developed for stormwater management planning in Golden Gate, Cocohatchee, Henderson-Belle Meade, and Faka Union Watersheds. Model files included detailed channel information for the Corkscrew Canal watershed north of Cocohatchee Canal upstream of Coco #4 and north of Immokalee Road. The model was calibration for Sept. 2013, Oct-Nov, 2011, and verified with Aug-Sept, 2008.

2.1 Model Domain and Grid

The model domain is shown below in **Figure 2.1**. The model grid spacing was reduced from 750 feet in the most recent MIKESHE models of the region to 375 feet, which increases the grid density by a factor of 4. The model utilizes measured canal stage data of the Faka Union, Golden Gate and Corkscrew Canals at FU-6, GOLDW5, GOLD.846, respectively and also at the water control structures in the Cocohatchee Canal. A tidal boundary was used for the mouth of the Imperial River, and measured data were used for Halfway Creek and the South Branch of the Estero River.

The 375-foot model grid size was selected based on a number of considerations. Previous models for the South Lee County area have grid cell size of 750 feet. Dividing the cell size by two is a way for the new higher-resolution grid to be aligned with the grid from previous models. A nested grid facilitates the use of previous conceptualizations, as well as results from previous models. On the other hand, the spatial resolution is limited by the run time, which needs to be reasonable. The Sanctuary model domain area is smaller than one of the predecessor models (the Edison Farms) which had a cell size of 750 feet. The selected cell size allows for more accurate representation of topographic differences within smaller isolated wetlands and still has manageable run times. The objective of this project was to have the highest spatial resolution possible in order to have more accurate spatial representations in general, and in particular, to better compute sheet flow in wetland areas.

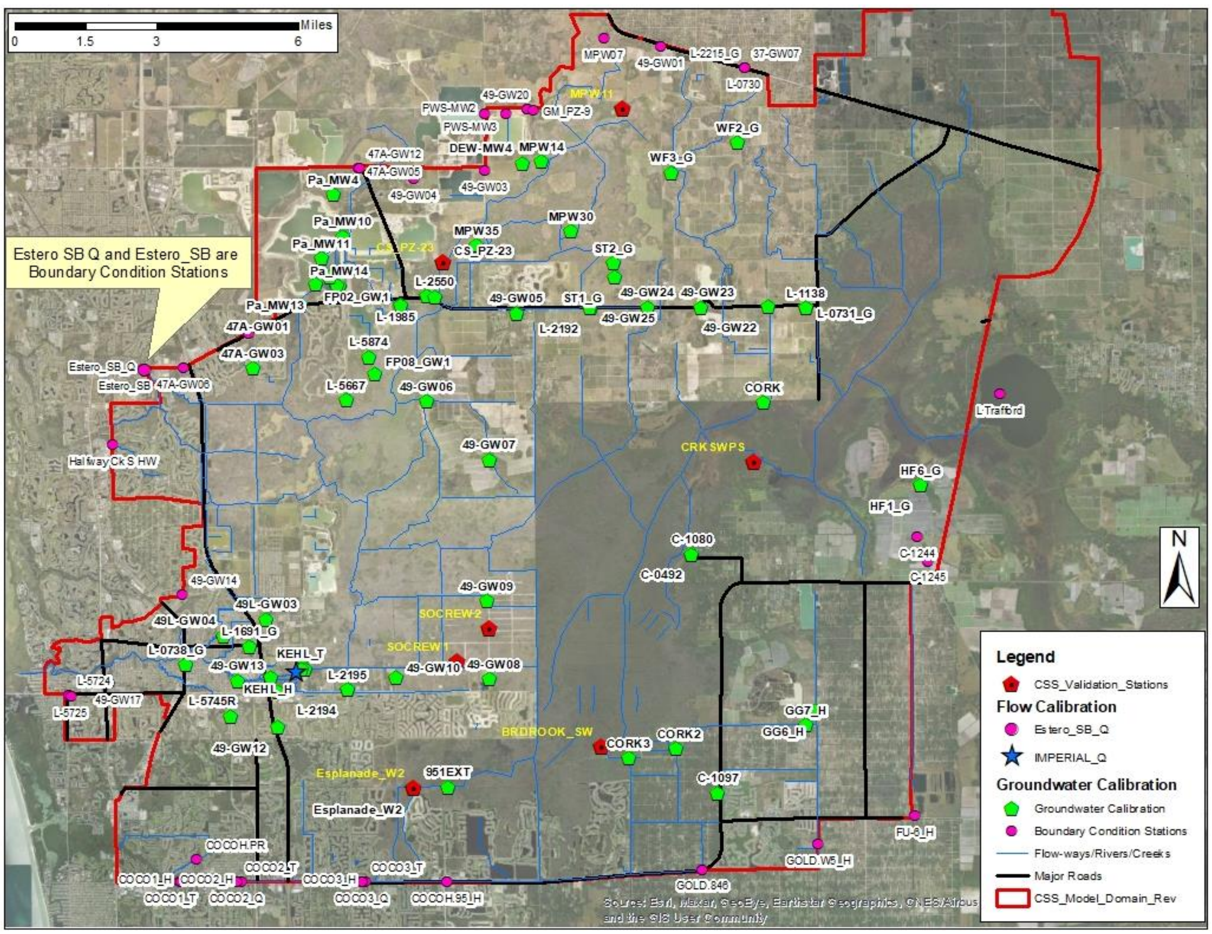
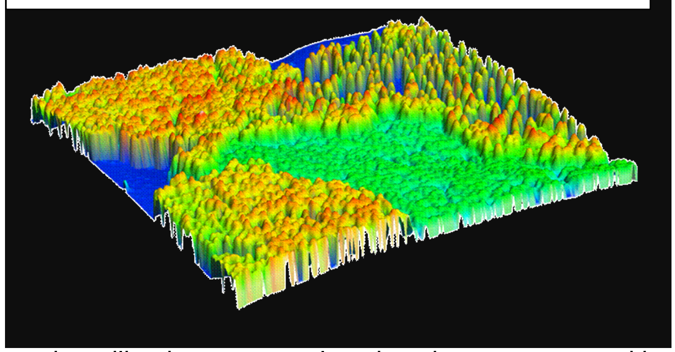


Figure 2.1 – Modeling Domain for the Corkscrew Swamp Sanctuary Model

2.2 Topographic Data

Topographic data for the model was primarily adapted from the one-meter resolution 2018 bare-earth LiDAR data from the U.S. Geological Survey (USGS) supplemented by the 50-foot grid South Florida Water Management District (SFWMD) data using the cell center value. USGS 2018 LiDAR data were not available for a portion (less than 5 percent) of the northeast model domain, and this portion of the model domain was filled with SFWMD 50-foot data published in 2015. The composite map was then re-sampled to a 375-foot grid using an area-weighted average method. In cells classified as water, which are primarily mining pits or lakes within residential areas, the topographic elevations were approximated by lowering the LiDAR elevations by 3 feet. All of these water features have water depths in excess of 3 feet. This topographic adjustment was made to correct the LiDAR data, which cannot penetrate water, thereby making the LiDAR data inaccurate for areas of standing water. Lowering the elevation allows the model to properly simulate ponded-water processes such as evaporation and surface water flows.

Figure 2.2–Vegetation and Water Challenges with LiDAR



During the model calibration, maps of simulated average wet season water depths and wetland hydroperiods revealed some accuracy issues with the topographic data. A number of elevation discontinuities were discovered due to problems inherent in the 2018 LiDAR data. LiDAR cannot detect the ground elevation in flooded areas and raw LiDAR data includes elevations of tree branches in densely-forested areas (see **Figure 2.2**). It is possible to filter out these anomalies if numerous known ground elevations are available during the processing of the raw LiDAR data. Known ground elevations can be utilized to remove elevation signatures caused by vegetation from the database which improves the quality of the LiDAR data. Correcting for flooded areas is more of a challenge that can be overcome if surveyed cross sections are available in the flooded area. It appears that the processing of the raw data from the 2018 LiDAR database shown in **Figure 2.3** was not able to correct for the data anomalies. As a result, additional effort was expended to improve the quality of the topographic data.

Figure 2.4 illustrates some of the elevation discontinuities in the 2018 LiDAR data and **Figure 2.5** presents a composite topographic map that was created to address the problems with the LiDAR data. Data from a 2007 LiDAR file were compared to the 2018 LiDAR data for wetland areas within the model domain. Elevation differences less than one foot were identified at a 50-foot resolution, and the lower elevations were selected. The justification for this adjustment of the topographic data set is that some wetlands in Corkscrew Swamp have inundation for more than 10 months of the year, which can lead to inaccurate elevations.

Another data source that was identified late in the calibration effort was a topographic file that was compiled by Tim Liebermann of SFWMD from 2007 LiDAR data. That file was not significantly different from the merged file described above and also exhibited numerous linear elevation discontinuities. Our evaluation indicated that all elevation data sources have data quality issues and that more accurate topography data are needed for the model domain. While topographic data quality issues remain, the modeling team was able to adequately calibrate the model for the intended project purposes. In future modeling efforts, we recommend ground-level surveying during the model development phase so that predictions of changes in water depths and hydroperiod are represented more accurately.

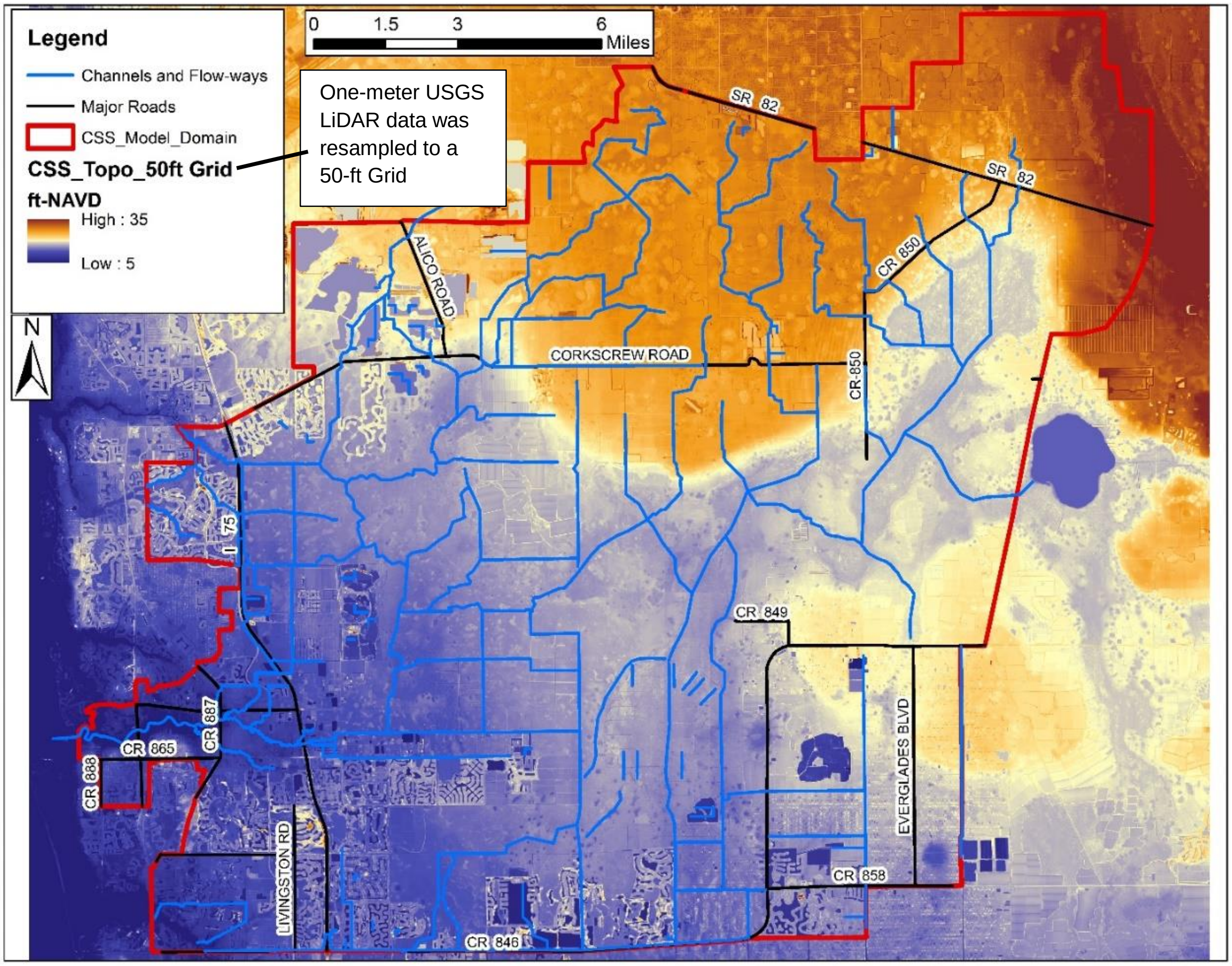


Figure 2.3 – Topography for the Corkscrew Swamp Sanctuary Model

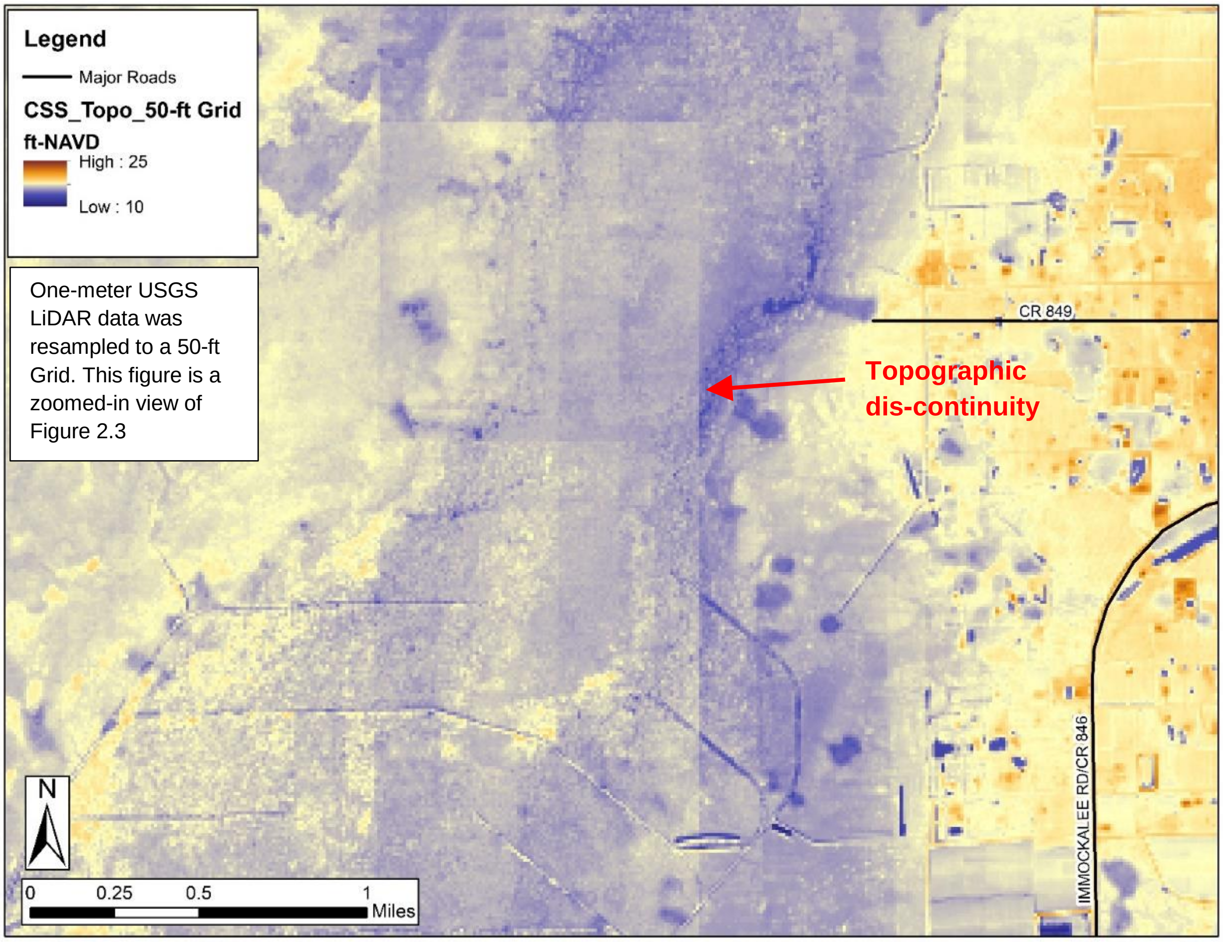


Figure 2.4 – Topographic Discontinuities in 2018 LiDAR

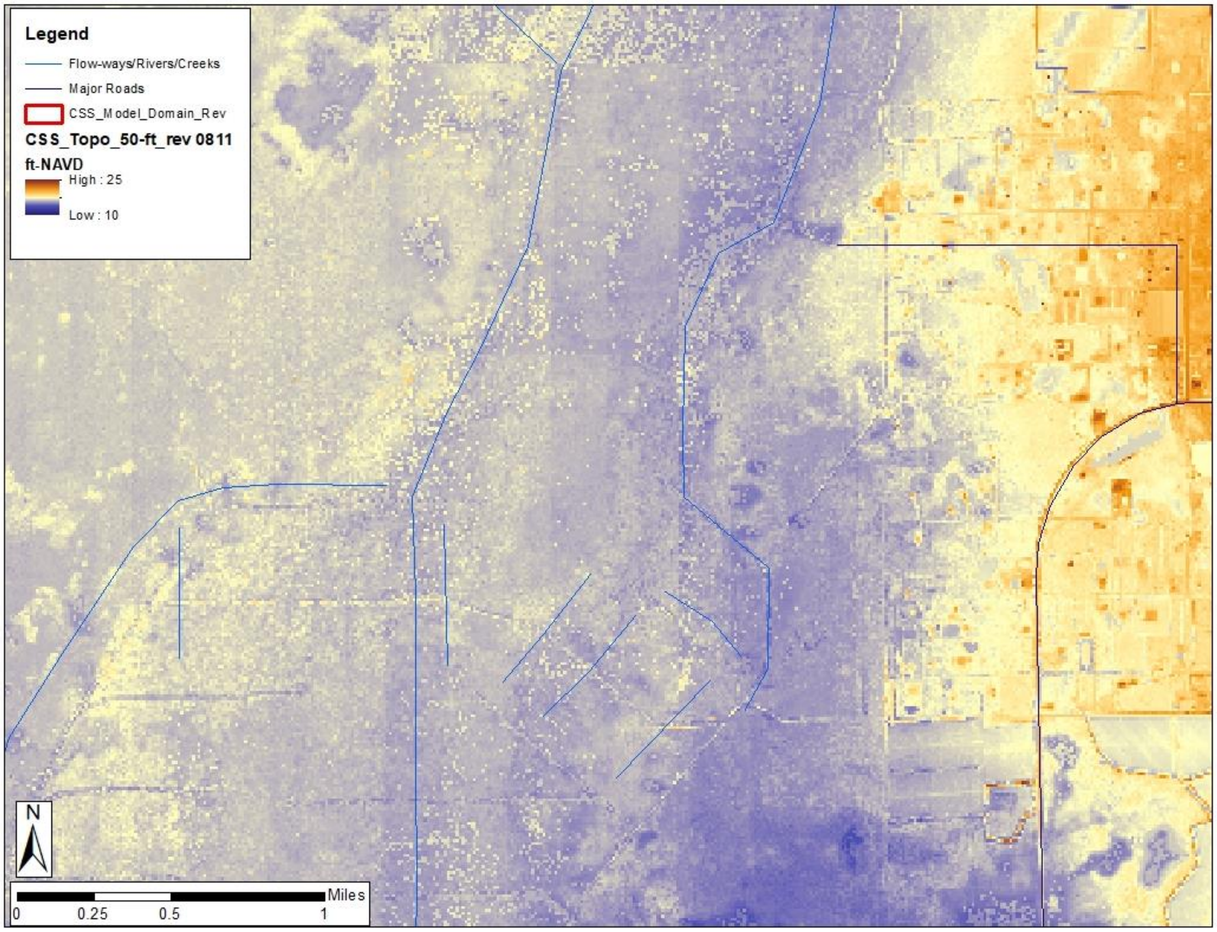


Figure 2.5 – Revised Topography Indicating Fewer Discontinuities

2.3 Climate Data

Hourly NEXRAD rainfall data were received from SFWMD and converted to "dfs0" files to be used in the model. Rainfall files were created for the period 1/1/96 through 12/31/19. Distributed daily reference evapotranspiration data were obtained from the USGS for the period from 1985 through 2018. Data quality in NEXRAD during prior to the mid-2000s was less than desired. Since the calibration and validation period for this modeling effort was 2013 through 2018, the issues with data accuracy of early NEXRAD data are not relevant to the calibration effort of this project. ET dfs0 files were extended for years 2019 and 2020 by calculating the Julian-day average for the period of record.

2.4 Land Use Data

Land use files representing 2016 were obtained from SFWMD GIS database. Corkscrew Swamp willow coverage developed by Audubon was substituted for the land cover type in the SFWMD land use file where applicable. The SFWMD land use file includes 109 FLUCCS codes, and the MIKE SHE model has 20 land use categories, not including willow. The crosswalk table used to condense the SFWMD land use coverages to the MIKE SHE land use categories is presented in **Attachment 1**. The land use categories that are used in the model are shown graphically in **Figure 2.6** and are described in **Table 2**. Irrigation command areas (where each area represents an agricultural water use permit) were taken from the Edison Farms model, as shown in **Figure 2.7.**

MIKE SHE allows for the use of separated overland flow areas to represent constraints to overland flow, such as I-75, Corkscrew Road, or a berm surrounding a permitted farm area. Overland flow is not allowed to cross these boundaries; therefore MIKE 11 is used to convey flows through these boundaries via culverts or other water management features. The separated overland flow area file was created using files from the Edison Farm model, water use permit information from the SFWMD, and ICPR sub-basins in the Bonita Springs model (see **Figure 2.8**). The separated overland flow area file was modified during calibration to represent above-ground impoundments south of Corkscrew Road (6 L's Farm and OCP) represented in **Figure 2.8** with a yellow star. In addition, a separated flow area was added north of Kehl Canal to more properly represent the impact of Terry Street on overland flow south to Kehl Canal. This change required modifications to the MIKE 11 network that are described below (see subsection **MIKE 11**). Overland flow Manning's n coefficient values are listed in **Table 2.2**.

The high resistance coefficient used in water cells was established based on calibration efforts in multiple prior models. The selected Manning's n coefficient of 0.5 for water cells avoids small OL time steps, longer runtimes, and potential numerical instabilities. In water-classified cells, the water depth is much higher than in other cells where sheet flows would occur so that even with the higher resistance, the water level at water cells would be much flatter than in other sheet flow cells. The effect of using a higher resistance in water cells on the model results is expected to be negligible.

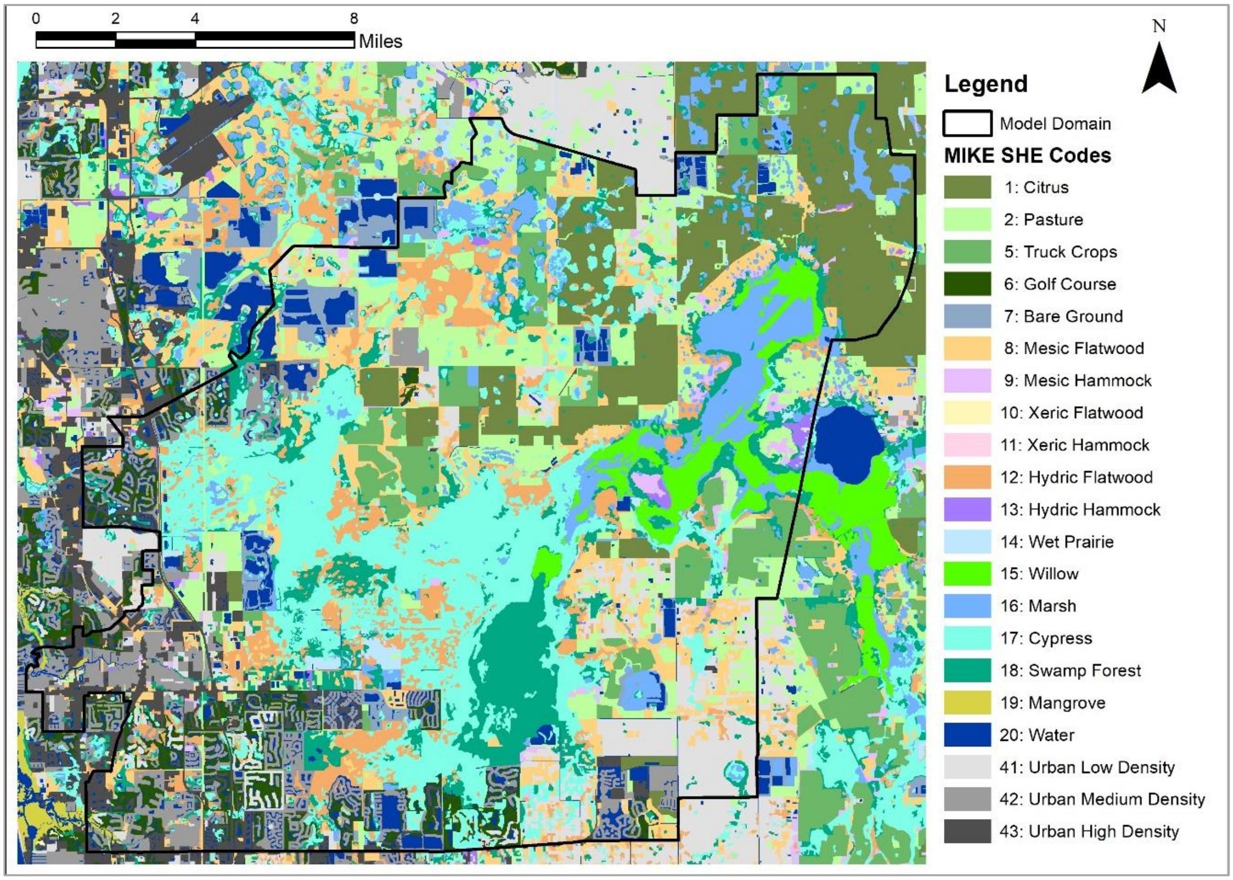


Figure 2.6 – Land Use for the CSS Model

Table 2.2 – Cross Reference Table for MIKE SHE and SFWMD Land Use Codes and Manning's n Overland Flow Roughness Coefficient

Code	MIKE SHE Label	Land Use FLUCCS Code	Manning's n
1	Citrus	2210, 2230	0.17
2	Pasture	1920, 2110, 2120, 2130, 2240, 2510, 2610, 3100, 8320	0.14
5	Truck Crops	2140, 2150, 2500	0.17
6	Golf Course	1820	0.14
7	Bare Ground	1610, 1620, 1630, 1670, 1810, 7200, 7400, 8350	0.09
8	Mesic Flatwood	1900, 2430, 3200, 3210, 3300, 4110, 4410, 4430, 7470	0.20
9	Mesic Hammock	4200, 4220, 4271, 4300, 4340	0.30
10	Xeric Flatwood	4130	0.17
11	Xeric Hammock	3220	0.20
12	Hydric Flatwood	6240, 6250	0.25
13	Hydric Hammock	4240, 4280, 6180, 7430	0.40
14	Wet Prairie	6430	0.30
15	Willow	File from Corkscrew Swamp Sanctuary	0.43
16	Marsh	6400, 6410, 6440	0.43
17	Cypress	6200, 6210, 6215, 6216	0.30
18	Swamp Forest	6170, 6172, 6191, 6300	0.40
19	Mangrove	6120, 6420	0.20
20	Water	1660, 1840, 2540, 5110, 5120, 5200, 5300, 5410, 5720, 6510	0.50
41	Urban Low Density	1110, 1120, 1130, 1180, 1190, 1480, 1850, 1860, 1890	0.14
42	Urban Medium Density	1210, 1220, 1230, 1290, 8330, 8340	0.12

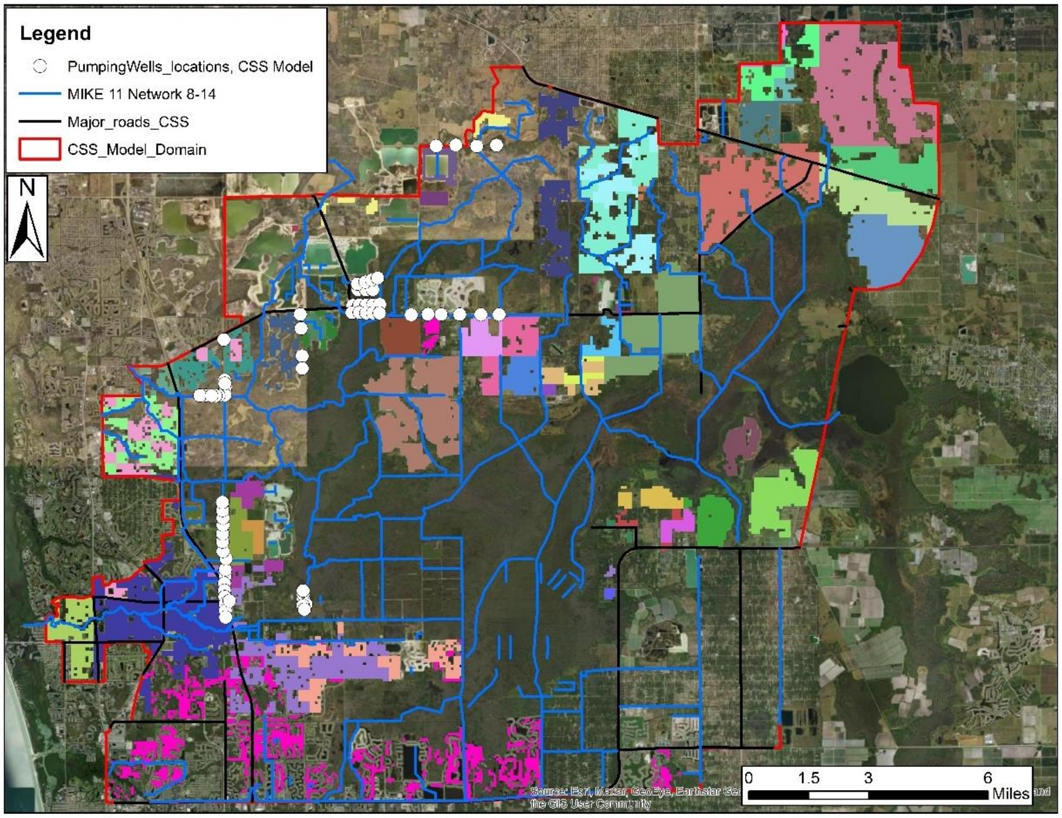


Figure 2.7 – Irrigation Areas and Public Supply Wells for the CSS Model

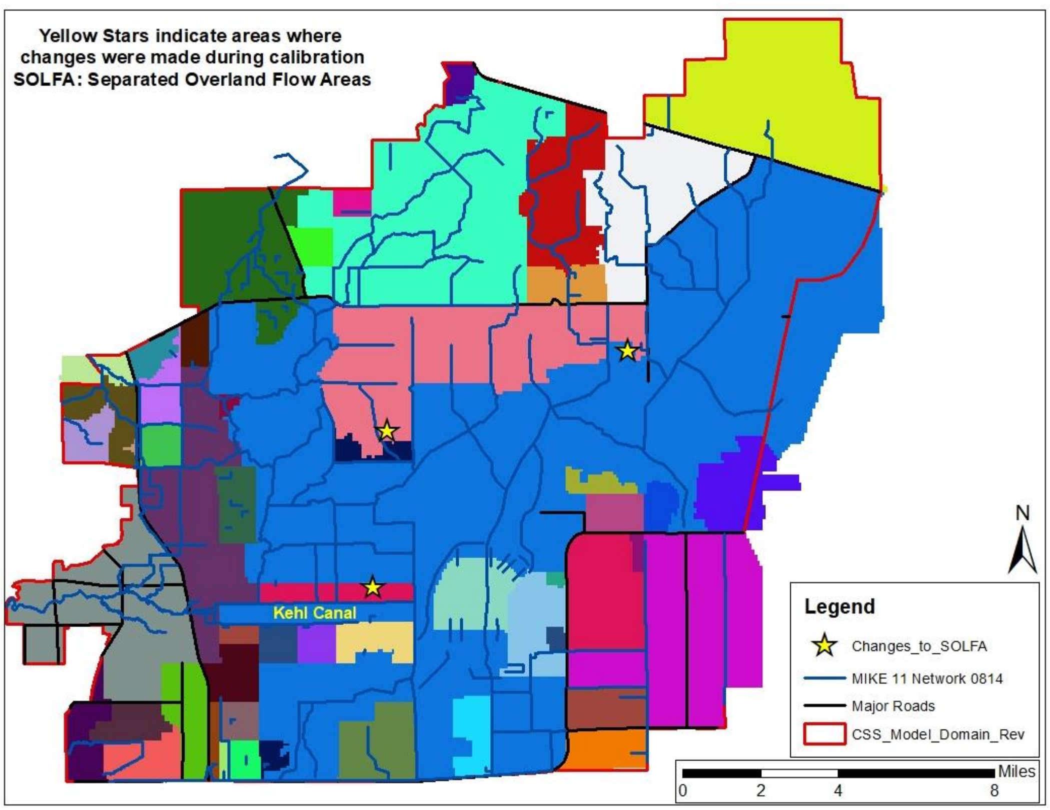


Figure 2.8 – Overland Flow Separated Flow Area

2.5 Soils Information

MIKE SHE represents water movement in the unsaturated zone through a variety of approaches, such as infiltration using the Green-Ampt equations and infiltration using soil profile definitions. The model handles infiltration through the unsaturated soil horizons for conditions where the groundwater table is lower than the ground surface elevation. The soil profiles used in the model range from Immokalee sand to Sanibel muck, as shown in **Figure 2.9**. Most of the MIKE SHE models for the west coast of South Florida use the soil classification and parameters that were first established for the regional MIKE SHE model developed during the South West Florida Feasibility Study (SWFFS). The soil classification was based on the predevelopment vegetation map prepared by the SFWMD in 2003 to represent the conditions of the SWFFS area. This approach was adopted in subsequent MIKE SHE models for smaller areas such as the DRGR, Village of Estero, Edison Farm, BCB, ECWCD, and C-43 models.

Each soil profile type has multiple zones, each with a defined thickness, a moisture retention curve, and hydraulic conductivity parameters based on equations developed by Averjanov (see MIKE SHE/MIKE 11 User's Manual for additional details). The Sanibel muck is the dominant soil type for the majority of Corkscrew Swamp. The initial model set-up has the thickness of the top horizon of the Sanibel soil profile set as 0.4 feet of muck with four layers of sand below the muck layer to a depth of 2.2 feet. A listing of the soil types and thicknesses is summarized in **Attachment 2**.

2.6 Geologic Layers

Geologic layer definitions were taken from the Edison Farm model. Those files were based on the most recent Hydro-stratigraphy data used in the SFWMD Lower West Coast Water Supply Plan studies, with additional details on the thickness and extent of underlying confining beds provided from local well data. Water Science Associates information was obtained from studies conducted for a number of projects, including the Bonita Springs Utilities, Pinewoods wellfields, and nearby investigations. That information was used to refine the extent and thickness of the Bonita Springs marl. In addition, the thickness of the water table aquifer was revised utilizing this information. Note that in areas where the Bonita Springs marl is absent, the water table aquifer is comprised of a combination of sandy deposits overlying highly transmissive limestones of both the Water Table Aquifer and the unconfined Lower Tamiami aquifer.

Aquifer hydraulic conductivity values were adjusted in the model calibration process to improve calibration statistics. Conductivities were increased and decreased during iterative simulations and statistical performance measures were used to determine the direction of conductivity change at each station. Conductivity values were increased or decreased in the vicinity of a calibration station if that change yielded improved calibration performance. Hydraulic conductivity values for the final calibration are presented in **Attachment 3**.

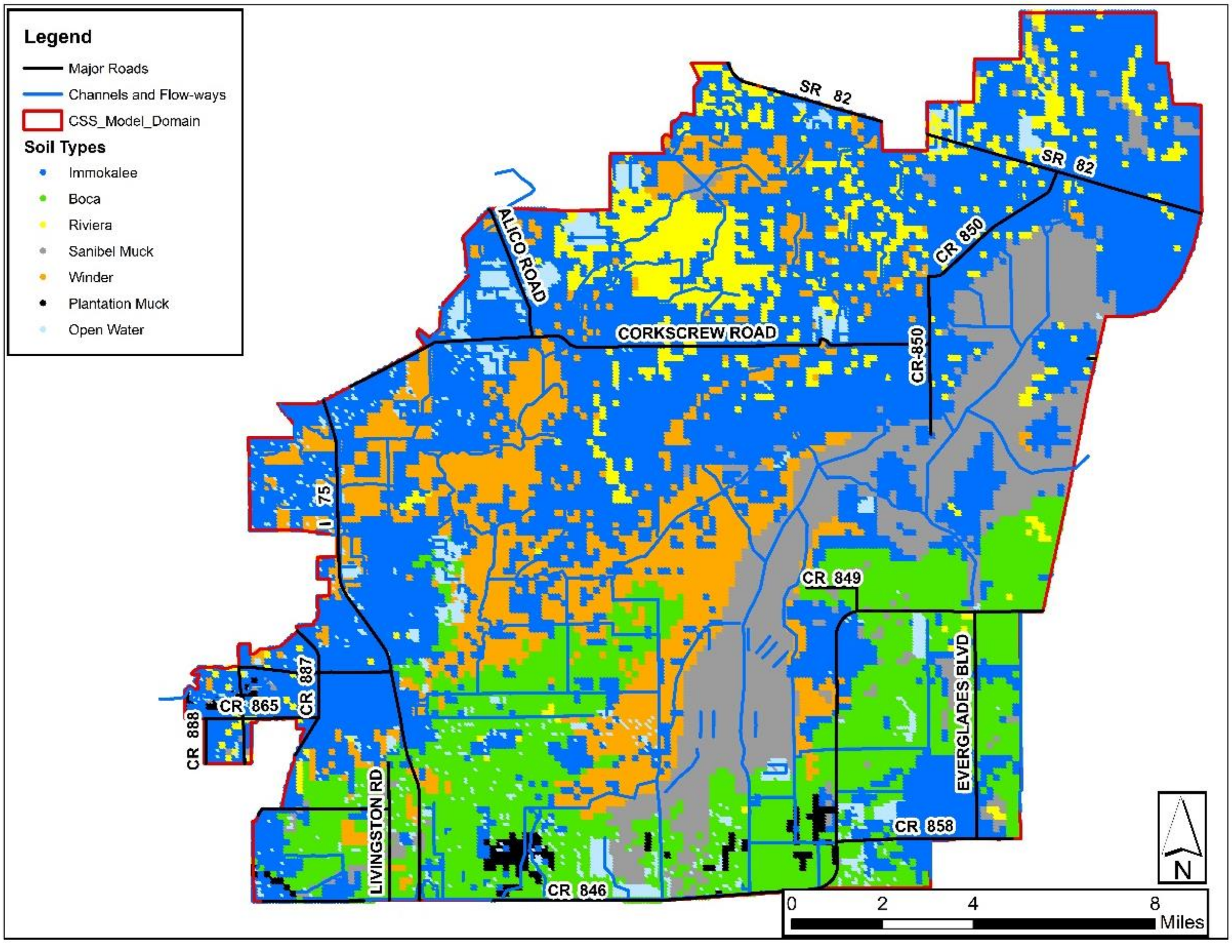


Figure 2.9 – Soil Delineations for the CSS Model

2.7 Groundwater Withdrawals

Public Water Supply. Public water supply wells in the model domain are included in the MIKE SHE model. Well locations (see **Figure 2.7**) and screening intervals were adopted from previous MIKE SHE models. The dfs0 files with the historic monthly pumping extraction rates at each well were updated from the District reported pumping up through year 2018. From years 2019 on, there are no data available, and the 2018 pumping rates are assumed.

Agricultural Irrigation. Irrigation of agricultural lands is permitted by SFWMD, and pumped irrigation deliveries to the farm fields is reported to SFWMD. Water Science Associates has reviewed permit files for agricultural lands near to the Sanctuary and has tabulated reported flows for 2013 – 2014 and for 2018. An irrigation command area (ICA) was created for each permitted farm, and the ICA extent was obtained from a SFWMD water use permit shape file. Non-agricultural land within each farm polygon was removed from the ICA coverage. Irrigation for each ICA is specified to be as close as possible to the permitted water source, application type, and pumpage rate for each permitted farm (e.g. farm XYZ is permitted to pump X MGD from the Sandstone aquifer with wells screened from A to B depths below land surface; water applied by microjet). Irrigation rates, type, and aquifer information was obtained from the permit. The model calculates soil moisture deficits for each cell and the model simulation irrigates model cells to satisfy a defined percentage of that moisture deficit. These model processes result in simulated irrigation for the agricultural lands defined in the model.

The irrigation rates, application method, aquifer depths, and ICA coverage were taken from prior modeling efforts (Village of Estero and Edison Farms models) and were checked against permit files, and revisions were made as necessary. Reported irrigation flows were compared to simulated irrigation at 8 different farms, and the average simulated irrigation was approximately 80 percent of reported pumpage.

Drainage. Previous MIKE SHE models for the area used the empirical drainage component to represent the drainage from agricultural and urban areas. This model component is one of the few empirical components in MIKE SHE. It is used to represent the impact of agricultural canals and roadside ditches that are typically not included in the MIKE 11 network of a large model domain (in this case 290 square miles). The drainage component is therefore used to convey runoff from ditches not included in the MIKE 11 network. The drainage component is part of the geologic portion of the model set-up because this component routes shallow groundwater to the MIKE 11 network.

A drainage depth is specified for developed lands, and any water accumulating within that depth below ground is routed to the nearest MIKE 11 branch or a local depression. In the Sanctuary model, the drain code map was adopted initially from previous models and refined based on the 375-foot resolution land use and the local knowledge. A drainage option map was also created to route the drainage to specific MIKE11 branches. Drain level and time constant parameter maps are correlated to the land use maps. Minor changes in drainage level and time constant values were made to improve the representation of farm drainage for selected farm areas. A drainage level of 3 feet below ground and a drainage time constant of 2 days was selected for one area of the model near Corkscrew Road and the drainage was routed to above ground impoundments that were added to the MIKE 11 network. **Figure 2.10** presents the drainage levels used in the calibrated model, **Figure 2.11** illustrates the drainage time constants, and **Figure 2.12** illustrates drain code values.

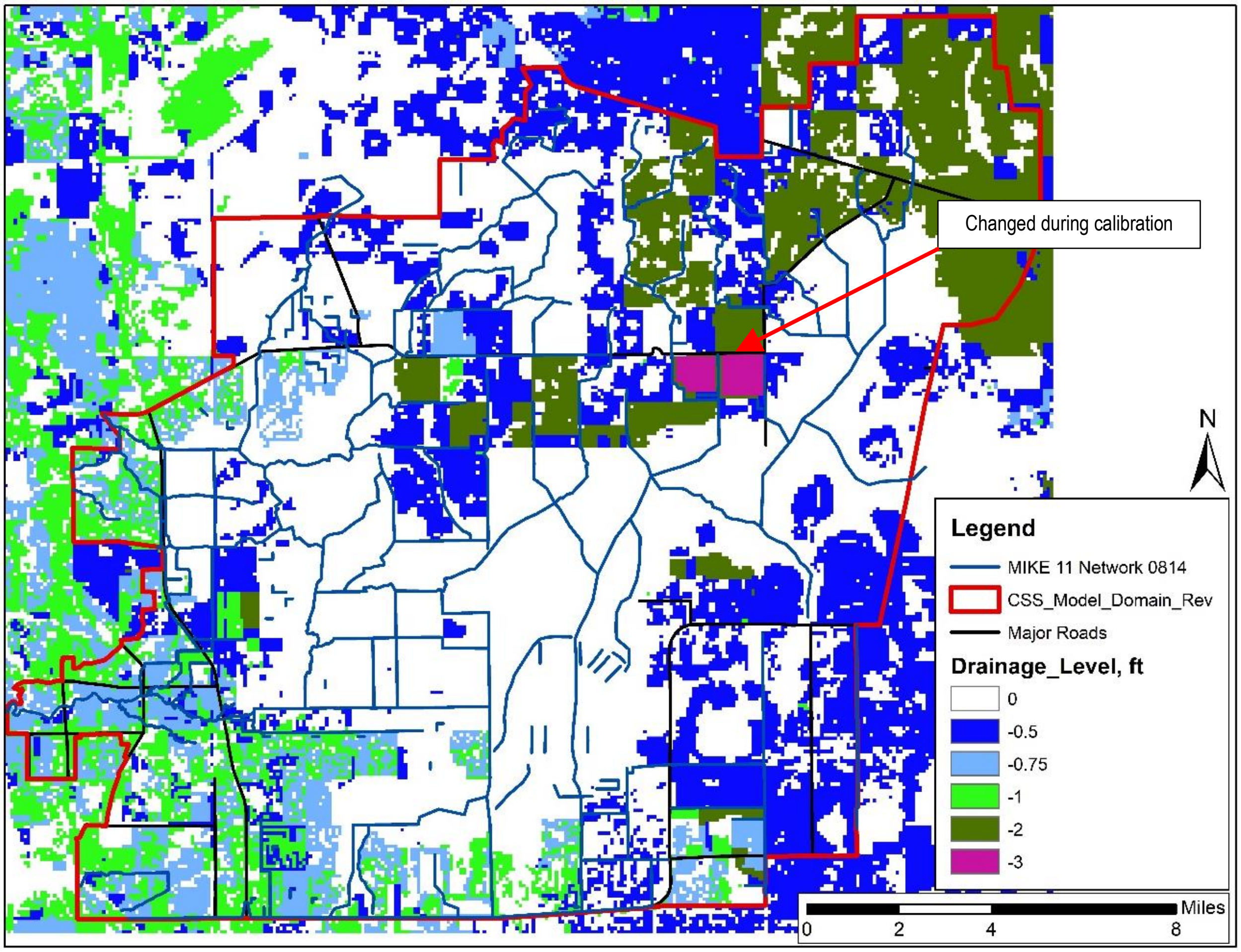


Figure 2.10 – Drainage Levels Used in Calibrated Model (Color Scale Represents Drainage Level Depth in Feet)

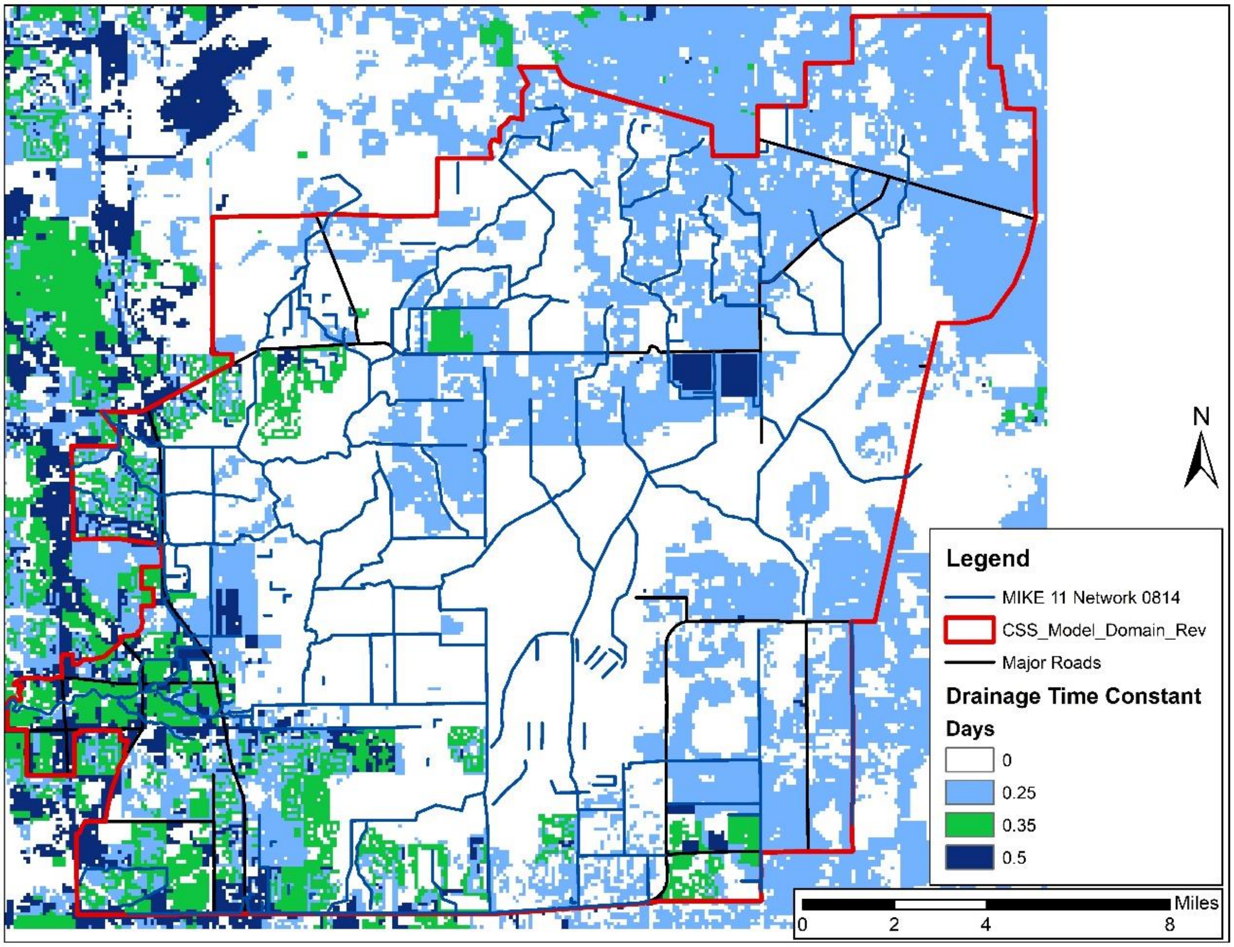


Figure 2.11 – Drainage Time Constants Used in Calibrated Model

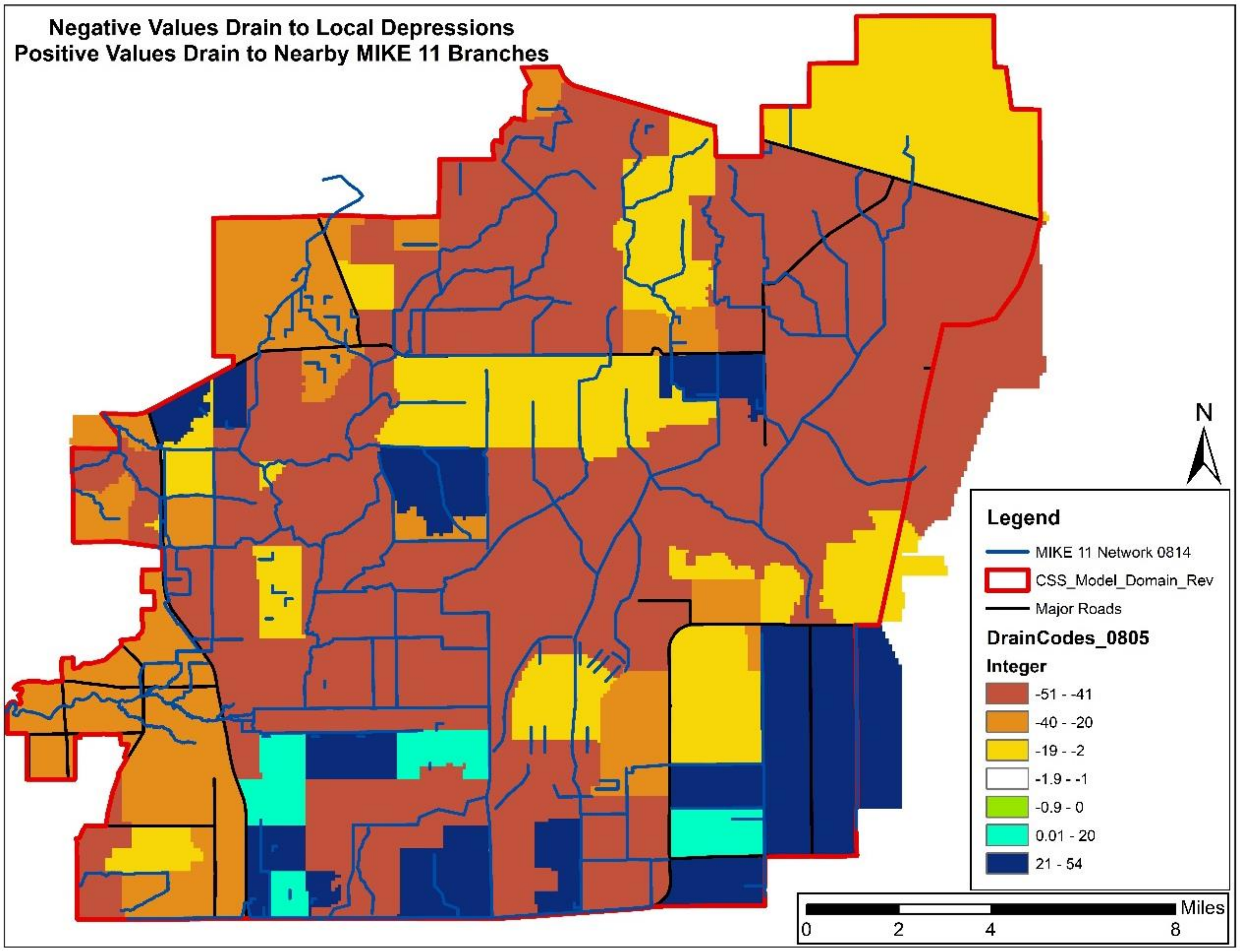


Figure 2.12 – Drainage Codes Used in the Calibrated Model

2.8 Mike 11 Set-up

Information for 1-D hydraulic routing of flow through channels or flowways by MIKE 11 was taken from the latest available models, such as the BCB Level of Service model and the Edison Farms model. Field visits were conducted to confirm the structures included in the BCB model and for portions of the Edison Farms model where Google Earth images indicated the presence of hydraulic control structures. A number of changes were made to the model where more detailed information was obtained. The changes are described below with locations indicated in **Figure 2.13**:

- Details in the Corkscrew Canal area were taken from the BCB model and were modified based on engineering plans for the Corkscrew Canal Improvement Plan (SFWMD, 2004). Corkscrew Canal cross sections were modified to represent increased width and depth based on engineering plans obtained for SFWMD Contract CN040113 (see point **1** on **Figure 2.13**).
- The 2004 Corkscrew Canal Improvement Plan implemented removal of culverts and installed bridges for Corkscrew Canal road crossings at 41st Ave NW, 39th Ave NW, 37th Ave NW, 35th Ave NW, and 33rd Ave NW. These bridges span the full width of the widened and deepened Corkscrew Canal. The model files were modified to reflect these changes. .
- Digital copies of paper records for gate operations of Cork 2 and Cork 3 (see **Figure 2.13**) were obtained A digital time series file of reported gate operations was created for each structure to augment DBHYDRO gate operation records that cover the period from July 2018 through present. In some cases, the paper records were incomplete (e.g. Cork 2 was opened to 0.5 feet on June 7,

2016 and the next record was on 8/10 to change the position from 1 to 1.5 feet). In these instances, the modeling team assumed dates when the gate levels were changed.

- A new MIKE 11 branch was added to represent a drainage ditch from the Bird Rookery Swamp (BRS) parking lot on the west end of Shady Hollow Blvd. to Cork 3 (point **2** on **Figure 2.13**). A weir was added to the MIKE 11 branch to represent gaps in the north berm of this ditch and a field visit indicated the presence of a culvert under that berm, which was added to the model just upstream of Cork 3.
- MIKE 11 flow pathways in the vicinity of Edison Farms were modified in the Edison Farms model based on surveying conducted by Mitigation Resources, Inc., as part of the Edison Farms hydrologic restoration effort led by EcoPlanz and that information was included in this assessment (see point **3**, **4**, and **5** on **Figure 2.13**).
- Early calibration results for the Imperial River indicated that simulated flows were less than measured flows. A detailed review of topography along Terry Street east of Bonita Grande Drive (see point **6** on **Figure 13**) indicated a breach of Terry Street and a flow pathway south to Kehl Canal. Field visits confirmed the location of the breach and a cross section of the breach was developed based on field measurements. In addition, a branch was added to represent a canal labeled Terry_Ditch_N. **Figure 2.14** illustrates these additions. These changes provided a flow pathway to represent observed flow patterns and improved calibration for Kehl Canal and the Imperial River.
- A field visit confirmed that the South Dike of Corkscrew Swamp Sanctuary does not have culverts east of the BRS hiking/biking trails (point **7** on **Figure 13**). The road elevation at the low point between Immokalee Road and the BRS hiking trails is more than 4 feet above natural ground elevations and topographic information suggests that flows are directed west towards the BRS wooden bridge. Accordingly, the MIKE 11 Branch from point 7 was routed to the wooden bridge (see point **8** on **Figure 2.13**).
- SFWMD permitting staff from the Fort Myers office provided information on a drainage canal in the 6 L's Farm (point **9** on **Figure 2.13**) that has a pump station which conveys agricultural drainage to wetlands south of the farmed lands. That canal and pump station were added to the model.
- Two above-ground impoundments were added to the model to better represent the routing of water from citrus operations on the eastern extent of Corkscrew Road (points **10** and **11** on **Figure 2.13**).

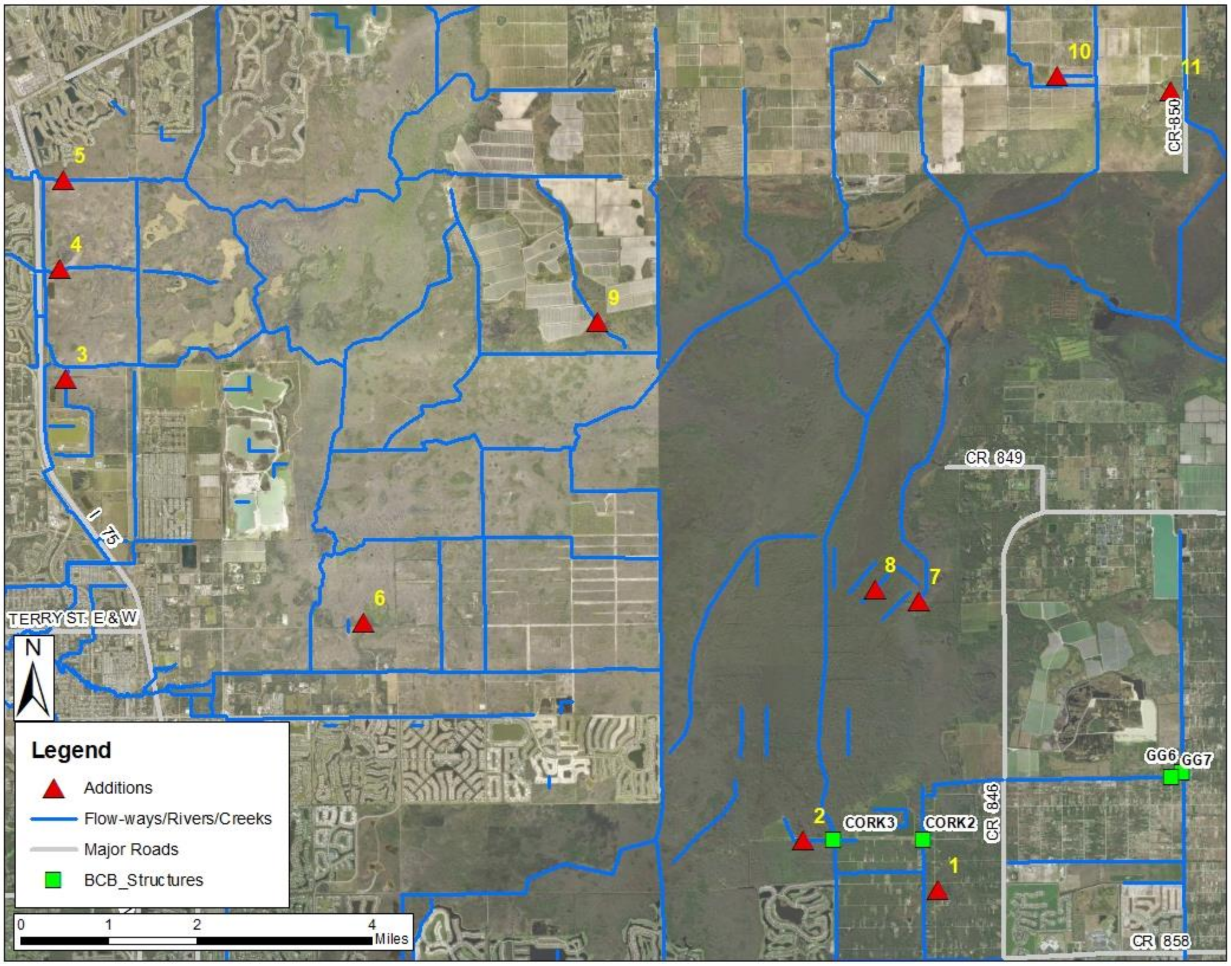


Figure 2.13 – Locations of MIKE 11 Improvements

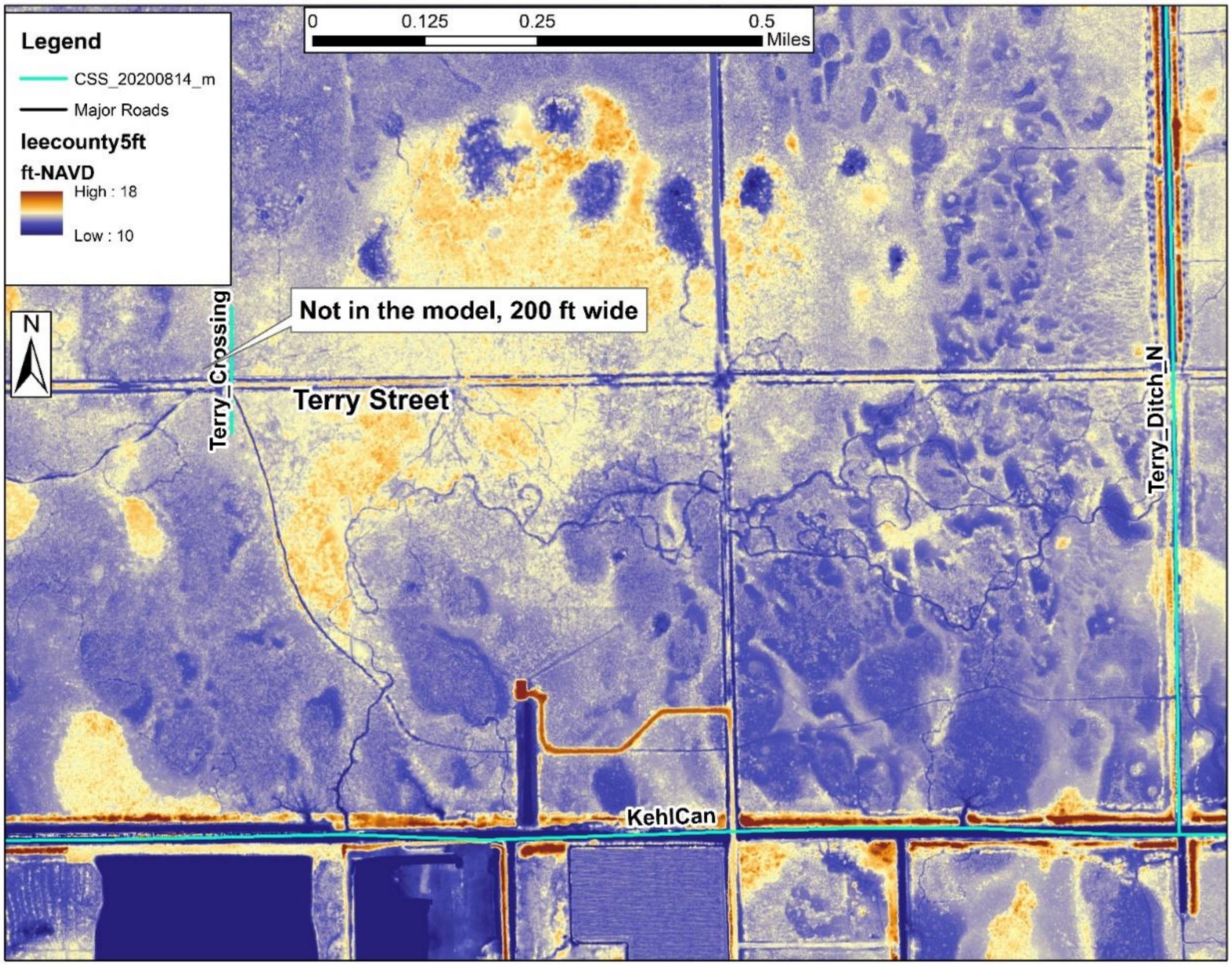


Figure 2.14 – Canal Improvements north of Kehl Canal (this location is point 6 in Figure 13)

3.0 MODEL CALIBRATION AND VALIDATION

3.1 Model Calibration

The model was calibrated for the 2013 – 2014 period with the objective of matching or exceeding calibration statistics of the prior modeling efforts. The 2013 – 2014 calibration period was selected for a number of reasons. First, 2013 was very wet, and 2014 was relatively dry. Secondly, a two-year period was selected because the simulation duration was more than 7 hours. Having a reasonably short calibration period with both wet and dry conditions maximized the number of calibration simulations that could be completed within the available project schedule. Lastly, the validation period included a number of monitoring wells that were not available during the calibration period and utilizing those stations only for validation provided an acid-test of model performance.

Calibration results are presented in **Table 3.1** (color coding is similar to the color coding shown **in Figure 3.1**, referenced below). Once this objective is realized, a validation simulation was conducted for 2015 - 2018 with the objective of evaluating model performance at stations that were installed after 2014, such as SOCREW1, SOCREW2, BIRDROOK, CRKSWPS, and Esplanade_W2. Calibration stations and model performance metrics are presented in **Figure 3.1**. Observation data from stations close to the boundaries are considered as boundary conditions, and the calibration was focused on improving the model performance at stations inside the model domain. The symbols used for the calibration stations are color-coded to indicate calibration performance using the following calibration metrics:

- Calibration is good if Mean Absolute Error (MAE) < 0.75 feet, and correlation coefficient (r) > 0.9
- Calibration is acceptable if MAE is between 0.75 and 1 foot, and r is between 0.8 and 0.9
- Calibration is less than acceptable if MAE is > 1 feet and r is < 0.8

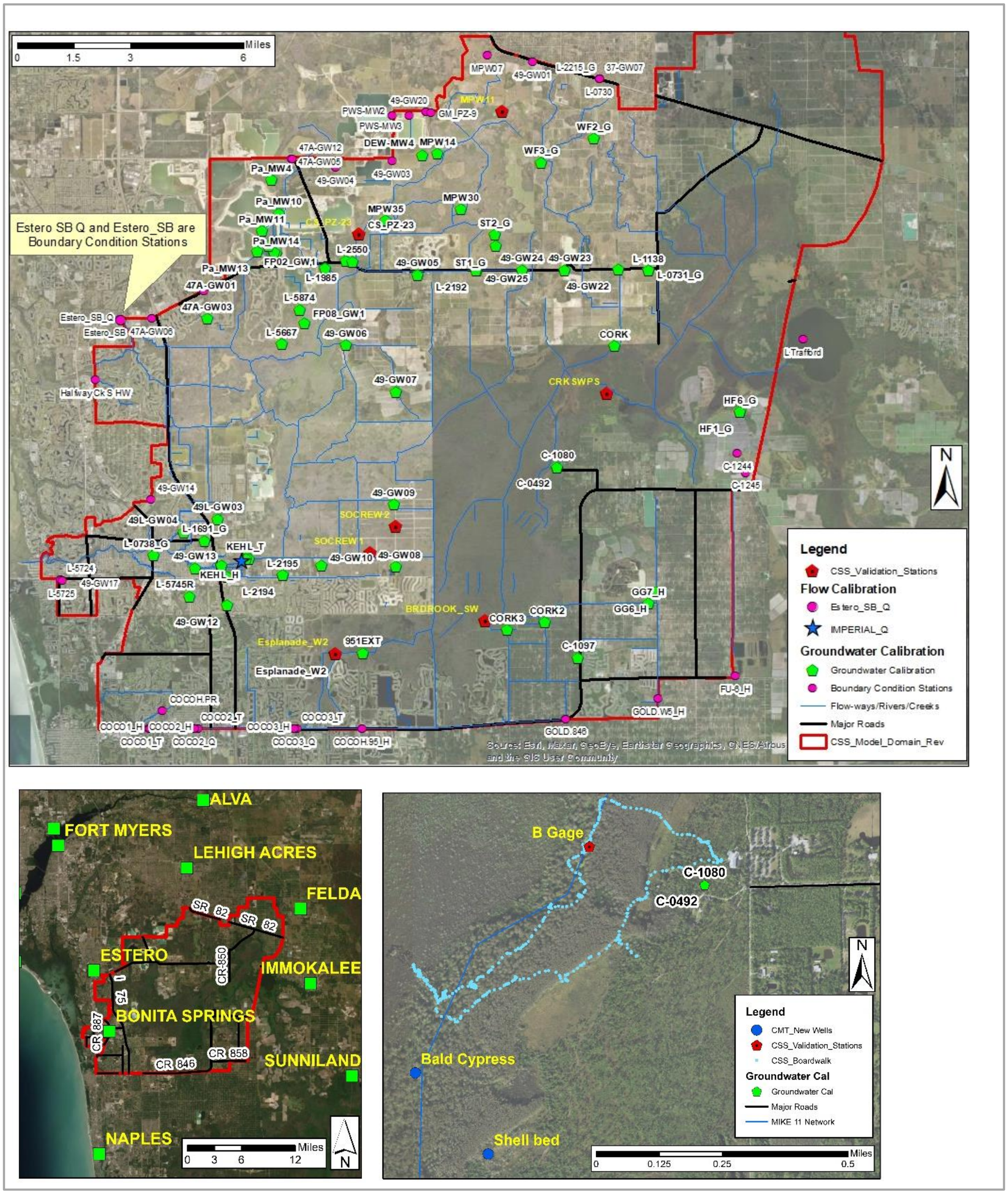


Figure 3.1 – Calibration Stations and Calibration Performance for the 2013 – 2014 Period

Table 3.1 – Calibration Statistics for 2013 – 2014

Name	Data_type	Layer	ME	MAE	RMSE	STDres	R_Correlat	R2_Nash_Su
47A-GW01	head elevation in saturated zone	3	-0.43	0.44	0.51	0.28	0.98	0.71
47A-GW03	head elevation in saturated zone	3	1.00	1.00	1.09	0.45	0.95	0.11
49-GW05	head elevation in saturated zone	1	1.27	1.51	1.89	1.39	0.90	-0.61
49-GW06	head elevation in saturated zone	1	0.02	0.33	0.42	0.42	0.95	0.90
49-GW07	head elevation in saturated zone	1	-0.59	0.78	0.87	0.64	0.88	0.58
49-GW08	head elevation in saturated zone	1	-0.84	0.99	1.28	0.96	0.92	0.57
49-GW09	head elevation in saturated zone	1	0.70	0.70	0.82	0.43	0.95	0.54
49-GW10	head elevation in saturated zone	1	0.14	0.42	0.55	0.53	0.97	0.94
49-GW11	head elevation in saturated zone	1	0.10	0.67	1.05	1.04	0.94	0.88
49-GW12	head elevation in saturated zone	1	-1.26	1.38	1.71	1.17	0.95	-0.03
49-GW13	head elevation in saturated zone	1	-0.70	0.72	0.80	0.37	0.98	0.75
49-GW19	head elevation in saturated zone	1	1.06	1.07	1.17	0.50	0.99	0.59
49-GW22	head elevation in saturated zone	1	-1.54	1.58	1.90	1.12	0.86	-10.45
49-GW23	head elevation in saturated zone	1	-0.88	1.30	1.57	1.29	0.86	-0.26
49-GW24	head elevation in saturated zone	1	0.47	0.94	1.22	1.13	0.79	0.55
49-GW25	head elevation in saturated zone	1	-0.50	1.37	1.61	1.53	0.78	0.32
49L-GW03	head elevation in saturated zone	1	-0.98	1.02	1.26	0.80	0.91	0.32
49L-GW04	head elevation in saturated zone	1	-0.02	0.35	0.44	0.44	0.98	0.88
951EXT	head elevation in saturated zone	1	-1.03	1.03	1.46	1.04	0.82	0.12
C-0492	head elevation in saturated zone	3	-1.23	1.23	1.29	0.41	0.97	0.06
C-1097	head elevation in saturated zone	1	-0.57	0.57	0.60	0.18	0.99	0.75
DEW-MW4	head elevation in saturated zone	1	0.36	0.98	1.32	1.27	0.69	-0.12
FP02_GW1	head elevation in saturated zone	1	-0.48	0.68	0.78	0.61	0.89	0.62
FP08_GW1	head elevation in saturated zone	1	-0.40	0.41	0.46	0.23	0.99	0.87
HF1_G	head elevation in saturated zone	1	-0.86	1.02	1.38	1.09	0.88	0.62
L-0738_G	head elevation in saturated zone	3	-1.01	1.12	1.37	0.93	0.95	0.67
L-1138	head elevation in saturated zone	1	-0.15	0.27	0.33	0.29	0.87	0.68
L-1691_G	head elevation in saturated zone	3	-0.05	1.03	1.27	1.27	0.87	0.76
L-1985	head elevation in saturated zone	3	-0.43	0.70	0.84	0.72	0.95	0.82
L-2195	head elevation in saturated zone	1	0.40	0.79	1.01	0.93	0.96	0.80
L-2550	head elevation in saturated zone	3	-0.68	0.94	1.06	0.81	0.94	0.75
L-5667	head elevation in saturated zone	3	0.74	0.74	0.77	0.21	0.98	0.29
L-5745R	head elevation in saturated zone	3	-0.42	0.92	1.01	0.92	0.96	0.81
L-5874	head elevation in saturated zone	3	-0.43	0.44	0.50	0.25	0.98	0.82
Pa_MW4	head elevation in saturated zone	1	-0.28	0.56	0.64	0.58	0.94	0.81
Pa_MW10	head elevation in saturated zone	1	-0.03	0.53	0.60	0.60	0.97	0.84
Pa_MW11	head elevation in saturated zone	1	0.51	0.54	0.69	0.46	0.97	0.61
Pa_MW13	head elevation in saturated zone	1	0.24	0.28	0.33	0.23	0.97	0.85
Pa_MW14	head elevation in saturated zone	1	0.18	0.27	0.35	0.30	0.96	0.88
Pa_MW14A	head elevation in saturated zone	3	-0.35	0.42	0.53	0.41	0.78	-0.01
ST1_G	head elevation in saturated zone	1	0.86	0.91	1.30	0.97	0.90	0.20
ST2_G	head elevation in saturated zone	1	1.02	1.03	1.33	0.85	0.94	0.02
WF2_G	head elevation in saturated zone	1	-0.71	0.99	1.15	0.90	0.90	-0.28
WF3_G	head elevation in saturated zone	1	0.25	0.34	0.48	0.41	0.95	0.84
Shark_Southeast_Lake3	head elevation in saturated zone	1	0.84	0.84	0.85	0.09	0.98	-1.96
Esplanade_W2	head elevation in saturated zone	1	-1.46	1.46	1.85	1.15	0.66	-0.74
CS_PZ-23	head elevation in saturated zone	1	-0.15	0.42	0.54	0.52	0.94	0.88
MPW14	head elevation in saturated zone	1	0.36	0.89	1.04	0.97	0.78	-0.03
MPW30	head elevation in saturated zone	1	1.09	1.32	1.80	1.43	0.79	-2.05
MPW35	head elevation in saturated zone	1	-0.28	0.45	0.56	0.49	0.91	0.65
CORK	water level in river h-point	0	-0.30	0.30	0.33	0.13	0.98	0.66
CORK2	water level in river h-point	0	-0.96	1.13	1.55	1.22	0.54	-3.35
CORK3	water level in river h-point	0	-0.32	1.12	1.43	1.40	0.73	-0.11
GG6_H	water level in river h-point	0	-0.34	0.41	0.54	0.42	0.84	0.51
GG7_H	water level in river h-point	0	-0.74	0.79	0.94	0.59	0.72	-0.25
IMPERIAL_H	water level in river h-point	0	-0.39	0.68	0.83	0.74	0.96	0.87
KEHL_H	water level in river h-point	0	-0.27	0.50	0.73	0.68	0.95	0.89
KEHL_T	water level in river h-point	0	-0.35	0.53	0.75	0.66	0.96	0.90

Statistics were not included in **Table 3.1** for the Imperial River USGS gaging station flow calibration. However, calibration was excellent, as shown in **Figure 3.2**. Mean absolute error was 20 cfs, and the correlation coefficient was 0.96.

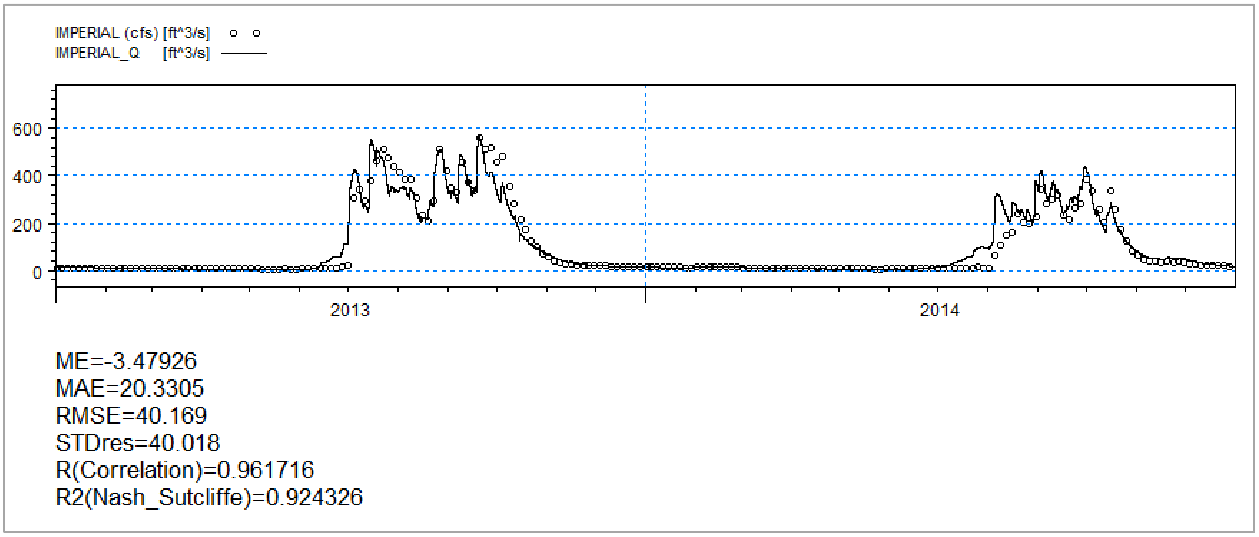


Figure 3.2 – Calibration Plot for the Flows (cfs) at the Imperial River USGS Gaging Station

Calibration plots are presented in **Attachment 4**. Calibration is good for 49 percent of the stations and acceptable for 28 percent of the stations. Calibration is poor for 23 percent of the stations. For those stations with poor calibration, a number of them meet good or acceptable calibration metrics for one or another measure or there are issues associated with the station, as described below:

- 49-GW5 correlation coefficient r is > 0.9, and wet season calibration is good
- 49-GW-12 correlation coefficient r is 0.95 and local drainage issues are not well understood. Site is south of the Imperial River adjacent to I-75, and is not a primary calibration station
- Station 49-GW-22 is adjacent to well L-1138 that has good calibration. Issues with well 49-GW22 are suspected.
- 49-GW23, -24, and -25 are only slightly outside of acceptable calibration range and have good correlation coefficient values
- 951EXT is only slightly outside of acceptable calibration range
- C-492 is a USGS well with a reference elevation determined from a topographic map, which may be inaccurate. The correlation coefficient is 0.97, which indicates that the model properly represents the seasonal changes in water levels. See additional discussion in the following paragraph.
- L-738 is a sandstone well and is only slightly outside of the range of acceptable calibration range. Correlation coefficient is 0.95
- Esplanade W2 was not used during calibration (data was obtained after calibration was complete) and the station is adjacent to a wide lake that has drawdown impacts on the adjacent aquifer.
- MPW30 calibration is good during the wet season. It is in the vicinity of the Lee County Utilities Corkscrew wellfield, and groundwater movement may contribute to the less than acceptable calibration. Calibration is good at nearby stations.
- Cork 2 and Cork 3 calibration stations are located at gated weirs that have incomplete gate operation records. The recorded gate operation records were not obtained until after the calibration

was more than 90 percent complete. MAE was 1.12 and 1.13 for these stations, which is just outside of acceptable calibration range.

The model calibration effort did not include a comparison of measured water levels at the Lettuce Lake staff gage (also known as the B-Gage) that is located on the Sanctuary boardwalk due to questions regarding measured data and actual ground elevations in the vicinity of the Lettuce Lake gage. In response to that concern, the Water Science Team had two permanent benchmarks established, one near the USGS monitoring well C-492 and one at the start of the Sanctuary boardwalk. Water Science staff attempted to confirm the datum used for the USGS C-492 gage but were not able to confirm the datum. Utilizing the benchmark at the start of the boardwalk, the elevation of the Lettuce Lake staff gage was surveyed, and hand measurements at that staff gage were then converted to elevations relative to the NAVD 1988 datum. This work was completed after the completion of the calibration effort, which prevented the model calibration effort to utilize the information available from the B-Gage. **Figure 3.3** presents a plot of measured data for the B-Gage and C-492 vs. simulated water levels at the B-Gage (location shown in **Figure 3.1**). Simulated peak stages are higher than measured for 2013 and the first half of 2014, and for May – June, 2015 and 2016. Model performance may be affected by the inaccuracies of topography in the vicinity of the Sanctuary boardwalk. Surveyed ground elevations are more than one foot lower than the LiDAR elevation at the B Gage and at the location of the Bald Cypress monitoring station along the Central Marsh Transect that was installed in May 2020. Calibration at the B-Gage should be reviewed once issues with topographic data are resolved, and calibration issues associated with monitoring well C-492 should be addressed once the datum used at that station can be confirmed.

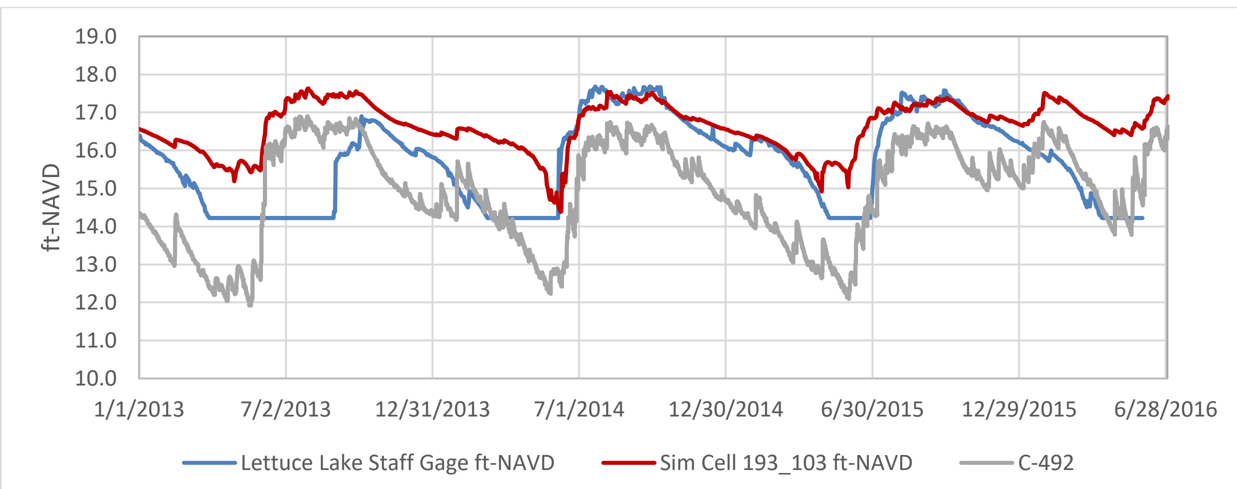


Figure 3.3 – Plot of Measured and Simulated Flows at the CSS B-Gage

3.2 Model Validation

The validation of the calibrated model for the period 2015 – 2018 included both very wet and very dry periods. The first part of 2017 was one of the driest periods on record, and heavy wet season rains in August and September were also close to historic maximum wet season water levels and flows. The validation period included a number of stations that were not installed as of 2013 – 2014 or where available data were obtained after substantial completion of the calibration. Model performance at those stations is presented in **Table 3.2** (note: see **Attachment 5** for a more complete list of validation performance metrics). The calibration metrics were good at MPW11, CRKSWPS, SOCREW1, and SOCREW2 for the validation period. Locations of these validation stations are shown in **Figure 3.1**. Performance was acceptable at Esplanade W2, BRDROOK_sw, and CS_PZ_23, as summarized below:

- MAE values were 0.88 and 1.69 feet for BRDROOK_sw and Espanade_W2 (the target is <0.75 feet). However, correlation coefficient r values were greater than 0.96 (very good) for BRDROOK_sw and Esplanade_W2. Both stations are rated as acceptable due to the high MAE.
  - BRDROOK_sw is located in a drainage ditch adjacent to the Bird Rookery Sanctuary. Simulated water levels were higher than measured water levels. The model grid (375 feet) could not capture the impact of this drainage ditch.
  - As explained earlier in the calibration discussion, Explanade_W2 is a monitoring well in a wetland near a wide drainage ditch for the Esplanade development. The model grid (375 feet) could not capture the impact of this drainage ditch.
- MAE at CS_PZ_23 was 0.87, which is only slightly outside the good range for that metric. This station is in the cone of influence of the Lee County Utilities Corkscrew wellfield, and a model grid size could not capture the impact of the groundwater pumping on this monitoring well.

Overall model performance during the validation period was either good or acceptable at 58 percent of the monitoring stations used in the validation simulation. Validation plots and the summary model performance statistics are presented in **Attachment 5**.

Table 3.2 – Model Performance for Stations Only Used in Validation Simulations

Name	Data_type	Layer	ME	MAE	RMSE	STDres	R_Correlat	R2_Nash_Su
CS_PZ-23	Head Elev Sat Zone	1	0.59	0.87	1.16	1.00	0.86	0.64
MPW11	Head Elev Sat Zone	1	-0.07	0.39	0.54	0.54	0.92	0.79
CRKSWPS	Head Elev Sat Zone	1	-0.55	0.60	0.86	0.66	0.97	0.59
SOCREW1	Head Elev Sat Zone	1	-0.01	0.34	0.43	0.43	0.97	0.93
SOCREW2	Head Elev Sat Zone	1	-0.05	0.42	0.60	0.60	0.93	0.80
BRDROOK_SW	Head Elev Sat Zone	1	-0.85	0.88	0.96	0.45	0.96	0.65
Esplanade_W2	Head Elev Sat Zone	1	-1.68	1.69	1.80	0.64	0.97	-0.04

3.3 Simulated Average Wet Season Depths and Hydroperiod

Model results were processed to generate maps of average wet season water depths and wetland hydroperiods. Average wet season (July 1 – Oct 15) for 2013 and 2014 are presented in **Figures 3.4** and **3.5**, respectively. Hydroperiods for 2013 and 2014 are presented in **Figures 3.6** and **3.7**, respectively. Average 2014 wet season water depths were in the range of 1.5 feet in the Sanctuary Central Marsh, with pockets of water depths slightly greater than 2 feet. **Figure 3.8** presents simulation results for a model grid in the vicinity of the Sanctuary boardwalk, and the simulated overland flow depths range from -1 to 2.2 feet (Calibration Run 0814). At this location, water exceeded a depth of 0.1 foot during 96 percent of the two-year simulation period.

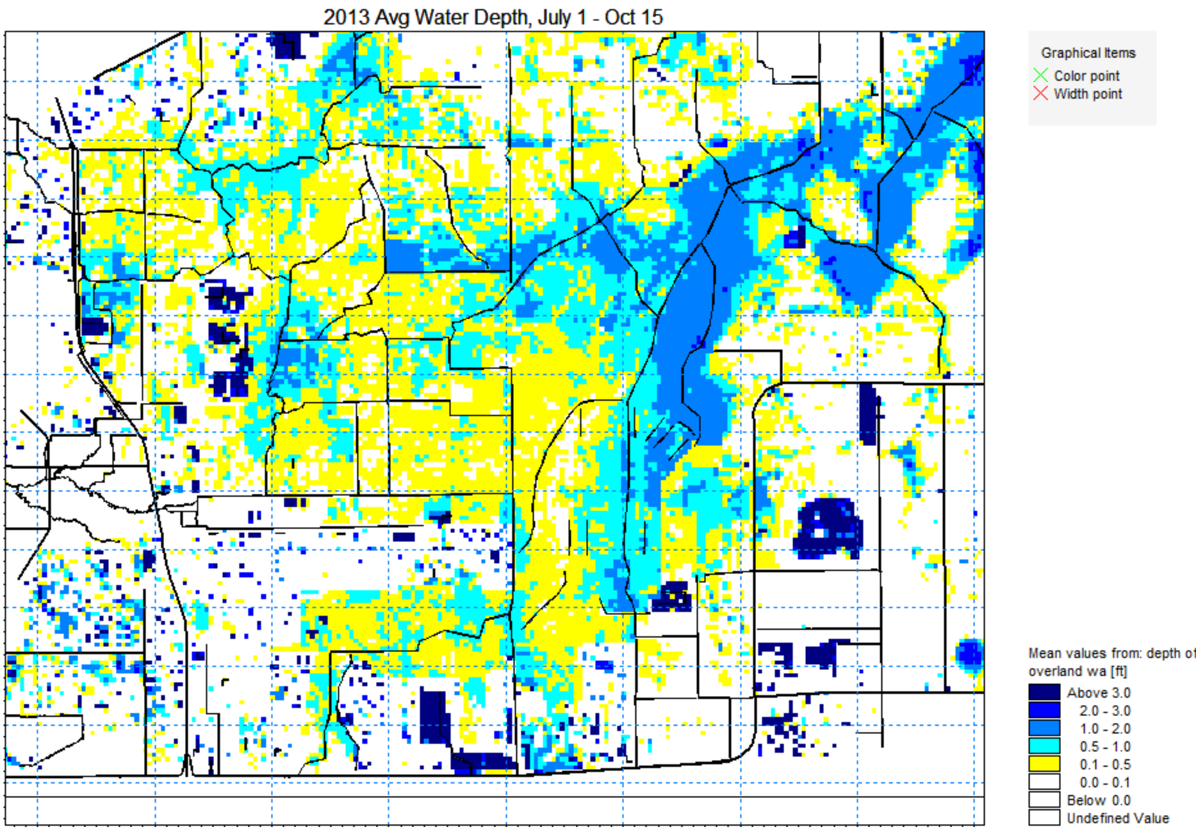


Figure 3.4 – Simulated Average Water Depth for 2013 Wet Season

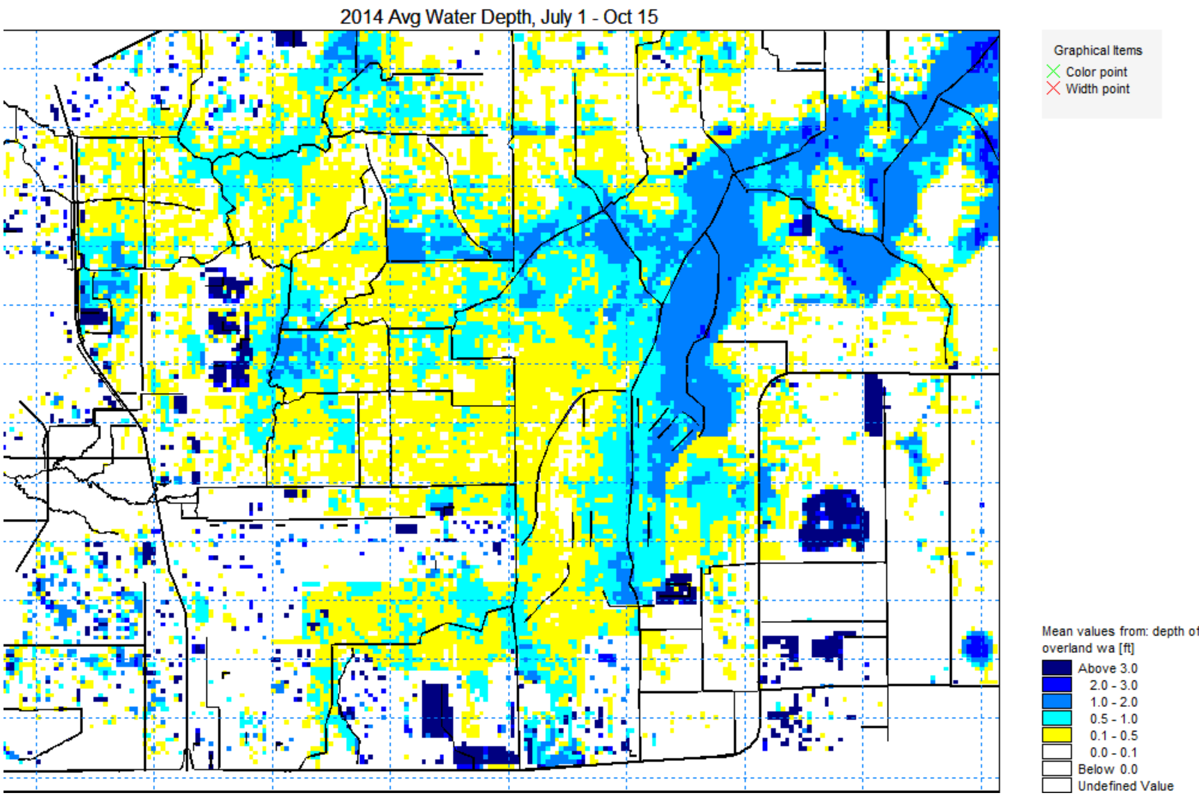


Figure 3.5 – Simulated Average Water Depth for 2014 Wet Season

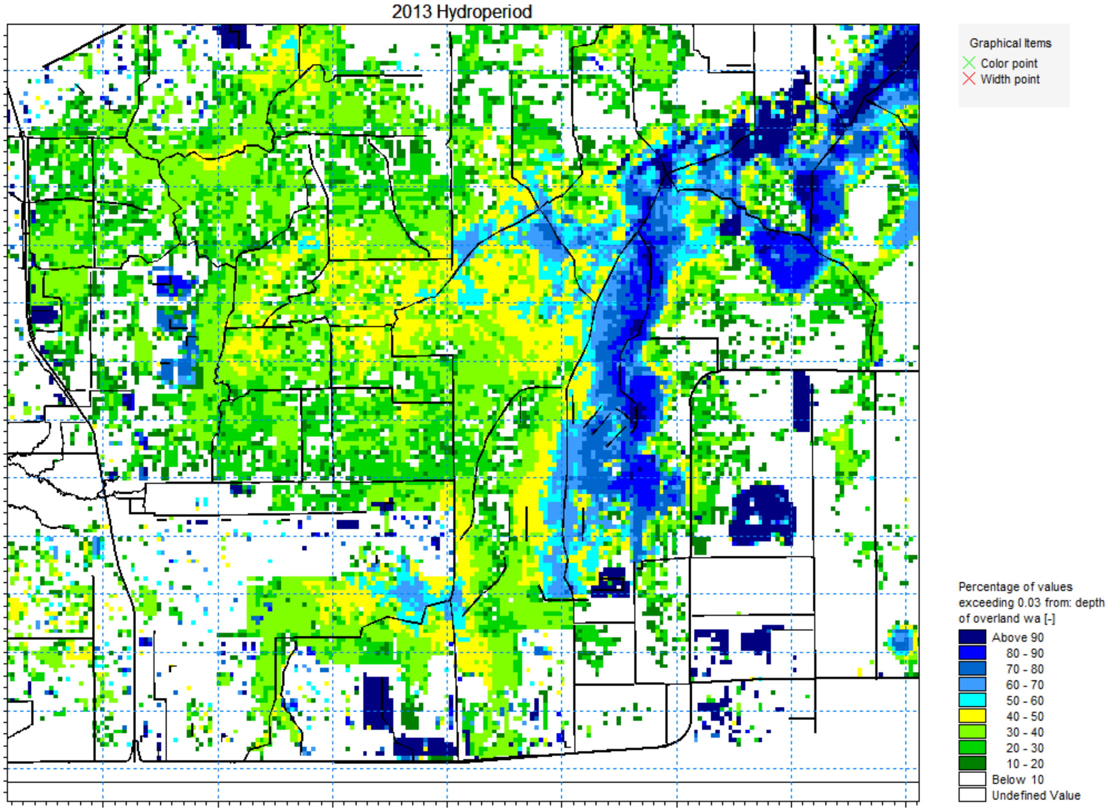


Figure 3.6 – Simulated Hydroperiod for Depths in Excess of 0.1 ft (0.03 m.) for 2013 Calendar Year

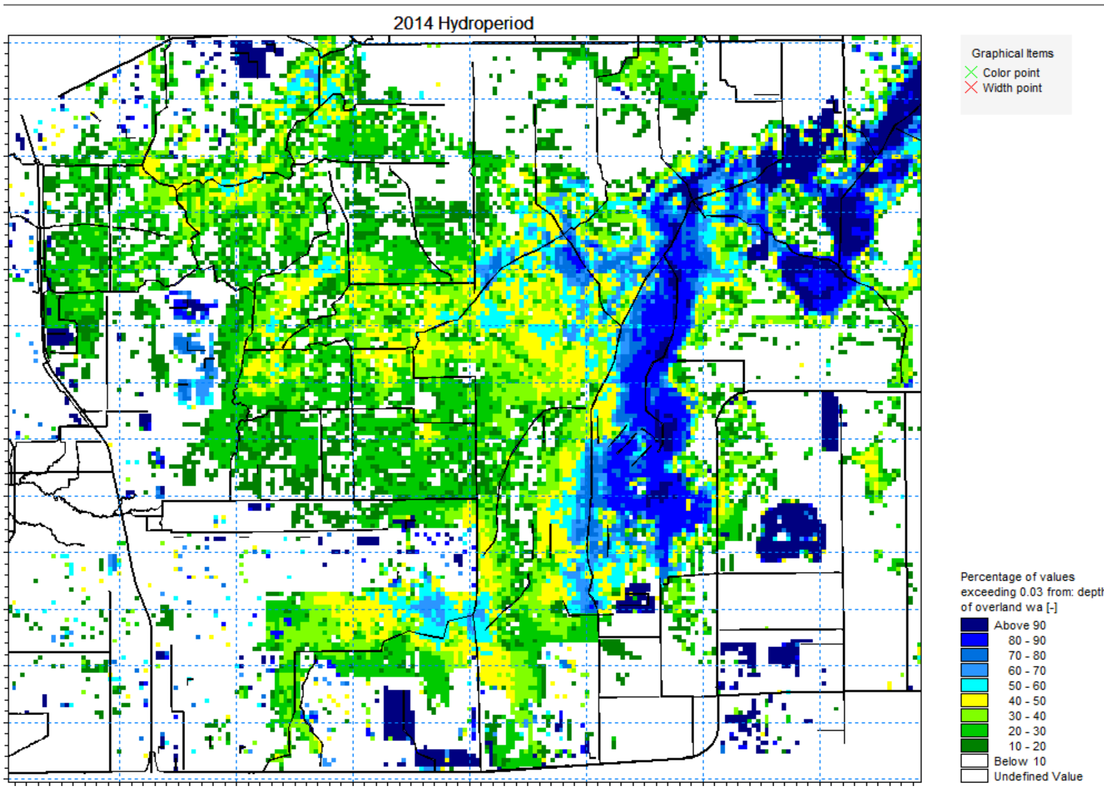


Figure 3.7 – Simulated Hydroperiod for Depths in Excess of 0.1 ft (0.03 m.) for 2014 Calendar Year

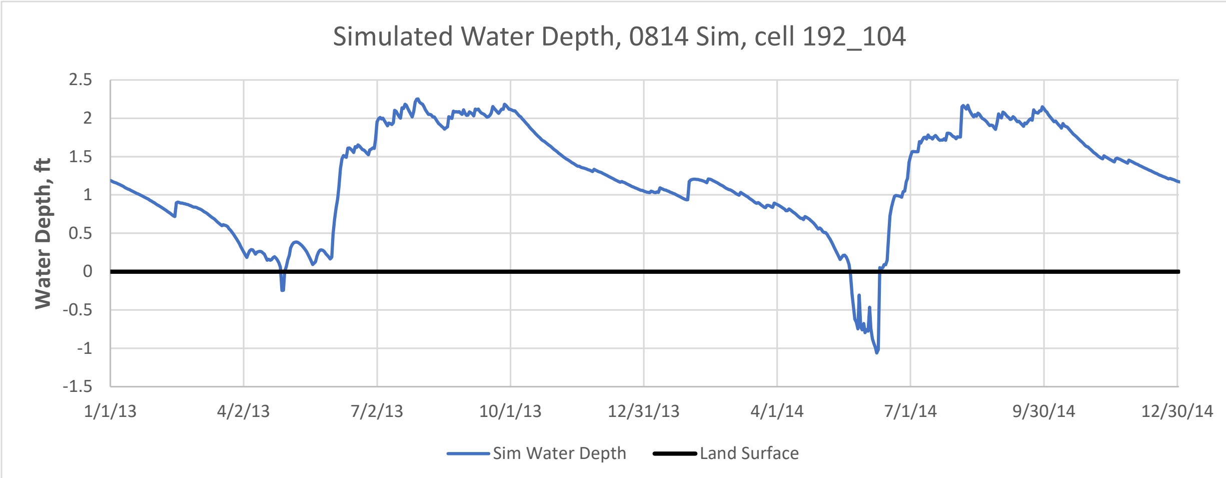


Figure 3.8 – Simulated Water Depth Relative to Land Surface for Wetlands West of Corkscrew Swamp Sanctuary Boardwalk (Calibration Run 0814)

3.4 Model Comparison to Ecologic Indicators

Simulated average wet season water depths presented above in **Figures 3.4** and **3.5** have been compared to vegetation indicators of hydrologic condition. As explained in the Model Development Memorandum, ecologists visited numerous locations and utilized a variety of vegetation indicators to estimate the average wet season water depth. Those water depths have been plotted on the same horizontal projection as the simulated average wet season water depth for the 2013 – 2014 simulation period. Hydrologic conditions in 2013 were slightly wetter than normal, and 2014 was a dry year. Therefore, the average of the two years provides a reasonable representation of "average" hydrologic conditions. **Figures 3.9, 3.10**, and **3.11** present the results of this comparison. Similar color scales were used for both for the vegetation indicators and the simulated average wet season. Therefore, differences between the color of a given vegetation indicator symbol and the underlying simulated average wet season water depth will be evident. A perfect match is not expected since wetland vegetation responds to local conditions that may not be accurately represented by the single elevation of a 375-foot grid cell used in the model. In addition, the topographic data set used in this project was less than ideal, which will also lead to differences between the water depths for the observed and simulated conditions.

Despite the inherent limitations of this type of comparison, the observed water depths based on vegetation indicators compare well to simulated water depths. Two notable differences were identified in **Figure 3.9**. The vegetation indicator depths inside the red circle are 0.6 and 1.3 feet, while the simulated average wet season depth is less than 0.1 foot. A detailed comparison of elevations was conducted for that area, and the monitoring location is adjacent to a LCPA monitoring well that is located in a small wetland depression. There are roads in the vicinity, which resulted in a 375-foot grid elevation that is more than one foot higher than the actual ground elevation. The other point with a significant difference is the point with the blue circle on **Figure 3.9**. Ground is 20.9, and the grid cell elevation is 21.7. The vegetation indicator suggests water depths of 1.4 feet while the simulated average wet season water depth is less than 0.1 feet. The average elevation of the grid cell is higher, which explains this discrepancy. The calibration well at this location, CS_PZ-23 also has a high MAE, most likely due to the elevation difference between the actual ground and the MIKE SHE grid cell.

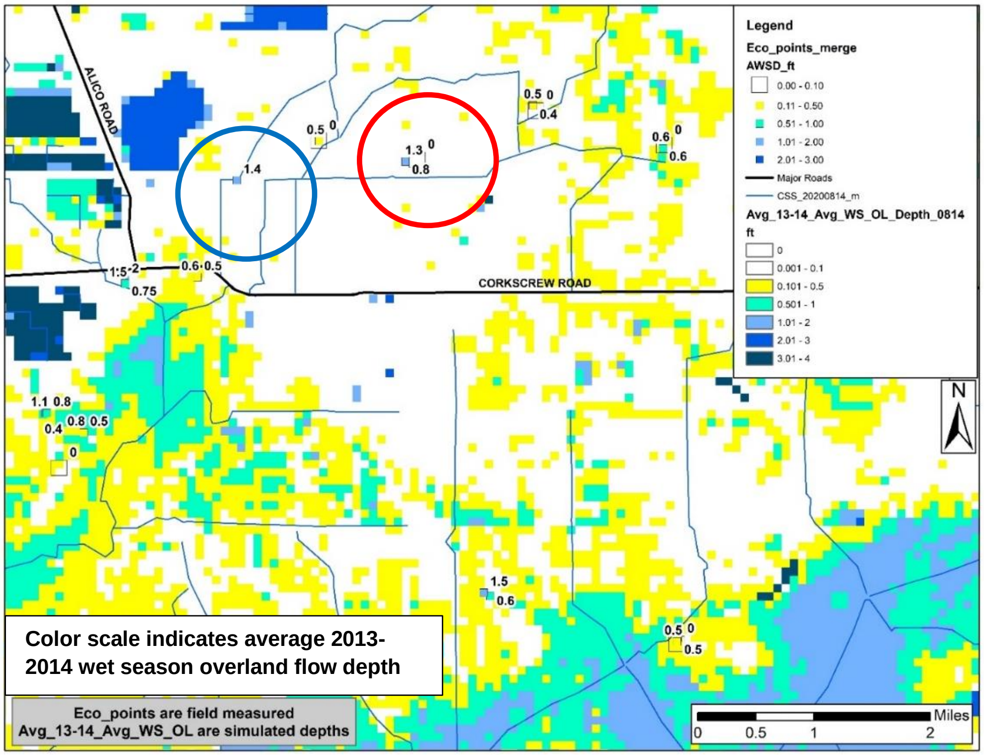


Figure 3.9 – Measured Vegetation Indicators of Average Wet Season Depth and Simulated Average Wet Season Water Depth, Flint Pen Strand

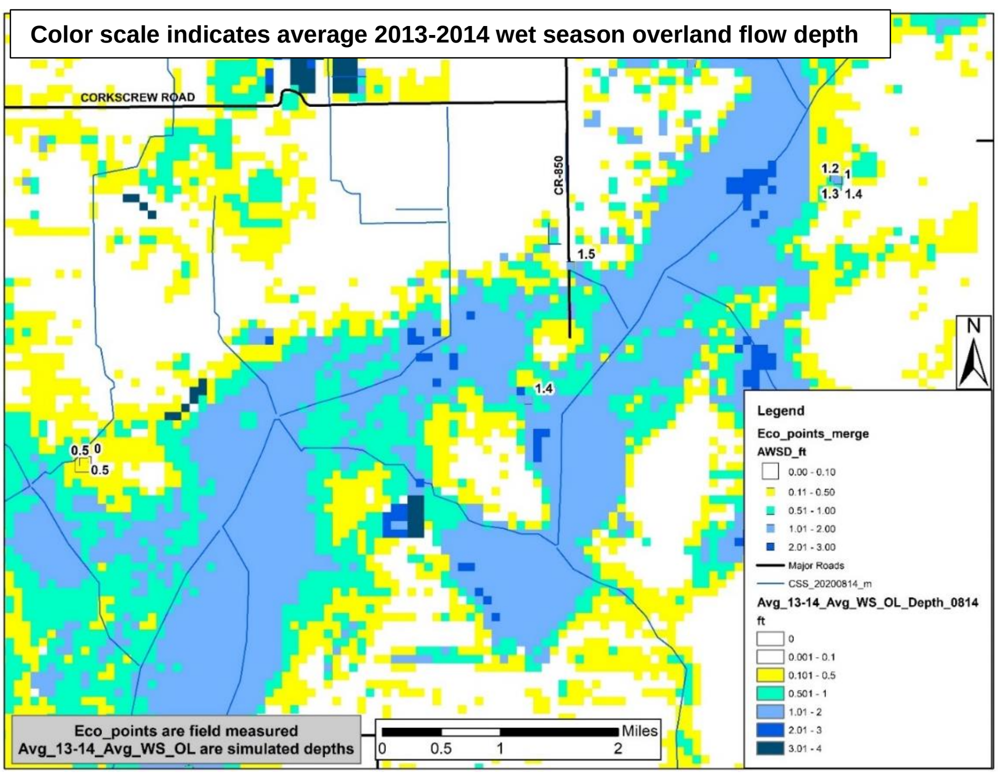


Figure 3.10 – Measured Vegetation Indicators of Average Wet Season Depth and Simulated Average Wet Season Water Depth, East Corkscrew

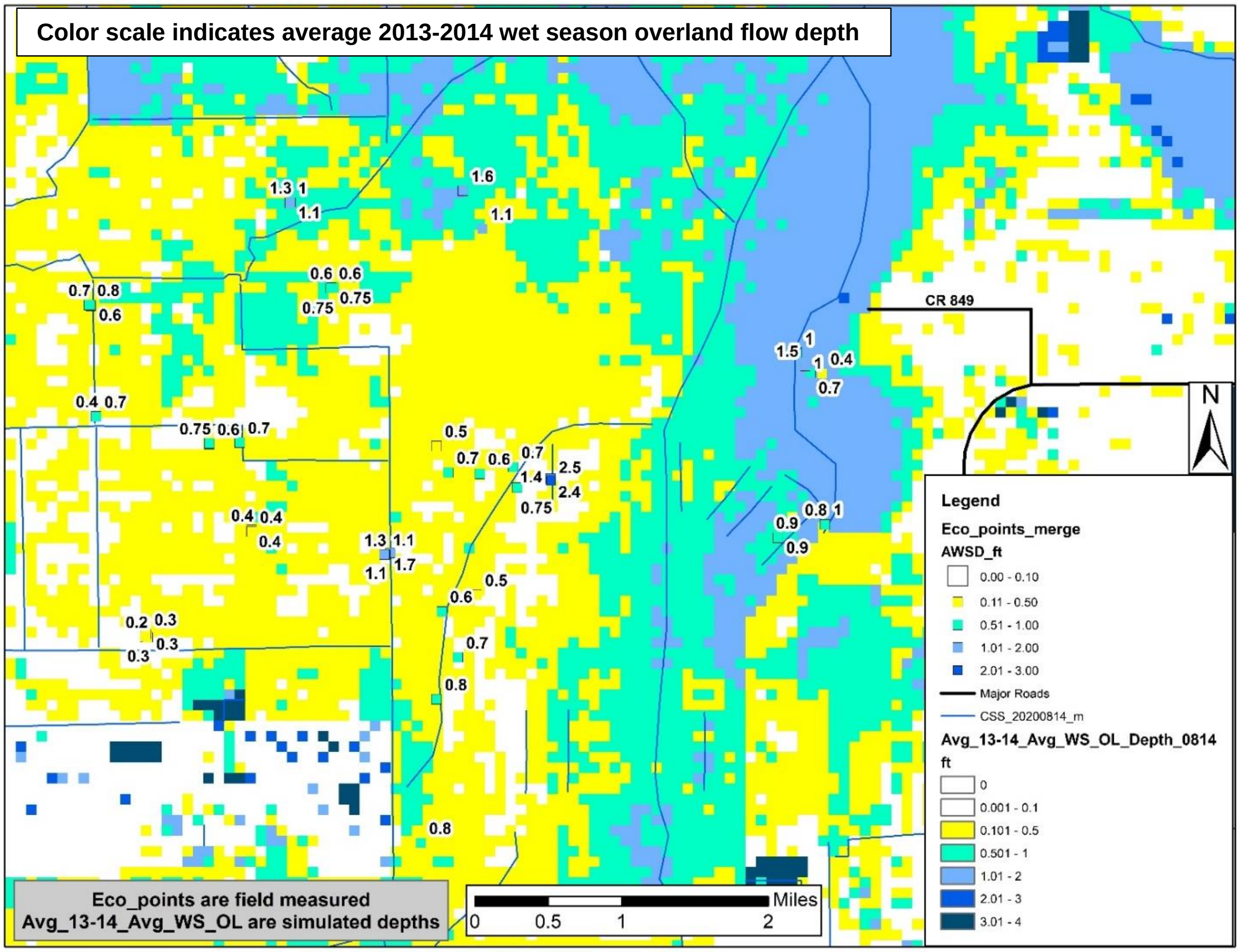


Figure 3.11 – Measured Vegetation Indicators of Average Wet Season Depth and Simulated Average Wet Season Water Depth, Southern CREW

3.5 Calibration Summary and Recommendations

The model was reasonably calibrated to be used for scenario analysis. However, there are still some improvements that could be implemented if additional information is obtained. The primary data concern is topography. Recommendations for a number of low-cost additional data collection items in the near future may include, but are not limited to:

- Survey cross sections across the main flow-way through Corkscrew Swamp Sanctuary and Bird Rookery Swamp are recommended in approximately 5 locations shown in **Figure 3.12**.
- Surveying is recommended at the location of a number of monitoring stations to confirm both ground elevations and reference elevations utilized for programming of data loggers.
- A transect of monitoring wells between the Corkscrew Swamp Sanctuary and Bird Rookery Swamp is also recommended to assist in model calibration.
- Accurate log of operation of the SFWMD/Lee County water control gates at CORK1, CORK2, CORK3, GG6, GG7, and KEHL structures. Since the data gaps in the records prior to 2016 likely

cannot be filled, it may be appropriate to calibrate to a period when the gate operation records are more accurate, such as 2018 – 2019.

- The CORK monitoring station should be re-activated.
- A monitoring station is recommended at the edge of wetlands east of existing monitoring well L-1138 (see Section 5 for additional information).

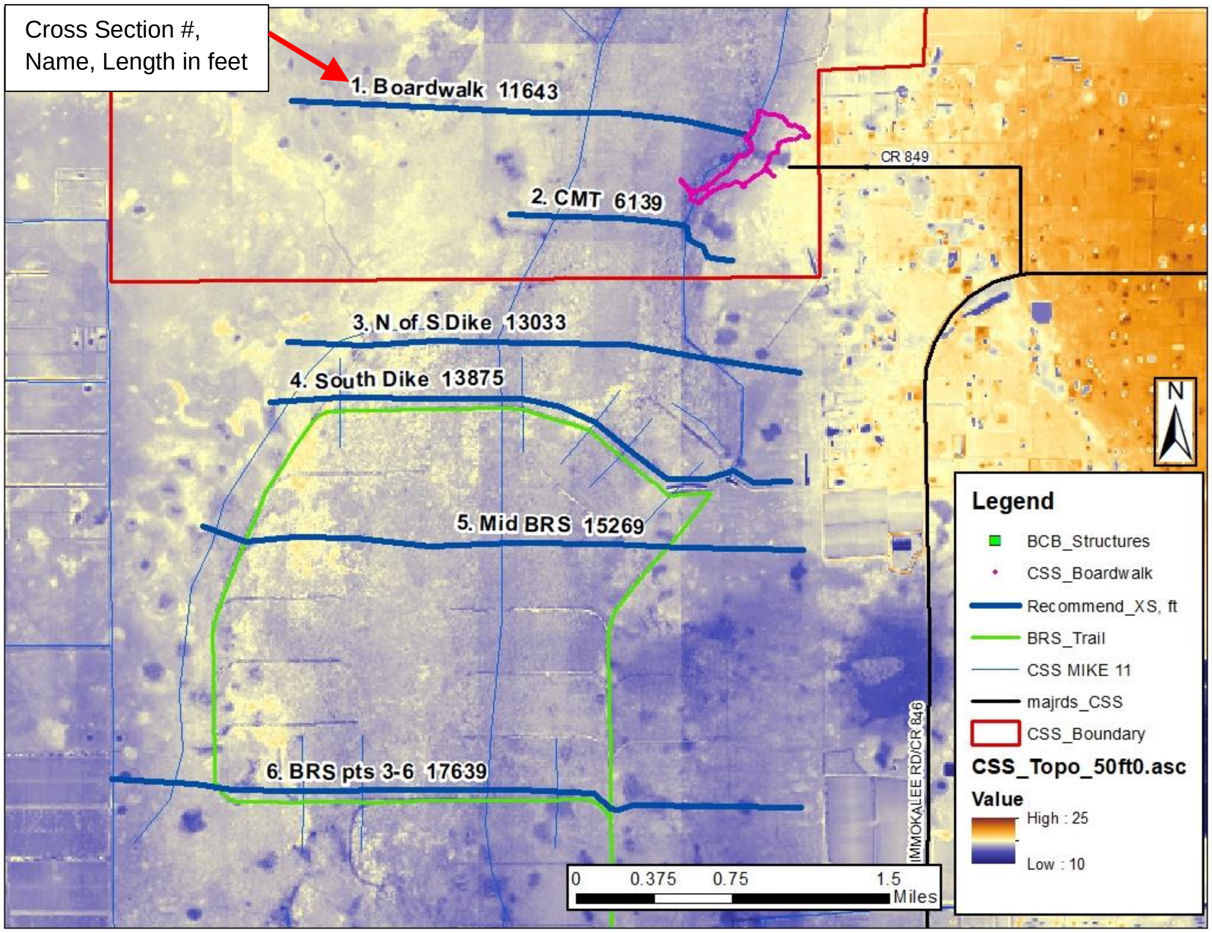


Figure 3.12 – Location of Recommended Cross Section Survey Transects

4.0 SCENARIO ANALYSIS

4.1 Summary of Scenario Analysis Approach

Four model scenarios were developed to evaluate the relative contribution of different anthropogenic drivers to dry season water levels within the Sanctuary. The first three model scenarios were intended to evaluate three key anthropogenic drivers on dry season water levels, but were not intended to be considered for implementation because of the associated implications for the region's residents, businesses, and infrastructure. These first three model scenarios assumed major changes in land use which were hypothesized to result in an observable simulated hydrologic response, particularly in the old-growth bald cypress central to the Sanctuary. Once the major factors that influence dry season hydrology were identified, a fourth modeling scenario was developed with proposed components that could be reasonably implemented and would minimize the dry season water loss that the Sanctuary has been experiencing in recent decades. The three model scenarios intended to identify key factors influencing dry season hydrology are summarized below:

- Groundwater extraction from agricultural irrigation and/or public water supply wellfields surrounding the Sanctuary were removed from the model.
- Willow coverage and mesic and hydric flatwood tree density were changed in the vicinity of the Sanctuary. The changes are summarized below:
    - Areas invaded by willows were changed to simulated marshes;
    - Simulated hydric flatwoods tree density was reduced by 75 percent and replaced with simulated wet prairies (see **Section 4.3** for additional explanation); and
    - Simulated mesic flatwoods tree density was reduced by 75 percent and changed to simulated unimproved pastures.
- Man-made drainage was reduced south of the Sanctuary. Simulated canal cross-sections were changed to have simulated invert elevations equivalent to adjacent natural land elevations and selected simulated water control structures were removed.

Detailed descriptions of the model scenarios are provided below in **Sections 4.2** through **4.4**. After review of the results of Scenarios 1 through 3, a fourth model scenario was developed with proposed improvements that **CAN FEASIBLY** be implemented. The configuration and results of the fourth model scenario are described in **Section 4.5**.

Graphs of existing vs scenario at key calculation points (e.g. Figures 4.2 through 4.4) presented in the section below vary between scenarios due to varying levels of impacts across the model domain. No graphs are presented for those areas where water levels are essentially the same for existing conditions and the scenario.

4.2 Scenario 1 – Reduce Groundwater Withdrawals

The purpose of this model scenario was to evaluate the impact of agricultural irrigation and public water supply withdrawals on wetland hydroperiods in the Sanctuary. This scenario is not deemed feasible and the only intent of the simulation is to evaluate the impact of these water uses on the Sanctuary hydrology. Three options were evaluated:

- Scenario 1A – No simulated agricultural irrigation;
- Scenario 1B – No simulated withdrawals from public water supply wellfields; and
- Scenario 1C – No simulated agricultural irrigation or withdrawals from public water supply wellfields

(Scenarios 1A and 1B combined).

Scenario 1A eliminated all agricultural irrigation (colored polygons) east of I-75 shown in **Figure 4.1** . Scenario 1B eliminated all public water supply pumping wells shown in **Figure 4.1**, and Scenario 1C eliminated all groundwater withdrawals both irrigation and public water supply pumping wells) east of I-75 within the model domain.

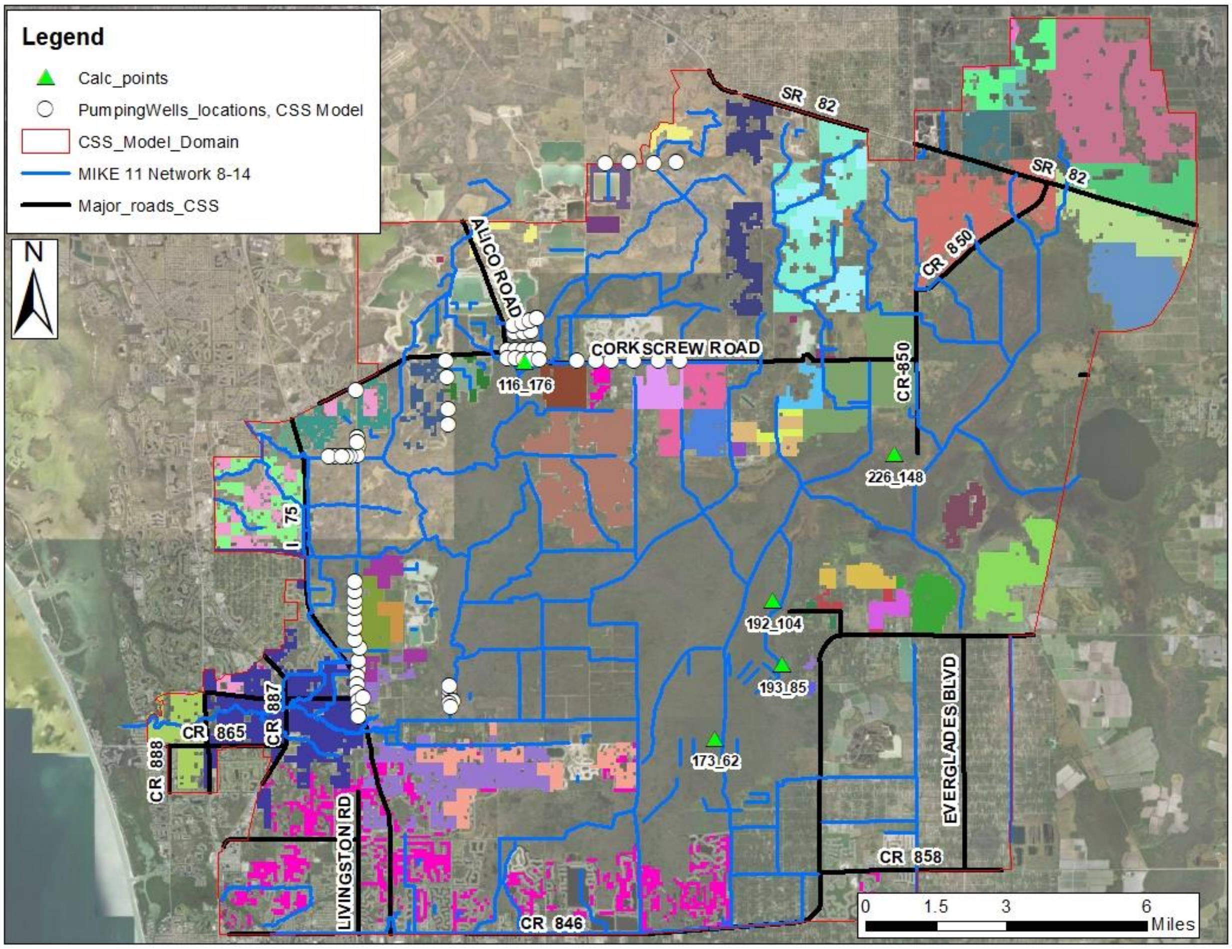


Figure 4.1 – Map of Groundwater Withdrawals Eliminated for Scenario 1

Figures 4.2 through **4.4** present water level changes for Scenario 1A and for the existing conditions simulation. Eliminating agricultural irrigation resulted in slight increases in dry season water levels in cell 116_176, which is in Flint Pen Strand south of Corkscrew Road near the intersection with Alico Road (**Figure 4.1**). In the existing conditions simulation, wetlands one mile south of agricultural lands (cell 226_148) never dry out due to irrigation of upstream agriculture, runoff into ditches, and/or seepage from detention areas. Appropriate seasonal drying is necessary for proper management of this land (e.g., prescribed fire), maintaining natural vegetation communities, and seasonally concentrating aquatic prey communities. Scenario 1A results in lower dry season water levels south of the agricultural lands that will improve ecological function and allow necessary land management activities. There was no response in water levels near the Sanctuary boardwalk from elimination of agricultural irrigation.

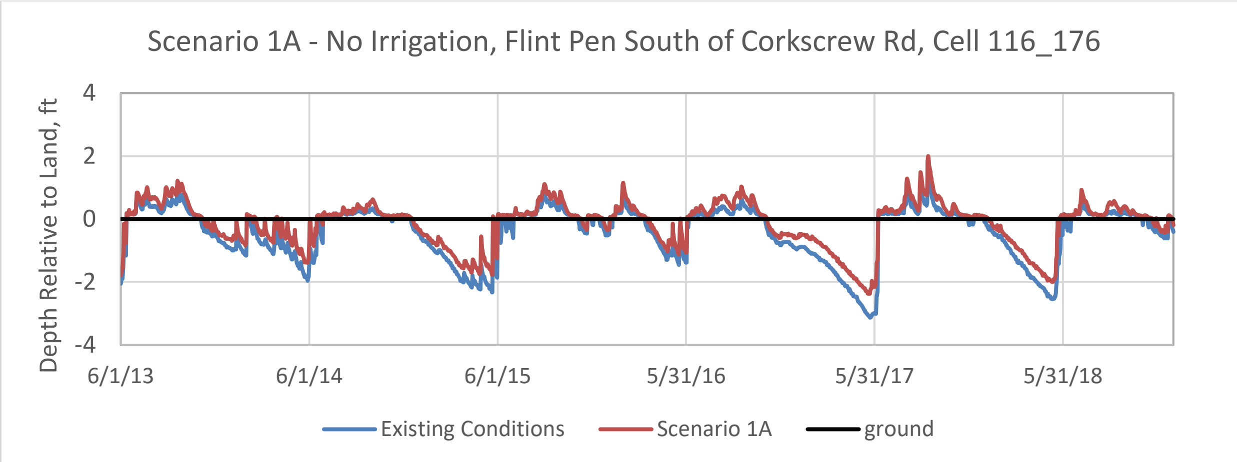


Figure 4.2 – Simulated Water Depths Relative to Land Surface for Scenario 1A and Existing Conditions for Flint Pen Strand South of Corkscrew Road, Cell 116_176

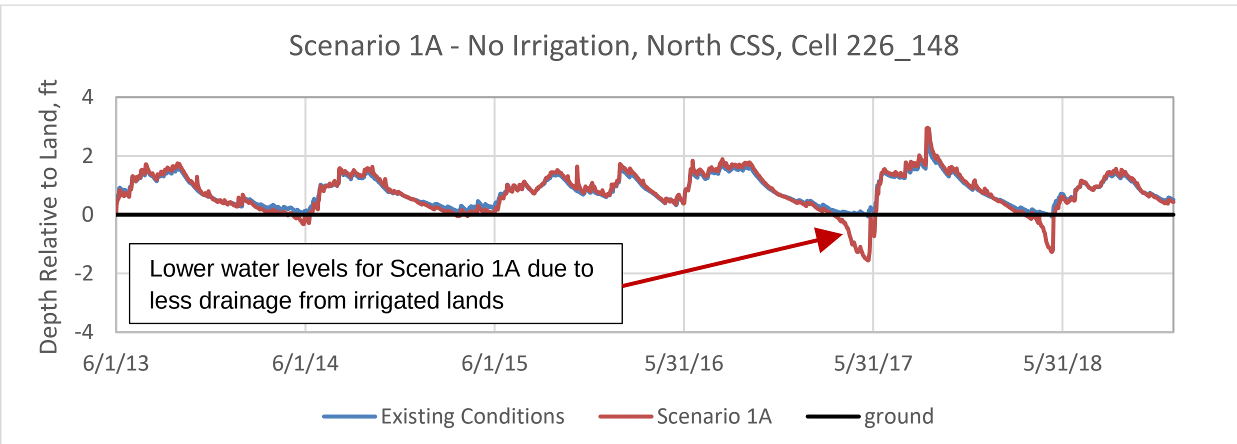


Figure 4.3 – Simulated Water Depths Relative to Land Surface for Scenario 1A and Existing Conditions for North Corkscrew Swamp Sanctuary, Cell 226_148

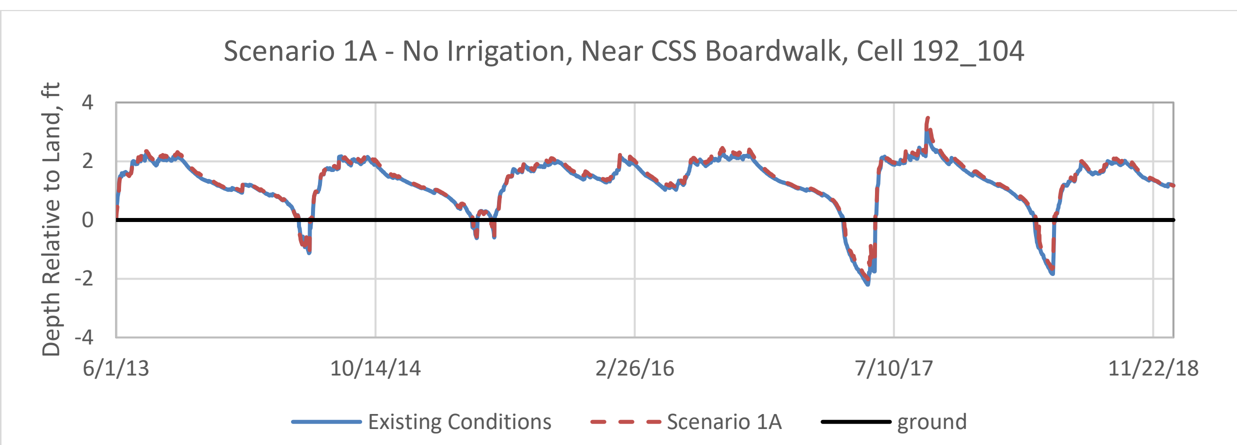


Figure 4.4 – Simulated Water Depths Relative to Land Surface for Scenario 1A and Existing Conditions for Corkscrew Swamp Sanctuary Near the Boardwalk, Cell 192_104

Figures 4.5 and **4.6** present water level changes for Scenario 1B and for the existing conditions simulation. Results from elimination of withdrawals from public water supply well fields were relatively similar to Scenario 1A in that changes were observed in Flint Pen Strand, but no hydroperiod or water level change was observed within the Sanctuary.

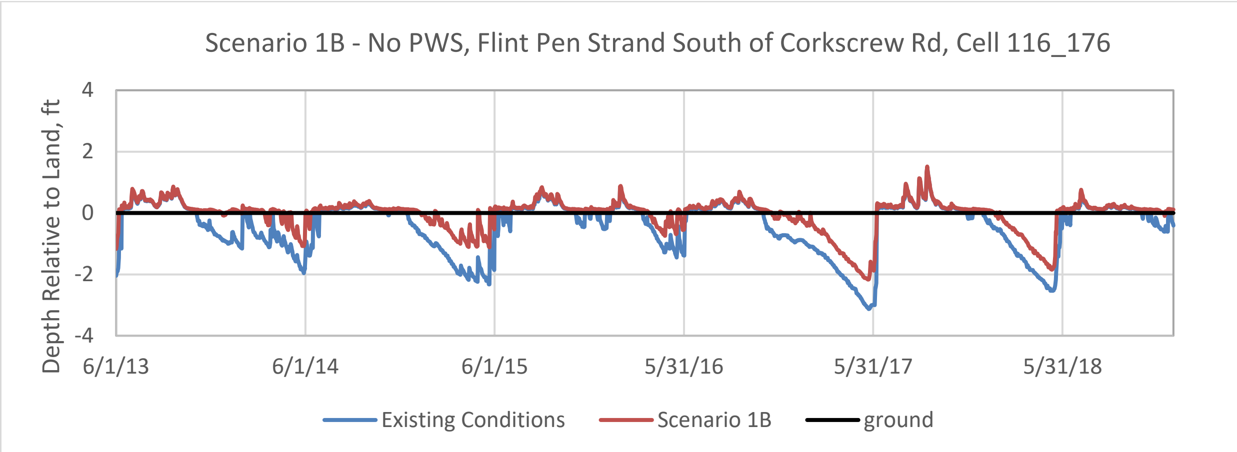


Figure 4.5 – Simulated Water Depths Relative to Land Surface for Scenario 1B and Existing Conditions for Flint Pen Strand, Cell 116_176

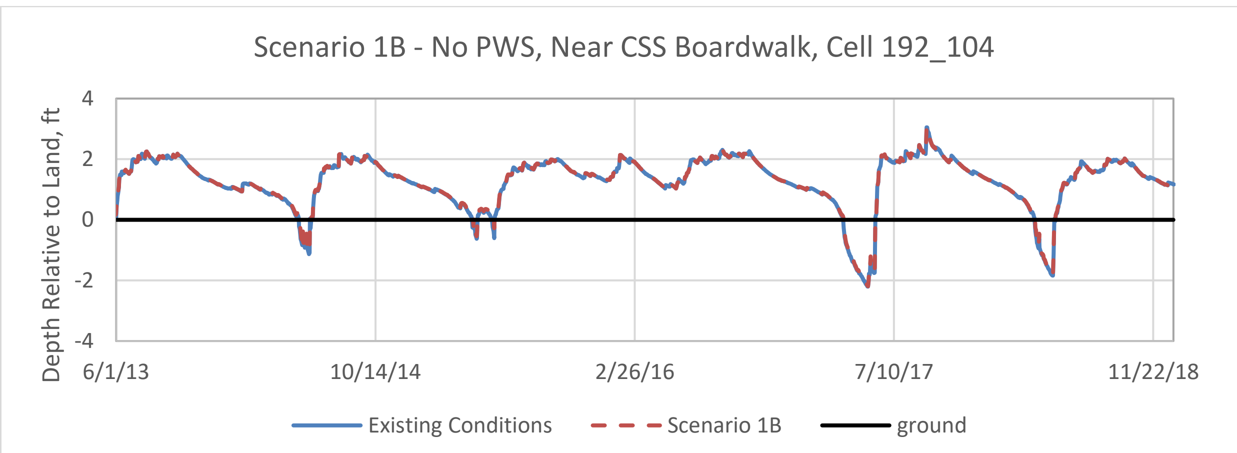


Figure 4.6 – Simulated Water Depths Relative to Land Surface for Scenario 1B and Existing Conditions for Corkscrew Swamp Sanctuary Near the Boardwalk, Cell 192_104

Scenario 1C assumed that both public water supply withdrawals and irrigation were eliminated. In addition, canals in the vicinity of irrigated areas were modified to reduce channel depths and drainage levels were reduced from lands no longer irrigated. The simulation results indicated significantly higher water levels in Flint Pen Strand and resulted in a modest increase in wetland hydroperiods in the Sanctuary near the boardwalk, as indicated in **Figures 4.7** and **4.8**. This simulation was only run for 2013 – 2014.

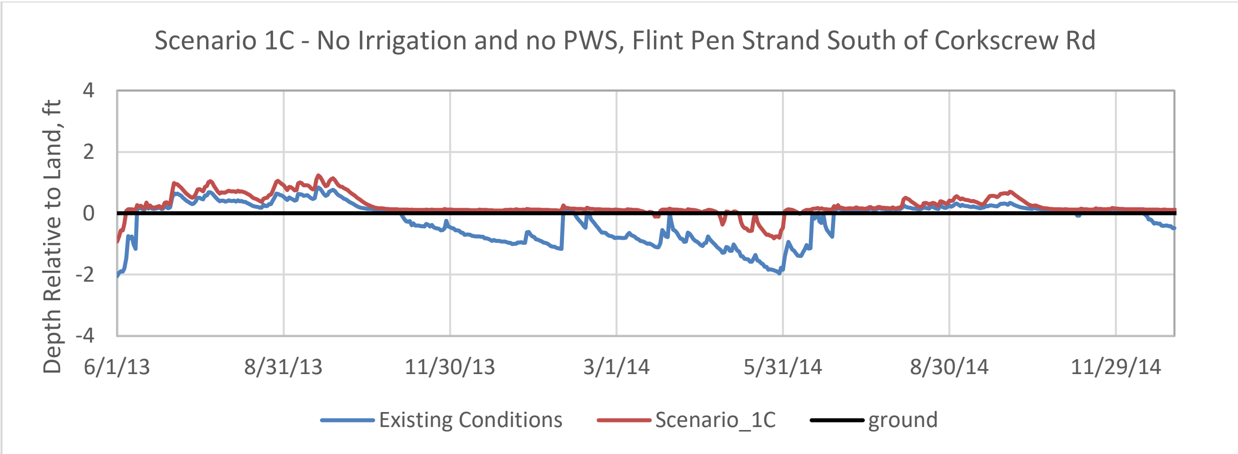


Figure 4.7 – Simulated Water Depths Relative to Land Surface for Scenario 1C and Existing Conditions for Flint Pen Strand, Cell 116_176

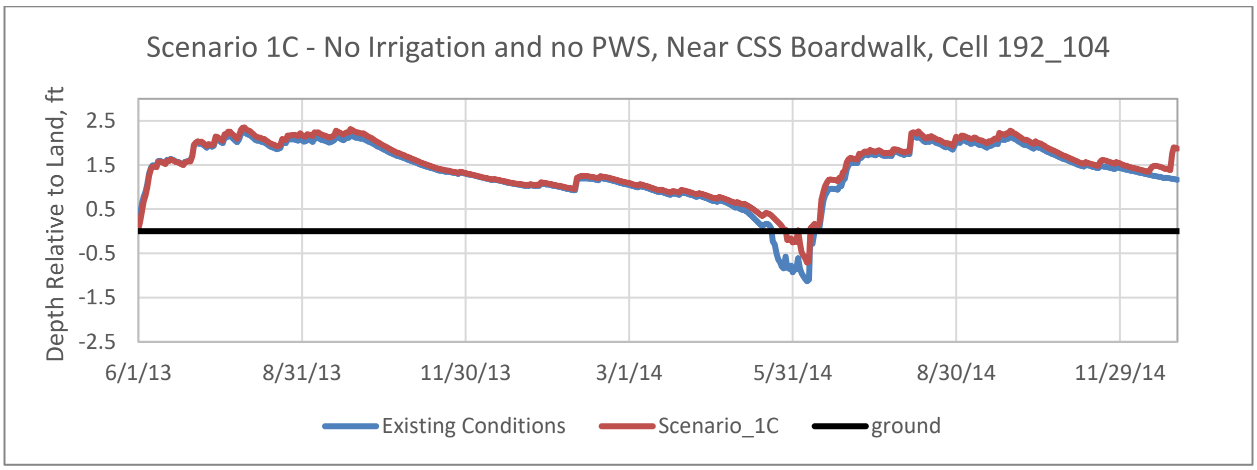


Figure 4.8 – Simulated Water Depths Relative to Land Surface for Scenario 1C and Existing Conditions for Corkscrew Swamp Sanctuary Near the Boardwalk, Cell 192_104

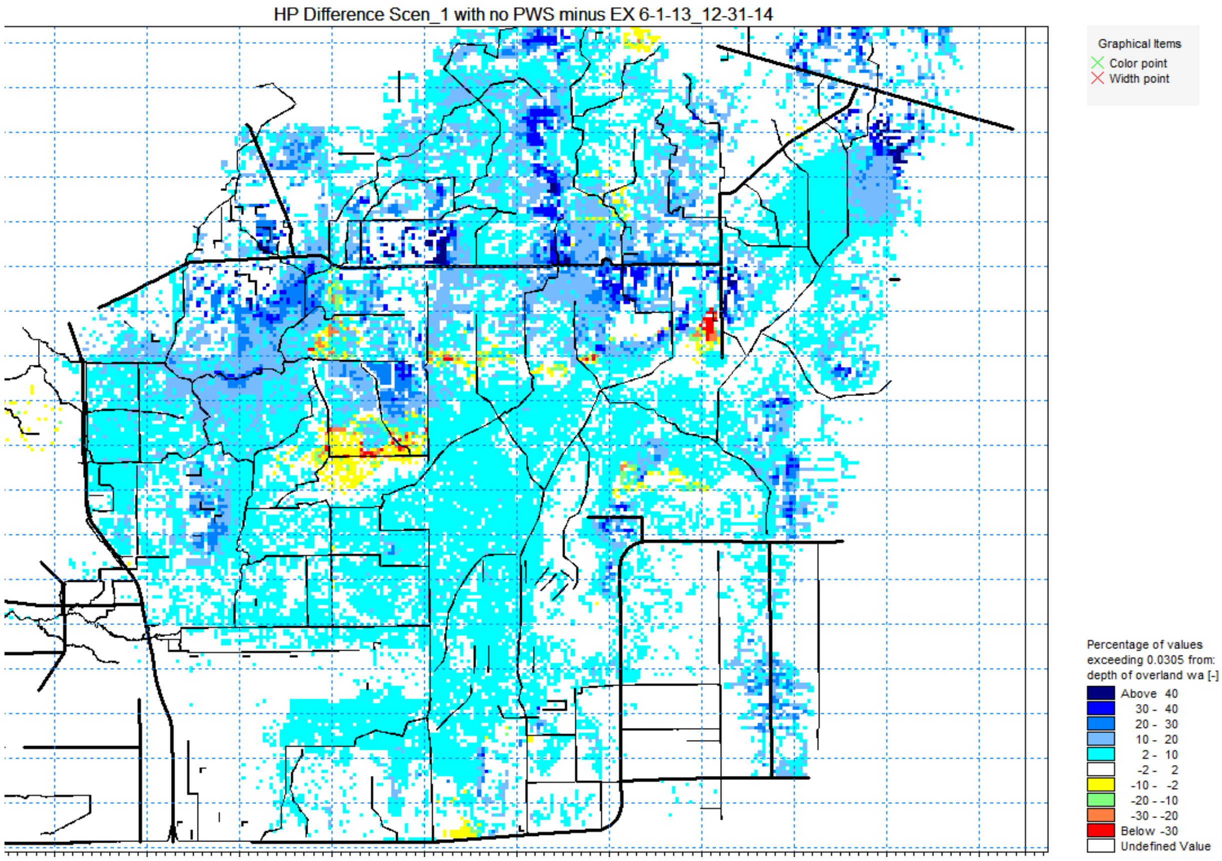


Figure 4.9 – Hydroperiod Difference for Scenario 1C minus Existing Conditions 6-1-13 through 12-31-14

4.3 Scenario 2 – Eliminating Willow and Reduced Density of Woody Vegetation

This model scenario included changes to the land use file to evaluate the impact of changes in vegetation communities and resulting changes in evapotranspiration on the Sanctuary water budget. All willow land cover cells were converted to marshes and flatwood (hydric and mesic) density was reduced by 75 percent. Hydric flatwoods were converted to wet prairies and mesic flatwoods were converted to pastures. In this region, woody marsh vegetation like Carolina willow (*Salix caroliniana*) and upland tree densities have increased markedly over the past few decades, likely due in large part to a reduction in fire frequency. Wet prairies and marshes once dominated by herbaceous vegetation (e.g., sawgrass) are now dominated by willow and upland tree densities have increased by two orders of magnitude (McCollum and Duever, 2018). Recent studies have shown that Carolina willow evapotranspiration rates are significantly higher than those of sawgrass (Budny, 2015; Hall et al., 2017), and the higher evapotranspiration rates could result in lowering of groundwater elevations in the dry season (Clem and Duever, 2019). Further, increased tree densities could also result in higher evapotranspiration due to the deeper root depths and higher leaf area index in comparison to either marsh or pasture (M. Duever, unpublished data).

Figure 4.10 presents water levels for Scenario 2 and existing conditions for a model cell near the Sanctuary boardwalk. The comparison indicates an absence of significant water level changes. Water budget analysis of model cells which were converted from willow to marsh (see **Figure 4.11** for location of the water budget area) indicated that annual evapotranspiration rates were decreased by 2 percent for Scenario 2 than for existing conditions. The water budget analysis indicated that the reduced evapotranspiration under Scenario 2 is >1,500 acre-feet per year. Water balance analysis of all vegetation within the footprint identified in **Figure 4.11** indicated that the overall water budget for Scenario 2 remained relatively similar to the existing conditions simulations. Despite these findings, reduction of willow coverage in this region is still highly recommended because of the decreased evapotranspiration, increased ability to manage the habitat using prescribed fire, and numerous benefits for wildlife associated with increasing openness and reducing habitat structure of wetland habitats.

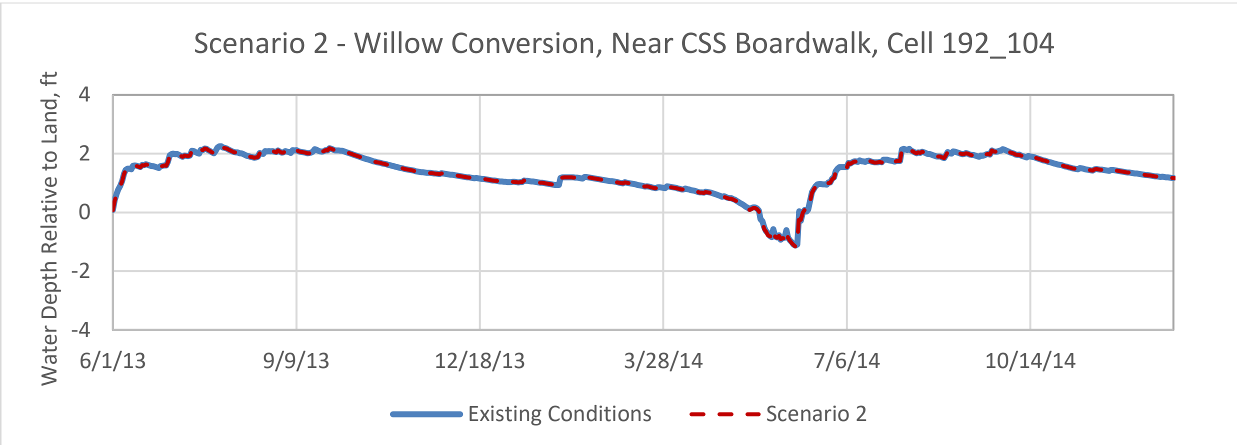


Figure 4.10 – Simulated Water Depths Relative to Land Surface for Scenario 2 and Existing Conditions for Corkscrew Swamp Sanctuary Near the Boardwalk, Cell 192_104

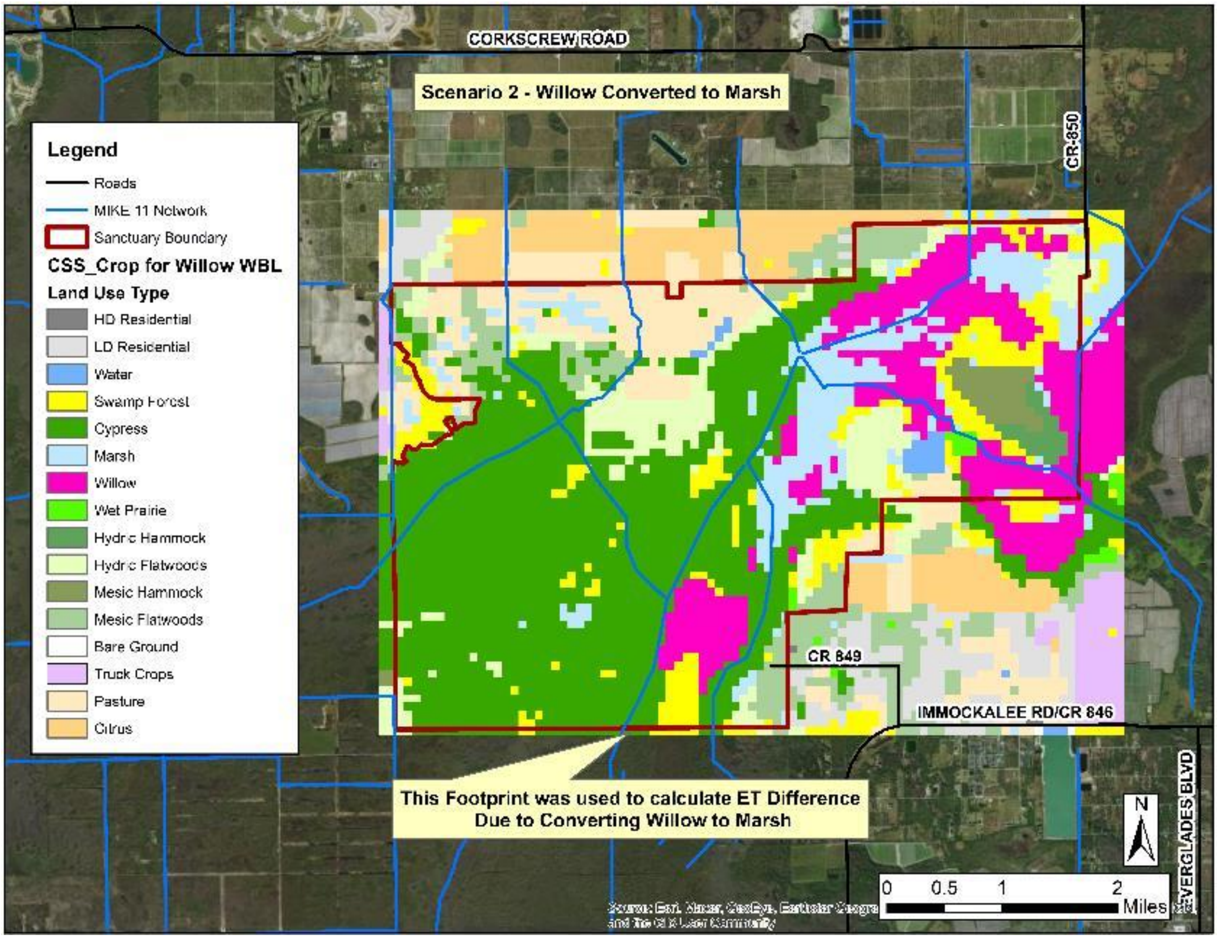


Figure 4.11 – Area in Vicinity of Corkscrew Swamp Sanctuary Used for Water Budget Analysis of Conversion of Willow and Woody Vegetation

4.4 Scenario 3 – Reduce Downstream Drainage

The area modified for Scenario 3 is shown in **Figure 4.12**. Canal cross-sections were changed to have simulated invert elevations equivalent to adjacent natural land elevations for all canals within the highlighted area. The following changes were implemented:

- Corkscrew Canal and tributary canal cross sections were modified, and water control structures Cork 2 and Cork 3 were removed. Manning's n was changed to 0.2.
- Cross sections for Golden Gate Canal and tributary canals upstream of GoldW5 were modified as described above and upstream structures were removed. Weir GoldW5 was removed and the downstream boundary condition was set to 15 feet-NAVD.
- Similar changes were made to Faka Union Canal upstream of FU-6. The weir elevation of FU-6 was not changed, but the V-notch gate was set to remain fully closed.
- Cross-sections for Cocohatchee Canal upstream of Coco #3 were modified and upstream water control structures Cork 1 and Curry #1 were removed. Outflows south from Cocohatchee Canal to Curry Canal and Corkscrew Canal through CORK1 were terminated. The weir elevation of Coco #3 was changed as shown in **Figure 4.13** and the two Coco #3 underflow gates were removed.

The land use for the modified area was changed back to natural land coverages (either unimproved pasture or wet prairie). There were no changes to topography; therefore, cells with elevations representing developed lands remain higher than the surrounding areas of undisturbed lands. It should be repeated that this was not seen as a realistic scenario that could be implemented. The purpose of the analysis was to implement a major change to the model set-up in order to force the model to yield the most important factors governing hydrology in the Sanctuary.

Figures 4.14 and **4.15** present simulated water levels relative to ground surface for Scenario 3 and existing conditions for calculation points 192_104 (the Sanctuary Boardwalk) and 176_62 (BRS south hiking trail). **Figure 4.13** presents the locations of these two calculation points. Significant increases in water level and hydroperiod were observed at both the Sanctuary Boardwalk and at the BRS south hiking trail, and water levels remain above ground throughout the dry seasons of 2014, 2015, 2017, and 2018. It is likely that the complete elimination of flows south of Cocohatchee Canal via Curry Canal and Corkscrew Canal (CUR1 and CORK1 on **Figure 4.13**) contribute to the significant water level increase.

With the aforementioned changes, the wetland hydroperiods (**Figure 4.16**) are increased in the Sanctuary and in the area south of SFWMD structures CORK2 and CORK3. The topographic file was not changed and high ground elevations west of Point A shown in **Figure 4.16** limit western flows from the area of the longest hydroperiods. It is likely that the hydroperiod response would not be as dramatic if the topographic file were modified. This change was not made in the model because the goal of this scenario was to determine if the drainage south of CORK2 and CORK3 had a significant impact on the hydrology of the Sanctuary. This simulation indicates that downstream drainage has a significant impact on the hydrology of the Sanctuary and that this key factor has a markedly greater influence on the hydrology of Sanctuary than the other factors evaluated in this modelling study.

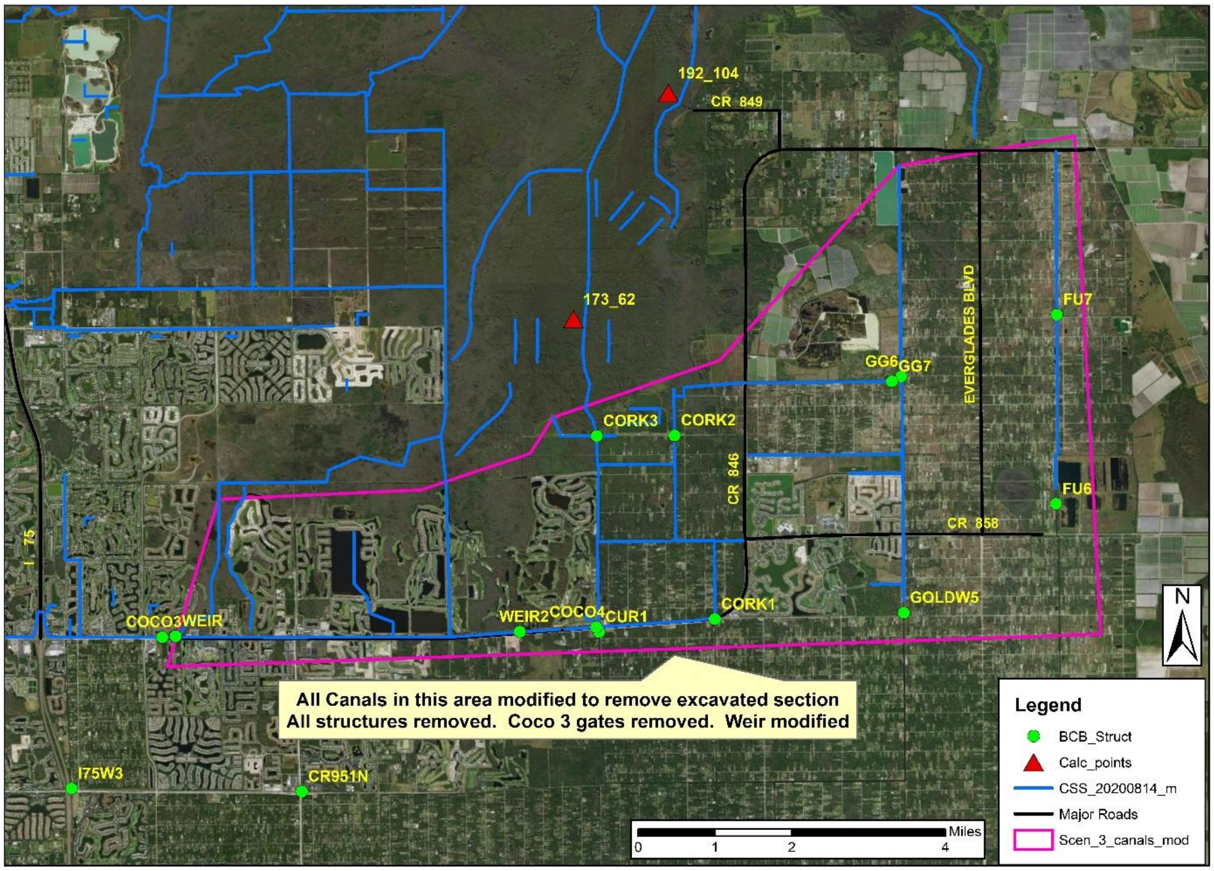


Figure 4.12 – Map of Area Converted from Urban Land Use to Natural Land Cover Types

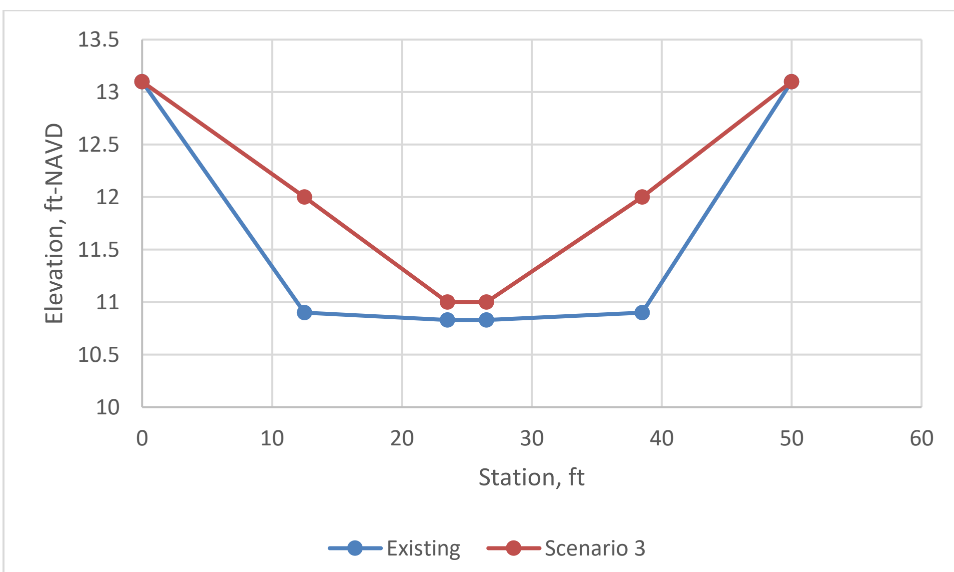


Figure 4.13 – Coco #3 Weir Dimensions for Existing Conditions and Scenario 3

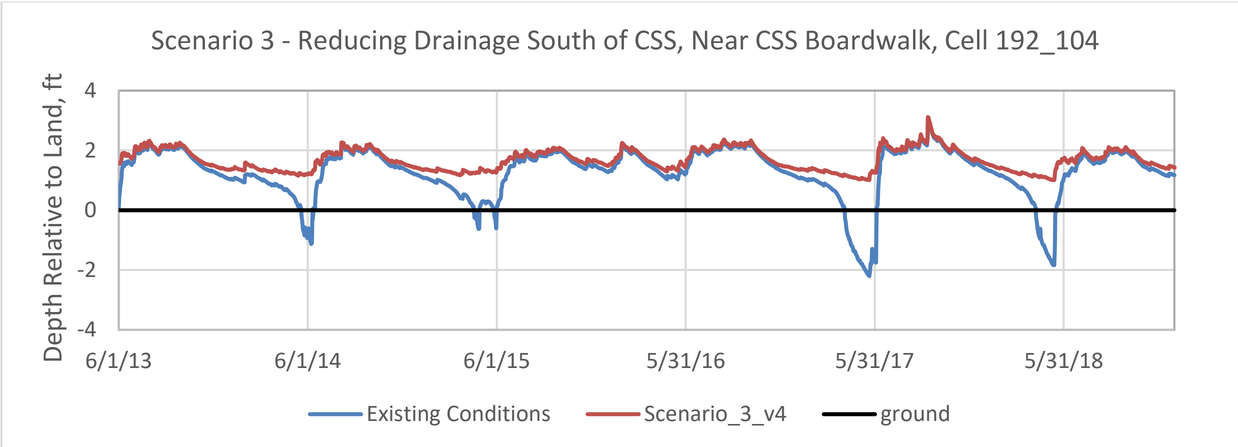


Figure 4.14 – Simulated Water Depths Relative to Land Surface for Scenario 3 and Existing Conditions for Corkscrew Swamp Sanctuary Near the Boardwalk, Model Cell 192_104

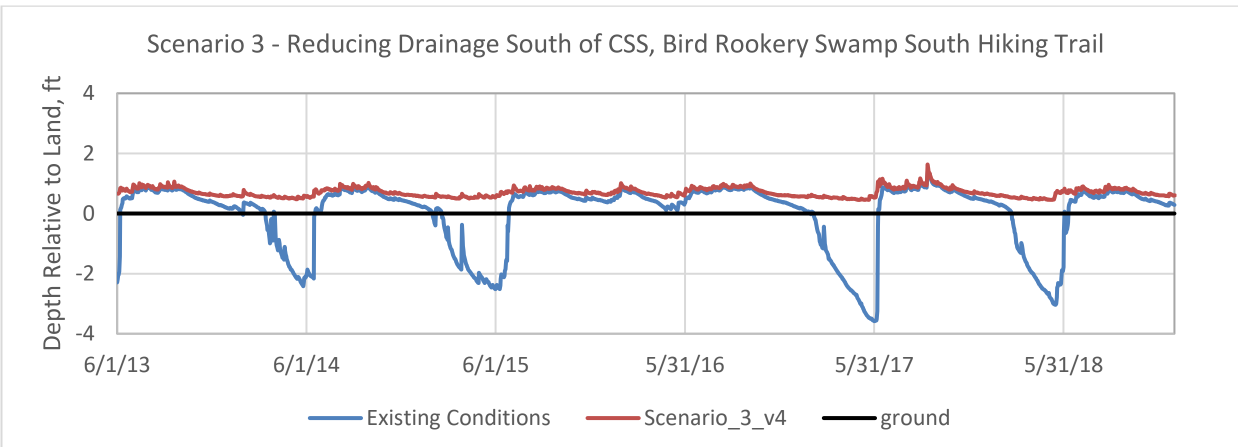


Figure 4.15 – Simulated Water Depths Relative to Land Surface for Scenario 3 and Existing Conditions for the Bird Rookery South Hiking Trail, Model Cell 173_62

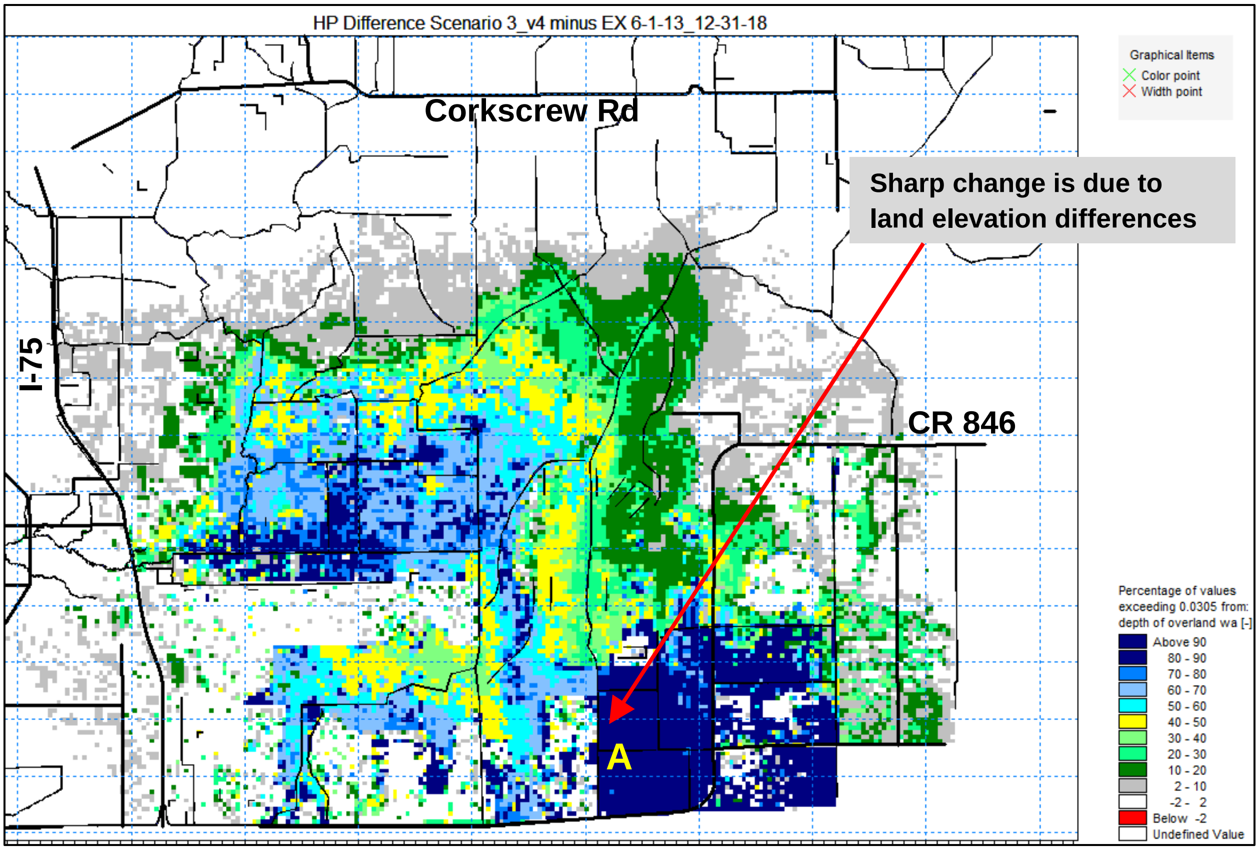


Figure 4.16 – Hydroperiod Difference Map for Scenario 3 and Existing Conditions for the Period June 1, 2013 through December 31, 2018

4.5 Scenario 4 – Reduce Outflows from Corkscrew Swamp Sanctuary

Scenario 3 had the greatest impact on increasing wetland hydroperiod in the Sanctuary. However, that model scenario was only hypothetical and could not be implemented, as it is unreasonable to assume that 24 square miles of existing residential areas and 31 miles of canals will be converted back to natural lands. Accordingly, Scenario 4 was developed with the objective of increasing wetland hydroperiods in the Sanctuary while maintaining existing levels of flood protection in the residential area downstream of Bird Rookery Swamp (BRS). Components of that scenario are illustrated in **Figure 4.17** and are listed below:

- Weirs were added upstream of culverts and weirs along the South Dike to slow the drainage of wet season water levels. The South Dike is a former logging tram and also known as the north loop of the BRS hiking trail (between Points 4 and 5).
- A clay slurry wall was assumed to be constructed under the South Dike to reduce southward groundwater flow from the Sanctuary.
- The invert elevations of existing culverts under the South Dike were increased.
- A weir was added at the upstream end of Corkscrew Canal north of NE 47th Street. The invert elevation was set at 14 feet-NAVD with a bottom width of 20 feet. The top of the simulated weir was assumed to be 16 feet-NAVD with a top width of 60 feet.
- The operating rules for Cork 2 and Cork 3 were modified in the simulation to maintain higher water levels in BRS. The gates were programmed to open one foot higher than existing conditions.
- The elevation of an existing weir north of Cork 3 was increased by one foot.

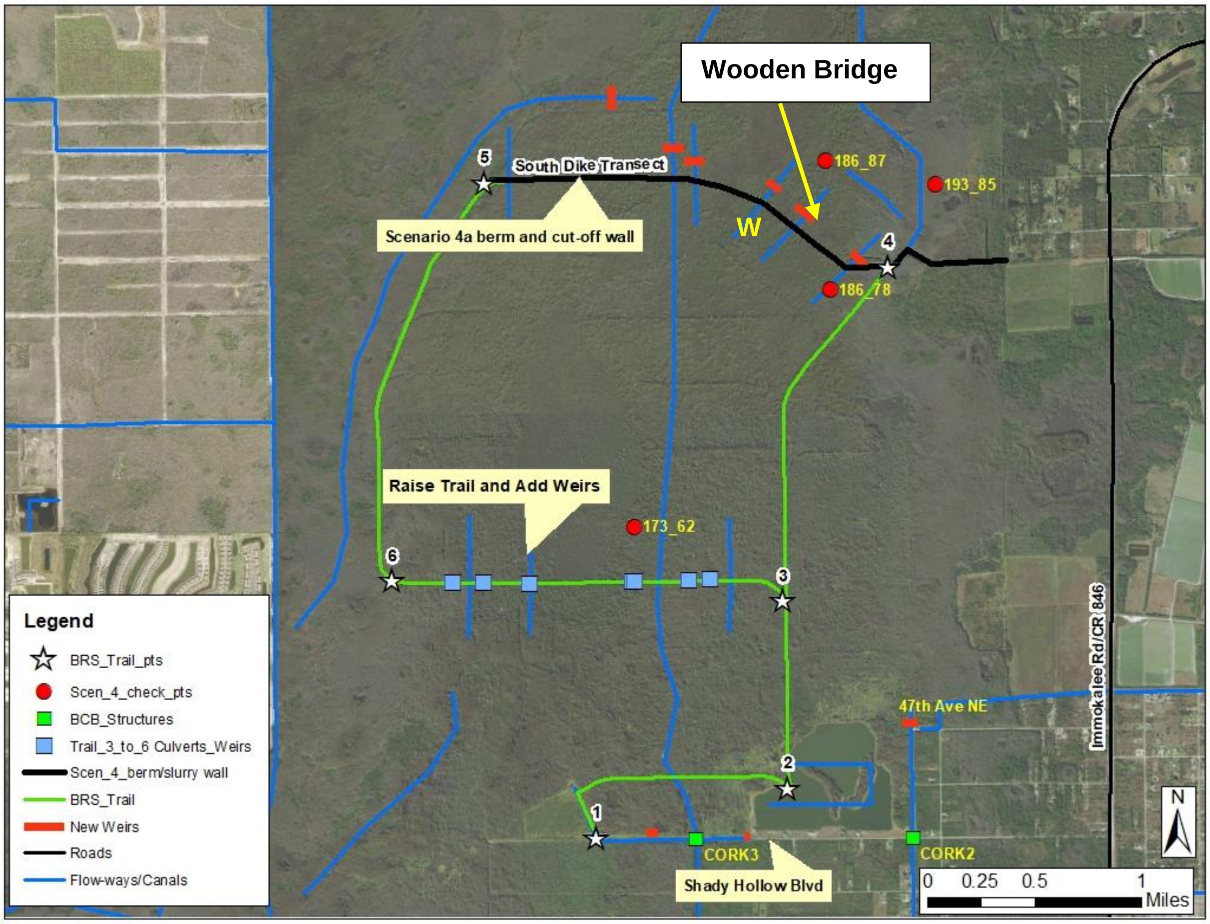


Figure 4.17. Scenario 4 Restoration Measures

Figures 4.18 and **4.19** present simulated water levels relative to land surface at the Sanctuary near the boardwalk (location shown in **Figure 4.1**) and at the South Dike Transect (location shown in **Figure 4.17**). The simulation results indicate that dry season water levels are approximately one foot higher than existing conditions during 2014 and 2015. The simulations indicate water levels below ground surface in the vicinity of the Sanctuary boardwalk for the 2017 and 2018 dry season. However, that representation is likely inaccurate for portions of the wetlands in the vicinity of the boardwalk, as field measurements of ground elevations along the boardwalk suggest that actual elevations may be one to two feet lower than the LiDAR elevations. Further evaluation of wetland hydroperiods are recommended once more accurate topography is available. **Figure 4.20** presents water levels relative to land surface at the BRS Trail (section 3 to 6, location shown in **Figure 4.17**). **Figure 4.21** presents a hydroperiod difference map for Scenario 4 relative to existing conditions for June 1, 2013 through December 31, 2018. Scenario 4 results in approximately 6 percent longer hydroperiods in the Sanctuary, Gordon Swamp, portions of BRS, and the Mirasol Flow-way (locations are shown in **Figure 4.21**). Hydroperiods are also higher in wetlands in Southern CREW (west of point 2 in **Figure 4.21**). The impact of Scenario 4 on the hydrologic changes in Southern CREW should be further evaluated once better topographic data are available in the Sanctuary.

The model scenario results indicate that Scenario 4 will have slightly lower water levels than existing conditions in portions of BRS. Refinements of this scenario may need to be made should additional analyses indicate that hydroperiods in BRS are less than optimum conditions. Due to questions regarding the accuracy of topography in BRS, refinement of BRS wetland hydroperiods was not conducted but should be evaluated in greater detail once more accurate topography is available.

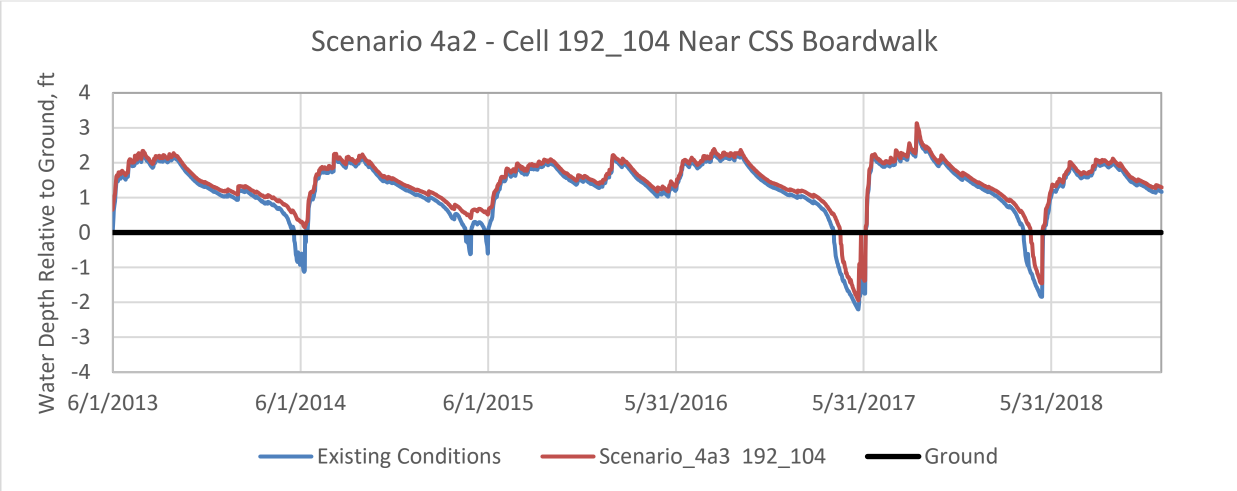


Figure 4.18 – Simulated Water Depths Relative to Land Surface for Scenario 4 and Existing Conditions for Corkscrew Swamp Sanctuary Near the Boardwalk, Model Cell 192_104

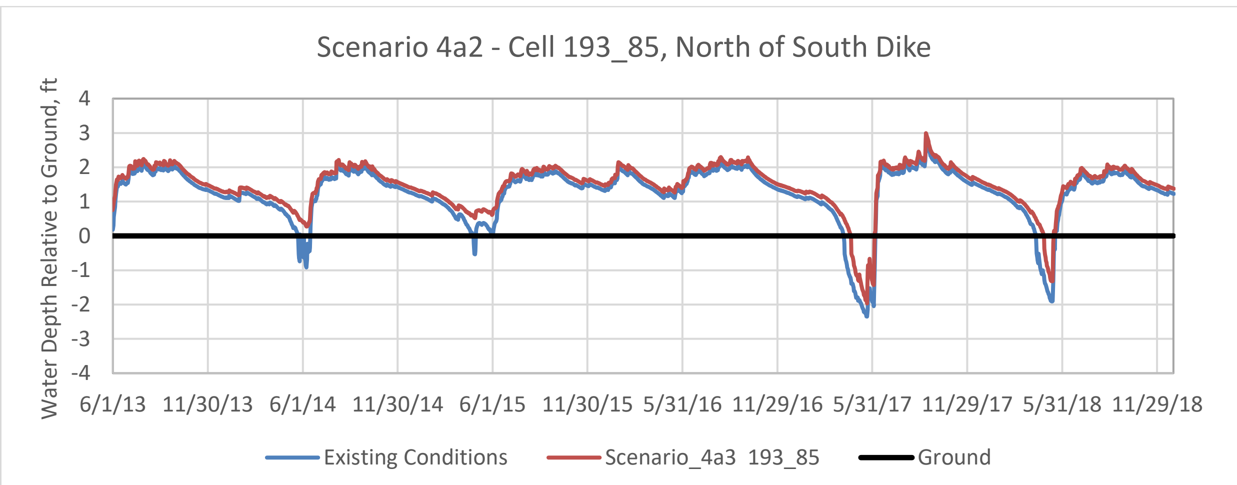


Figure 4.19 – Simulated Water Depths Relative to Land Surface for Scenario 4 and Existing Conditions for Corkscrew Swamp Sanctuary Near the Boardwalk, Model Cell 193_85

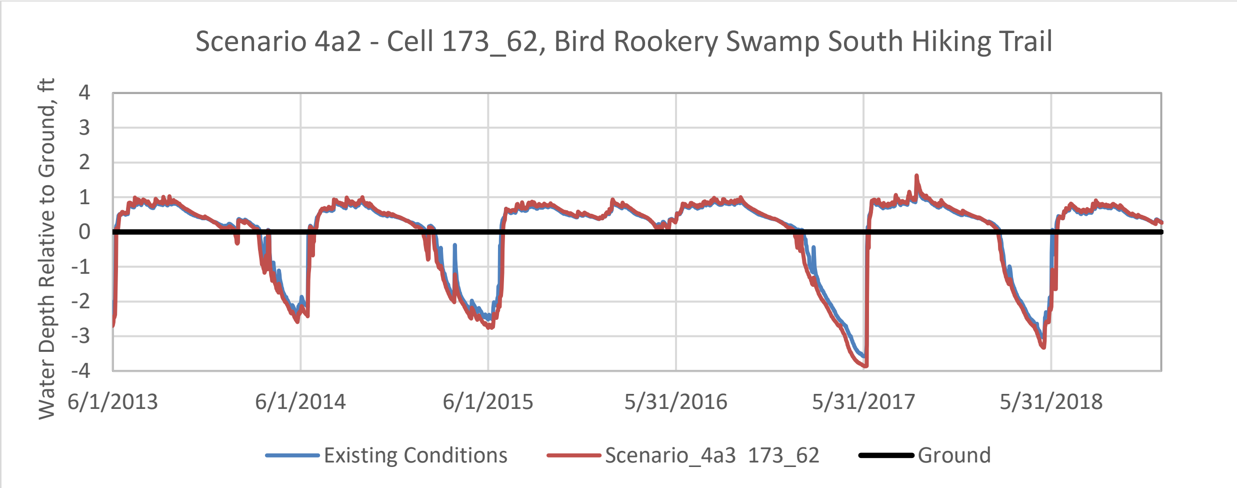


Figure 4.20 – Simulated Water Depths Relative to Land Surface for Scenario 4 and Existing Conditions for Bird Rookery Swamp South Hiking Trail, Model Cell 173_62

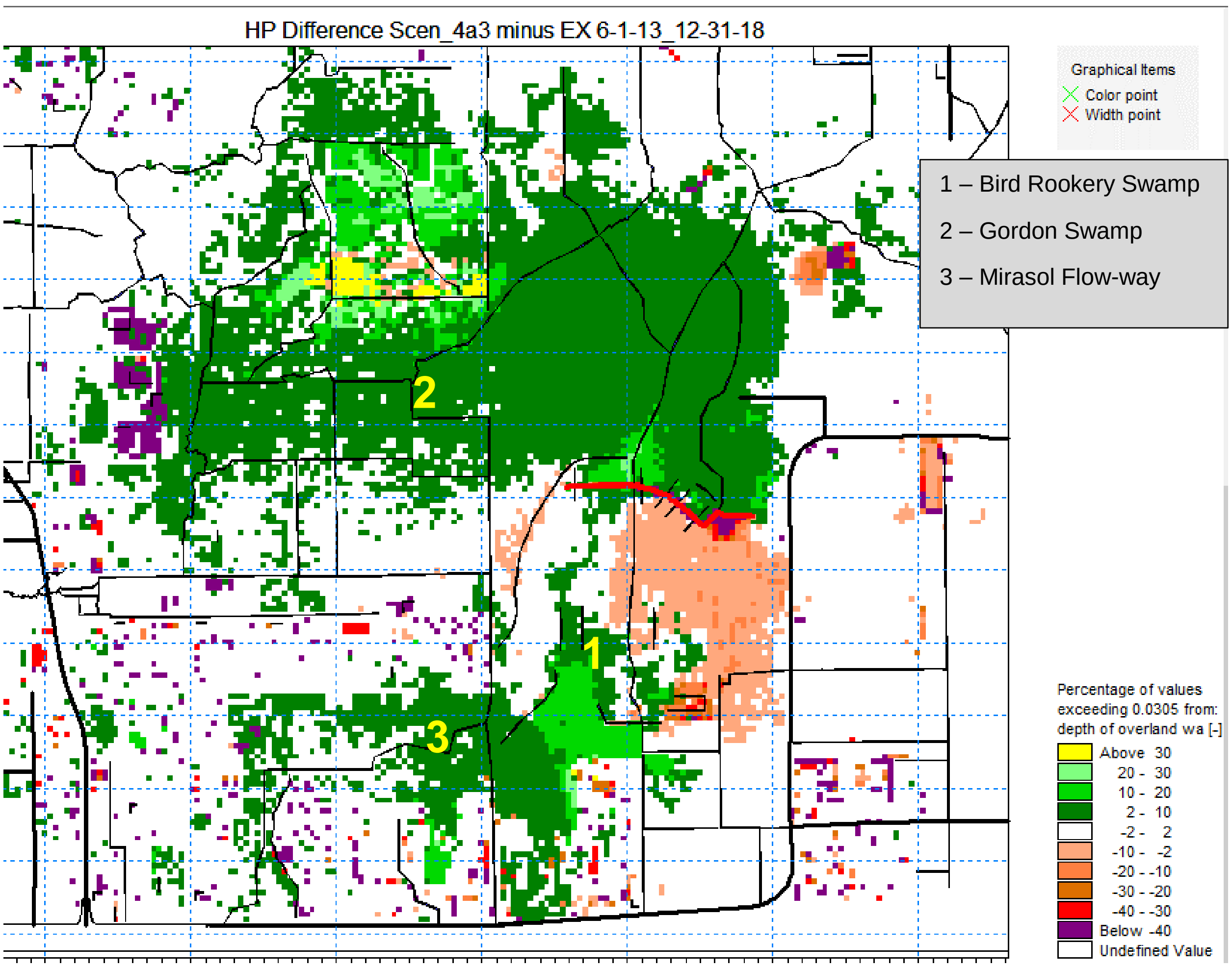


Figure 4.21 – Hydroperiod Difference for Scenario 4 and Existing Conditions for the Period June 1, 2013 through December 31, 2018

5.0 CONCLUSIONS AND RECOMMENDATIONS

The MIKE SHE/MIKE 11 model developed for this project was successfully calibrated for 2013 – 2014 and the 2015 – 2018 simulation period validated the successful calibration. The validation period included periods of extreme drought and flooding and the model performed well across a wide variety of climatic conditions. The accuracy of the LiDAR topography for portions of the model domain is less than desired; however, these challenges did not prevent the project objectives from being achieved. The model was able to evaluate a range of model scenarios, and simulated responses in wetland hydroperiod were demonstrated within Corkscrew Swamp Sanctuary.

The model was used to evaluate four scenarios, summarized below:

1. Reduction of groundwater withdrawals from agricultural irrigation and public water supply wells;
2. Elimination of willow and reduced tree density of mesic and hydric flatwoods;
3. Elimination of downstream drainage; and
4. Addition of weirs and clay slurry cutoff walls to reduce discharges from the Sanctuary

Scenarios 1 through 3 were designed to test which factors “move the needle” and create a hydrologic response but were not considered to be reasonable scenarios that could ever be implemented. Scenario 4, however, was developed based on an evaluation of the results of Scenarios 1 through 3 and represents a reasonable restoration option using restoration measures that are commonly used in hydrologic restoration projects. Scenario 4 included a clay slurry cutoff wall and a number of weirs upstream of existing culverts and conveyances (see **Section 4.5** for a detailed description of this scenario).

Scenario 1 was evaluated in three different configurations. Reduction of agricultural irrigation (Scenario 1A) resulted in hydroperiod improvements in wetlands in Flint Pen Strand south of Corkscrew Road. In Flint Pen Strand, increased dry water levels were beneficial for cell 116_176 (see Figure 4.2). Reduction of irrigation reduced dry season flows from agricultural lands to the northern portion of the Sanctuary, as represented by water levels in cell 226_148 shown in Figure 4.3. As a result, water levels in the dry season at cell 226_148 were reduced by 1 to 1.5 feet, which is more representative of the natural hydroperiod for that habitat type, and the hydroperiod that was observed in that area prior to recent decades. Reduction of public water supply groundwater withdrawals (Scenario 1B) had a positive impact on wetland hydroperiod in Flint Pen Strand just south of the Corkscrew wellfield. Neither Scenarios 1A nor 1B had any impact on the wetland hydroperiods in the vicinity of the Sanctuary boardwalk. Reduction of both agricultural and public water supply withdrawals (Scenario 1C) was the only variant of Scenario 1 that resulted in increased wetland hydroperiods in the vicinity of the Sanctuary boardwalk, although the increase was modest.

Scenario 2 reduced evapotranspiration in habitats currently dominated by Carolina willow or a high density of upland trees. Water balance analysis of all vegetation within the vicinity of the Sanctuary indicated that the overall budget for Scenario 2 remained relatively similar to the existing conditions simulations. Reduction of willow coverage is still recommended, because a decrease in willow results in a number of benefits to native plant communities and wildlife and facilitates land management using prescribed fire.

Scenario 3 had the greatest impact on wetland hydroperiods within the Sanctuary and resulted in a complete elimination of dry season water levels below ground surface for 2013 through 2018.

Scenario 4 demonstrated an improvement in wetland hydroperiods in the Sanctuary and in other wetlands in the vicinity of the Sanctuary. This scenario includes:

- A clay slurry cutoff wall along the South Dike transect;
- Weirs upstream of culverts under the South Dike;
- Weirs upstream of an east-west hiking trail in BRS;
- A weir in Corkscrew Canal near the upstream limit of the excavated canal;
- A reduction in drainage along the southern limit of BRS; and
- Slight reductions in gate openings for Cork2 and Cork3.

Additional analysis is recommended to further refine Scenario 4 and maximize hydrologic restoration of the Sanctuary. This scenario should also be evaluated further once issues with the accuracy of topographic data (described below) have been addressed.

Improvements in the accuracy of topographic data are recommended in the southern portion of the Sanctuary and BRS. The LiDAR topography is inaccurate due the inability of LiDAR to determine accurate ground elevations in flooded areas and in areas of dense woody vegetation. Since Corkscrew Swamp has extensive coverage of dense swamp forests and cypress that have long hydroperiods, it should be expected that LiDAR topography might have limitations that impact the accuracy of modeling evaluations. At least five transects using traditional surveying techniques are needed to correct the topography with 2 to 3 of the transects located in BRS. A map illustrating the locations of the desired cross sections is included above in **Section 3.5**.

Additional monitoring wells are also recommended, as mentioned above in **Section 3.5**. Recommended locations are indicated in **Figure 5.1** and include:

- A north-south transect of monitoring wells through the Sanctuary and BRS is also recommended to assist in model calibration;
- The Cork monitoring station should be re-activated; and
- A monitoring station is recommended at the edge of wetlands in the Caracara Prairie Preserve east of existing monitoring well L-1138 (see **Figure 5.1** for the location of the station labeled as **Caracara**).

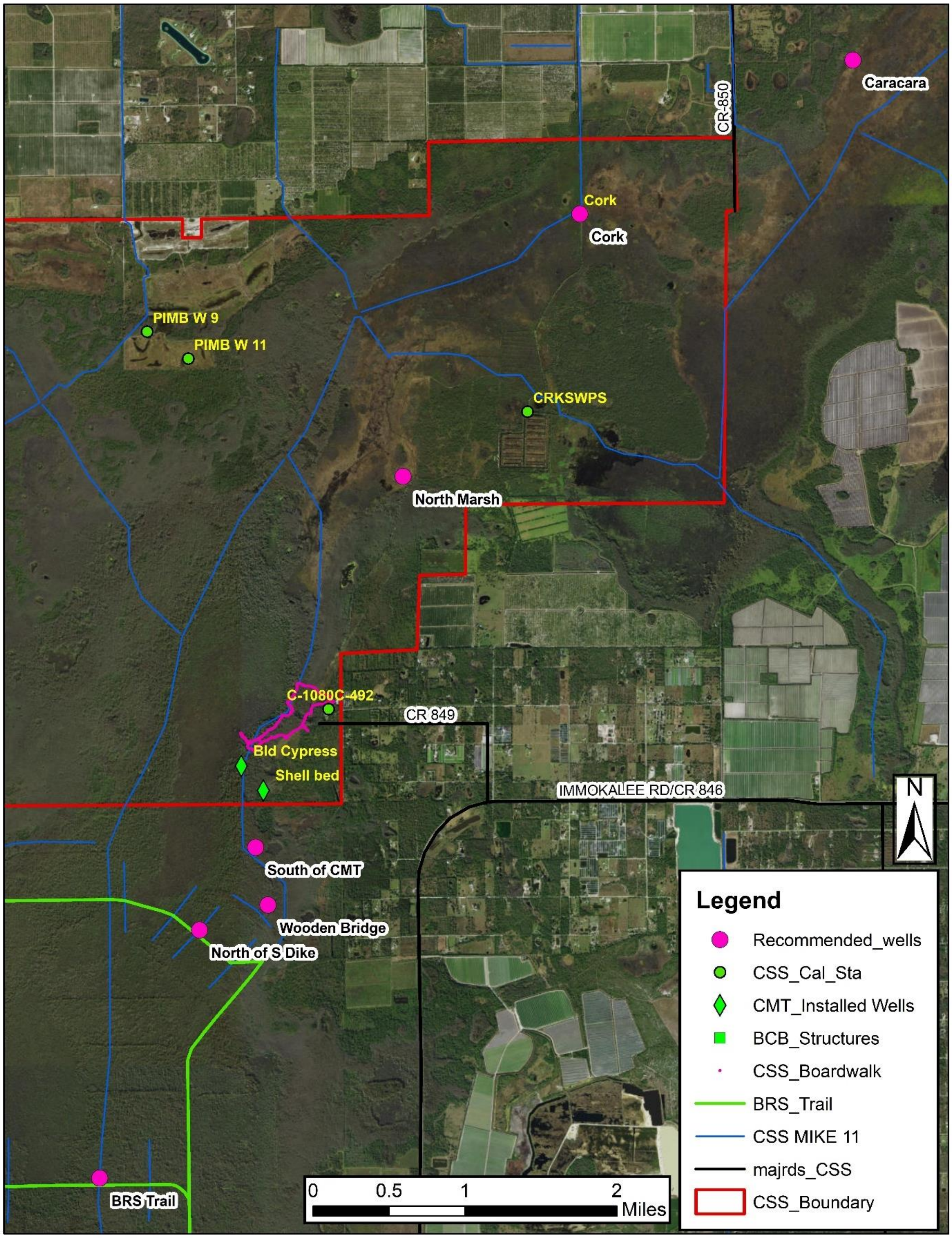


Figure 5.1 – Map of Current and Additional Recommended Monitoring Stations

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ATTACHMENT 1

Crosswalk Table Between SFWMD Land Use Files and MIKE SHE Land Use Categories

Attachment 1 – Crosswalk Table Between SFWMD Land Use Files and MIKE SHE Land Use Categories (SFWMD 2018).

MSHE_Code	MSHE_Description	FLUCCS	FLUCCS_Description
1	Citrus	2210	Citrus Groves
1	Citrus	2230	Other Groves
2	Pasture	1920	Inactive Land with Street Pattern
2	Pasture	2110	Improved Pastures
2	Pasture	2120	Unimproved Pastures
2	Pasture	2130	Woodland Pastures
2	Pasture	2610	Fallow Cropland
2	Pasture	8320	Electrical Power Transmission Lines
2	Pasture	2240	Abandoned Groves
2	Pasture	3100	Herbaceous (Dry Prairie)
2	Pasture	2510	Horse Farms
5	Truck Crops	2140	Row Crops
5	Truck Crops	2150	Field Crops
5	Truck Crops	2500	Specialty Farms
6	Golf Course	1820	Golf Course
7	Bare Ground	1610	Strip mines
7	Bare Ground	1620	Sand and Gravel Pits
7	Bare Ground	1630	Rock Quarries
7	Bare Ground	1670	Abandoned Mining Lands
7	Bare Ground	1810	Swimming Beach
7	Bare Ground	7200	Sand Other Than Beaches
7	Bare Ground	7400	Disturbed Land
7	Bare Ground	8350	Solid Waste Disposal
8	Mesic Flatwood	1900	Open Land
8	Mesic Flatwood	2430	Ornamentals
8	Mesic Flatwood	3200	Upland Shrub and Brushland
8	Mesic Flatwood	3210	Palmetto Prairies
8	Mesic Flatwood	3300	Mixed Rangeland
8	Mesic Flatwood	4110	Pine Flatwoods
8	Mesic Flatwood	4410	Coniferous Plantations
8	Mesic Flatwood	4430	Forest Regeneration Areas
8	Mesic Flatwood	7470	Dikes and Levees
9	Mesic Hammock	4200	Upland Hardwood Forests
9	Mesic Hammock	4220	Brazilian Pepper
9	Mesic Hammock	4271	Oak - Cabbage Palm Forest
9	Mesic Hammock	4300	Upland Mixed Forests
9	Mesic Hammock	4340	Upland Mixed Coniferous / Hardwood
10	Xeric Flatwood	4130	Sand Pine
11	Xeric Hammock	3220	Coastal Shrub
12	Hydric Flatwood	6240	Cypress - Pine - Cabbage Palm

MSHE_Code	MSHE_Description	FLUCCS	FLUCCS_Description
12	Hydric Flatwood	6250	Wet Pinelands Hydric Pine
13	Hydric Hammock	4240	Melaleuca
13	Hydric Hammock	4280	Cabbage Palm
13	Hydric Hammock	6180	Cabbage Palm Wetland
13	Hydric Hammock	7430	Spoil Areas
14	Wet Prairie	6430	Wet Prairie
16	Marsh	6400	Vegetated Non-Forested Wetlands
16	Marsh	6410	Freshwater Marshes / Graminoid Prairie - Marsh
16	Marsh	6440	Emergent Aquatic Vegetation
17	Cypress	6200	Wetland Coniferous Forests
17	Cypress	6210	Cypress
17	Cypress	6215	Cypress- Domes/Heads
17	Cypress	6216	Cypress - Mixed Hardwoods
18	Swamp Forest	6170	Mixed Wetland Hardwoods
18	Swamp Forest	6172	Mixed Shrubs
18	Swamp Forest	6191	Wet Melaleuca
18	Swamp Forest	6300	Wetland Forested Mixed
19	Mangrove	6120	Mangrove Swamp
19	Mangrove	6420	Saltwater Marshes / Halophytic Herbaceous Prairie
20	Water	1660	Holding Ponds
20	Water	1840	Marinas and Fish Camps
20	Water	2540	Aquaculture
20	Water	5110	Natural River, Stream, Waterway
20	Water	5120	Channelized Waterways, Canals
20	Water	5200	Lakes
20	Water	5300	Reservoirs
20	Water	5410	Embayments Opening Directly to Gulf or Ocean
20	Water	5720	Gulf of Mexico
20	Water	6510	Tidal Flats
41	Urban Low Density	1110	Fixed Single Family Units
41	Urban Low Density	1120	Mobile Home Units
41	Urban Low Density	1130	Mixed Units, Fixed and Mobile Home Units
41	Urban Low Density	1180	Rural Residential
41	Urban Low Density	1190	Low Density Under Construction
41	Urban Low Density	1480	Cemeteries
41	Urban Low Density	1850	Parks and Zoos
41	Urban Low Density	1860	Community Recreation Facilities
41	Urban Low Density	1890	Other Recreational Facilities
42	Urban Medium Density	1210	Fixed Single Family Units
42	Urban Medium Density	1220	Mobile Home Units
42	Urban Medium Density	1230	Mixed Units, Fixed and Mobile Home Units
42	Urban Medium Density	1290	Medium Density Under Construction
42	Urban Medium Density	8330	Water Supply Plants - Including Pumping Stations
42	Urban Medium Density	8340	Sewage Treatment
43	Urban High Density	2320	Poultry Feeding Operations
43	Urban Low Density	2410	Tree Nurseries
43	Urban High Density	1310	Fixed Single Family Units
43	Urban High Density	1320	Mobile Home Units
43	Urban High Density	1330	Multiple Dwelling Units, Low Rise
43	Urban High Density	1340	Multiple Dwelling Units, High Rise
43	Urban High Density	1350	Mixed Units, Fixed and Mobile Home Units
43	Urban High Density	1390	High Density Under Construction

MSHE_Code	MSHE_Description	FLUCCS	FLUCCS_Description
43	Urban High Density	1400	Commercial and Services
43	Urban High Density	1411	Shopping Centers
43	Urban High Density	1423	Wholesale Sales
43	Urban High Density	1460	Oil and Gas Storage - not Industrial or Manufacturing.
43	Urban High Density	1490	Commercial and Services Under Construction.
43	Urban High Density	1540	Oil and Gas Processing
43	Urban High Density	1550	Other Light Industry
43	Urban High Density	1560	Other Heavy Industrial
43	Urban High Density	1700	Institutional
43	Urban High Density	1710	Educational Facilities
43	Urban High Density	1830	Race Tracks
43	Urban High Density	8110	Airports
43	Urban High Density	8115	Grass Airports
43	Urban High Density	8140	Roads and Highways
43	Urban High Density	8200	Communications
43	Urban High Density	8300	Utilities
43	Urban High Density	8310	Electrical Power Facilities

SFWMD, 2018. Land cover and land use within the South Florida Water Management District as it existed in 2014-16. https://geo-sfwmd.hub.arcgis.com/datasets/sfwmd-land-cover-land-use-2014-2016

ATTACHMENT 2

Soil Profile Definitions

Attachment 2 – Soil Profile Definitions

Name	Layer Description	Name	Layer Description
Boca A	fine sand, rock, 0-8 cm	Plantation A/E	sand, marsh, 23-48 cm
Boca E1	fine sand, rock, 8-23 cm	Plantation Bw	sand, marsh, 48-84 cm
Boca E2	fine sand, rock, 23-36 cm	Pompano A1	fine sand, slough, 0-10 cm
Boca Bw	fine sand, rock, 36-64 cm	Pompano C1	fine sand, slough, 10-30 cm
Boca Btg	fsl, rock, 64-76 cm	Pompano C2	fine sand, slough, 30-51 cm
Chobee A	loamy fine sand, marsh, 13-38 cm	Pompano C3	fine sand, slough, 51-74 cm
Immokalee A1	fine sand, flatwoods, 0-10 cm	Pompano C4	fine sand, slough, 74-203 cm
Immokalee AE	sand, flatwoods, 10-23 cm	Riviera Ap	fine sand, depressional, 0-15 cm
Immokalee E1	sand, flatwoods, 23-41 cm	Riviera A	fine sand, depressional, 15-28 cm
Immokalee E2	sand, flatwoods, 41-91 cm	Riviera E1	fine sand, depressional, 28-41 cm
Immokalee Bh1	sand, flatwoods, 91-127 cm	Riviera E2	fine sand, depressional, 41-64 cm
Immokalee Bh2	sand, flatwoods, 127-140 cm	Riviera Bw	sandy loam, depressional, 64-74 cm
Immokalee Bw/Bh	sand, flatwoods, 140-203 cm	Riviera Btg	sandy clay loam, depressional, 74-132 cm
Oldsmar A1	sand, flatwoods, 0-8 cm	Sanibel Oa1	muck, marsh, 0-12 cm
Oldsmar E1	sand, flatwoods, 8-33 cm	Sanibel Oa2	sand, marsh, 12-15 cm
Oldsmar E2	sand, flatwoods, 33-107 cm	Sanibel A1	sand, marsh, 15-23 cm
Oldsmar Bh	sand, flatwoods, 107-119 cm	Sanibel A2	sand, marsh, 23-30 cm
Oldsmar Bt	fsl, flatwoods, 119-135 cm	Sanibel C1	sand, marsh, 30-66 cm
Oldsmar Btg	fsl, flatwoods, 135-203 cm	Sanibel C2	sand, marsh, 66-167 cm
Pineda A	sand, depressional, 0-2 cm	Winder A1	sand, depressional, 0-8 cm
Pineda E	fine sand, depressional, 2-13 cm	Winder E	sand, depressional, 8-33 cm
Pineda Bw1	fine sand, depressional, 13-33 cm	Winder B/E	sand, depressional, 33-41 cm
Pineda Bw2	fine sand, depressional, 33-58 cm	Winder Btg	sandy loam, depressional, 41-58 cm
Pineda Bw3	fine sand, depressional, 58-74 cm	Winder BCg	sand, depressional, 58-74 cm
Pineda E1	fine sand, depressional, 74-91 cm	Winder C1	sand, depressional, 74-89 cm
Pineda Btg/E	fsl, depressional, 91-137cm	Winder C2	sand, depressional, 89-104 cm
Pineda Cg	fine sand, depressional, 137-203cm	Winder C3	loamy sand, depressional, 104-165 cm
Plantation OAp	Muck, Marsh, 0-23 cm	Open Water	Lakes, mining pits, etc
		Bottom Rock	below soil horizons

The soils coverage was developed as part of a 1999 modeling study conducted by the Danish Hydraulic Institute for SFWMD, and the soils database was prepared with assistance from the Southwest Florida Research and Education Center.

DHI, 1999. Caloosahatchee Basin Integrated Surface Water – Ground Water Model. Prepared for SFWMD, June 1999.

ATTACHMENT 3

Groundwater Aquifer Depths and Conductivity Maps for Calibration Run 0814

Attachment 3 – Groundwater Aquifer Depths and Conductivity Maps for Calibration Run 0814

Modeling file: CSS_20200814.she Also referred to as 0814 Sim in Figure 3.8

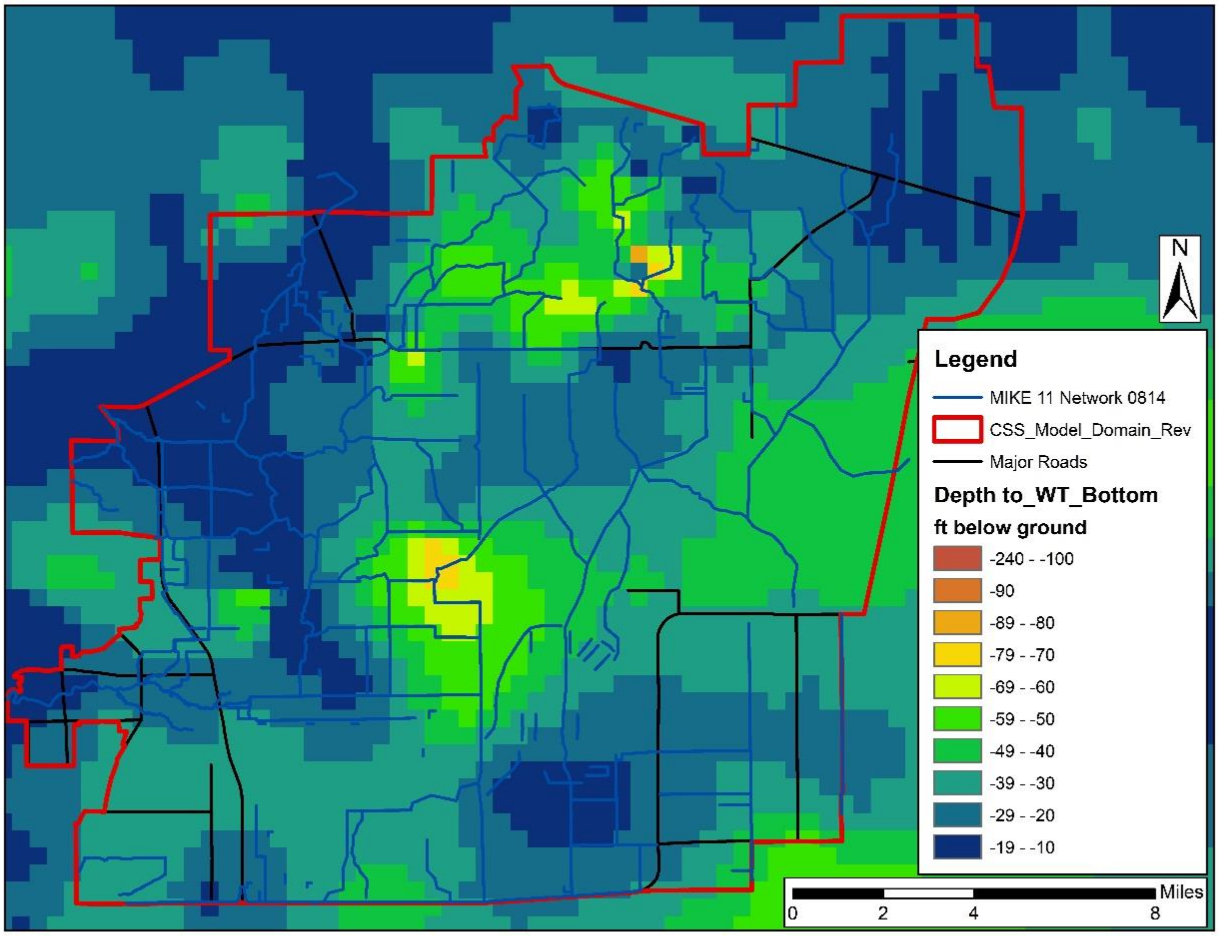


Figure A3-1 – Depth to Bottom of the Water Table Aquifer

File: DepthToBottom_LWC+wWSA_filled.dfs2

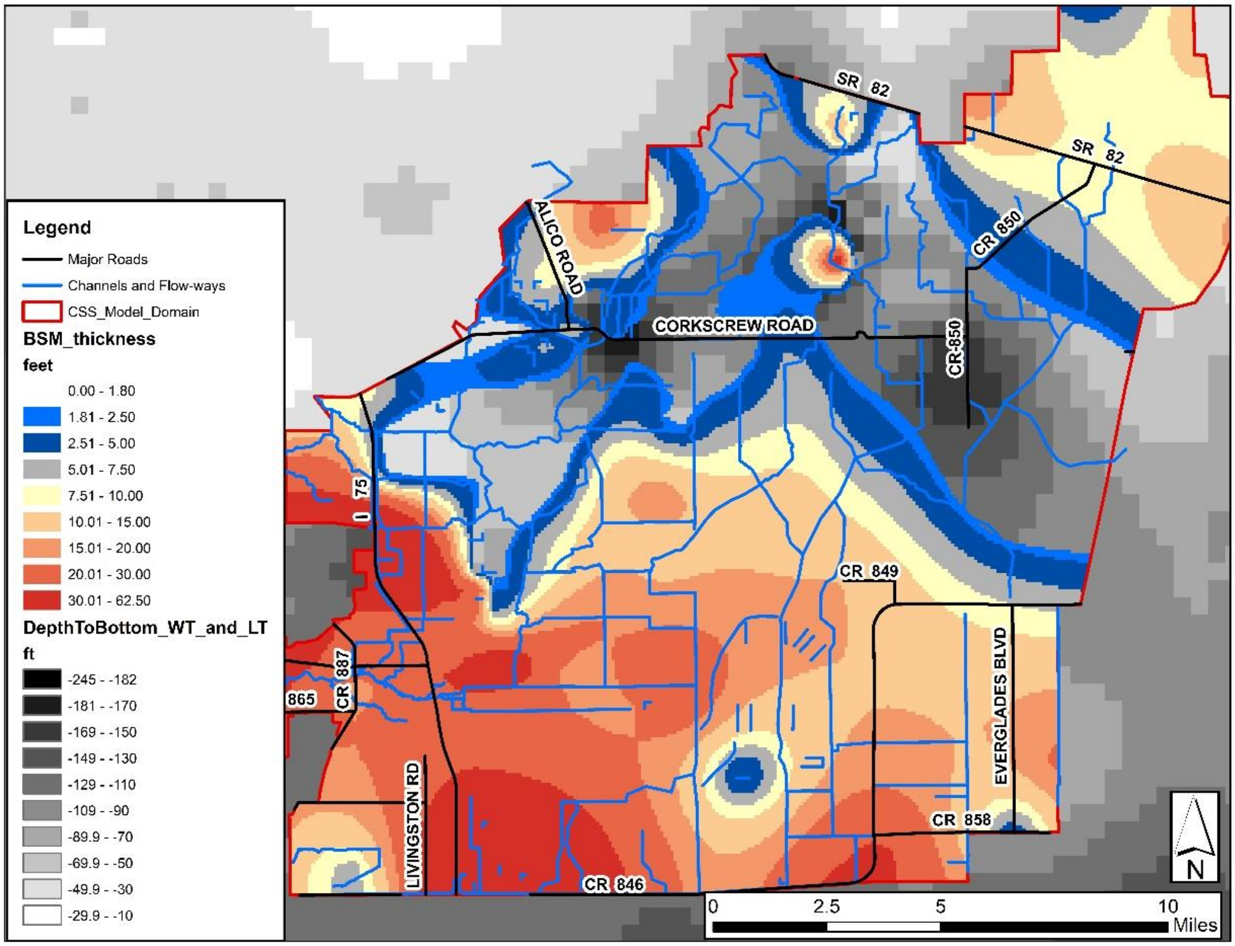


Figure A3-2 – Depth to Bottom of the Lower Tamiami Aquifer and Extent of the Bonita Springs Marl Confining Unit

File: DepthToBottom_LWC+wWSA_filled.dfs2
DepthToBottom_LWC+wWSA_filled_BSM_Thickness_CSS.dfs2

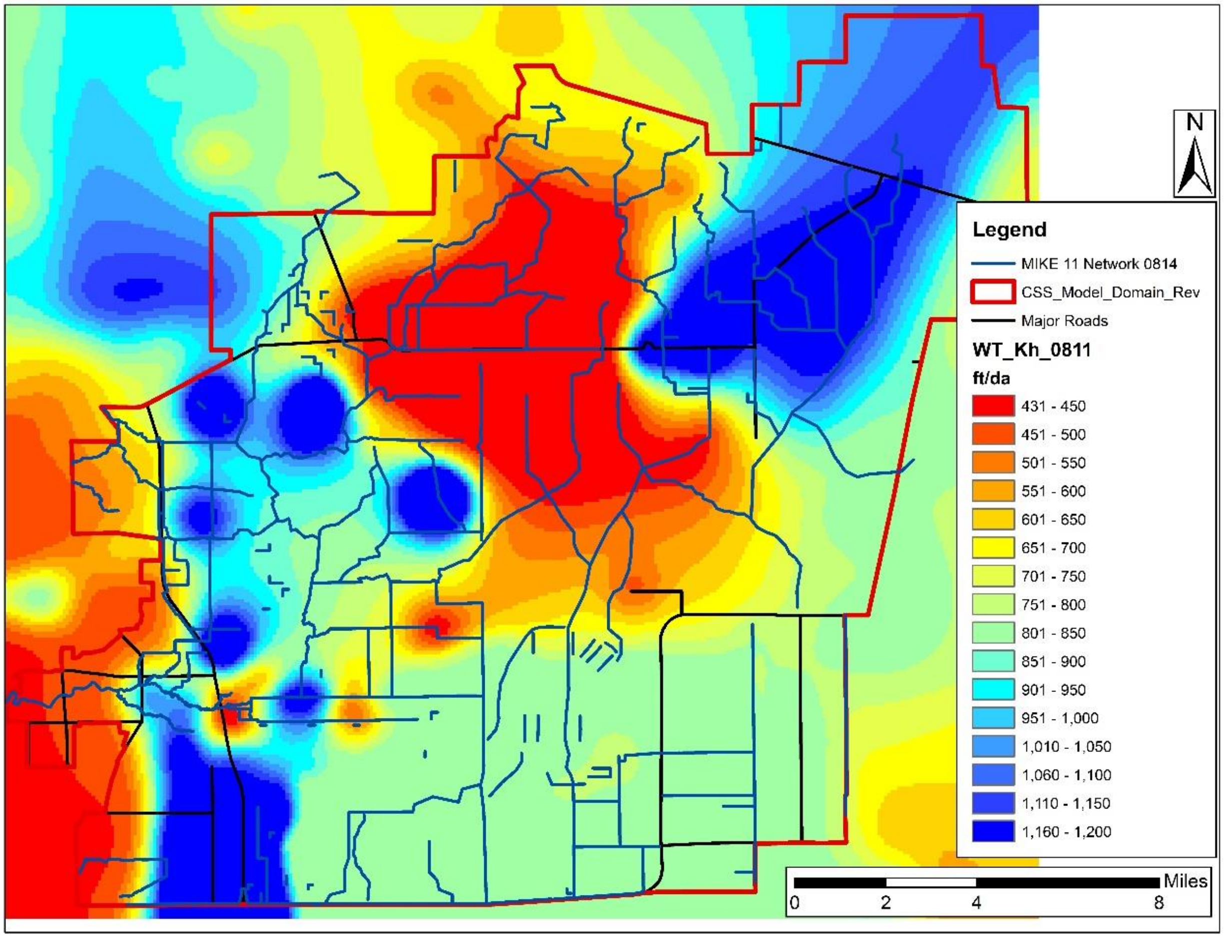


Figure A3-3 – Horizontal Conductivity of the Water Table Aquifer

File: CSS_Conductivities_375ft_20200811.dfs2

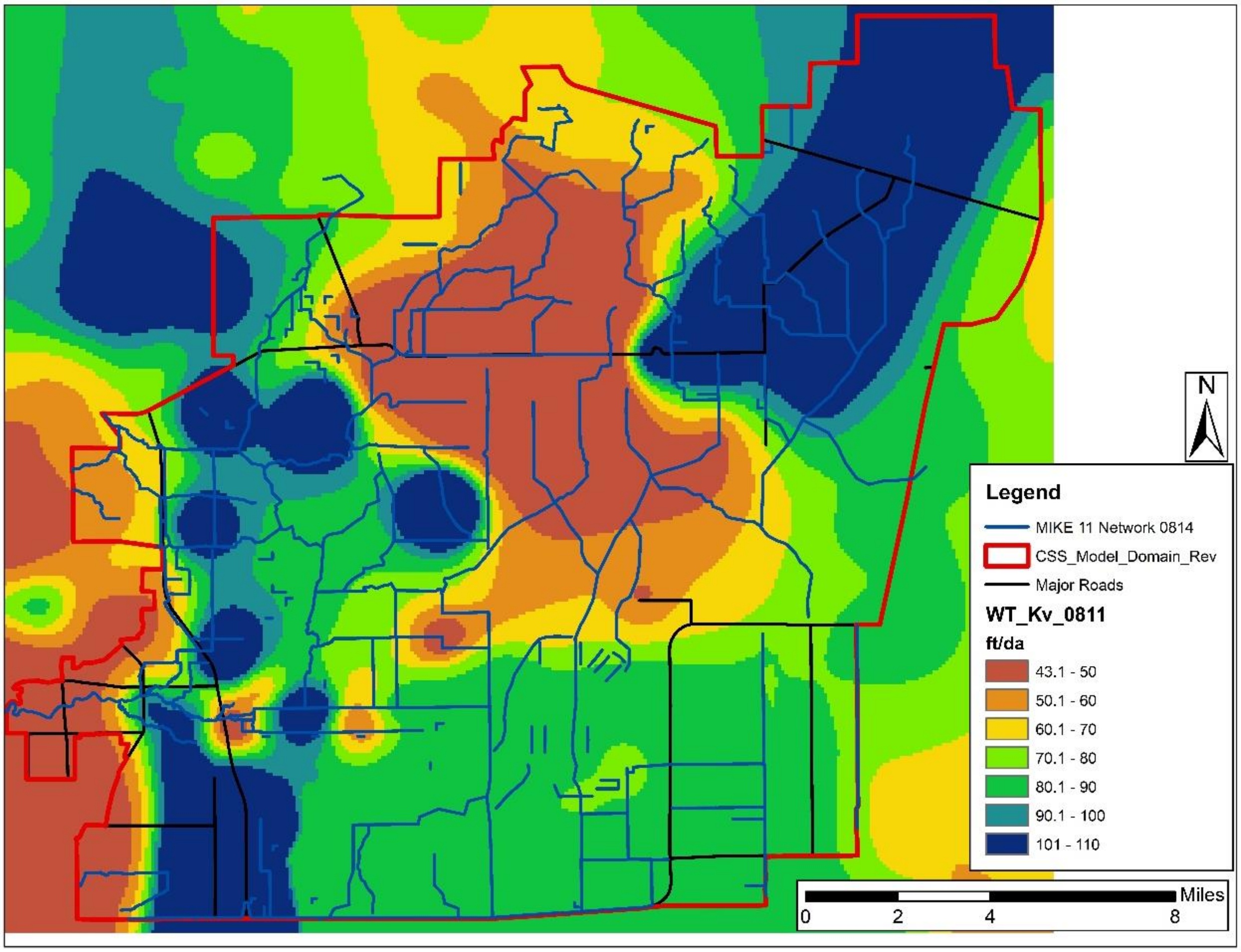


Figure A3-4 – Vertical Conductivity of the Water Table Aquifer

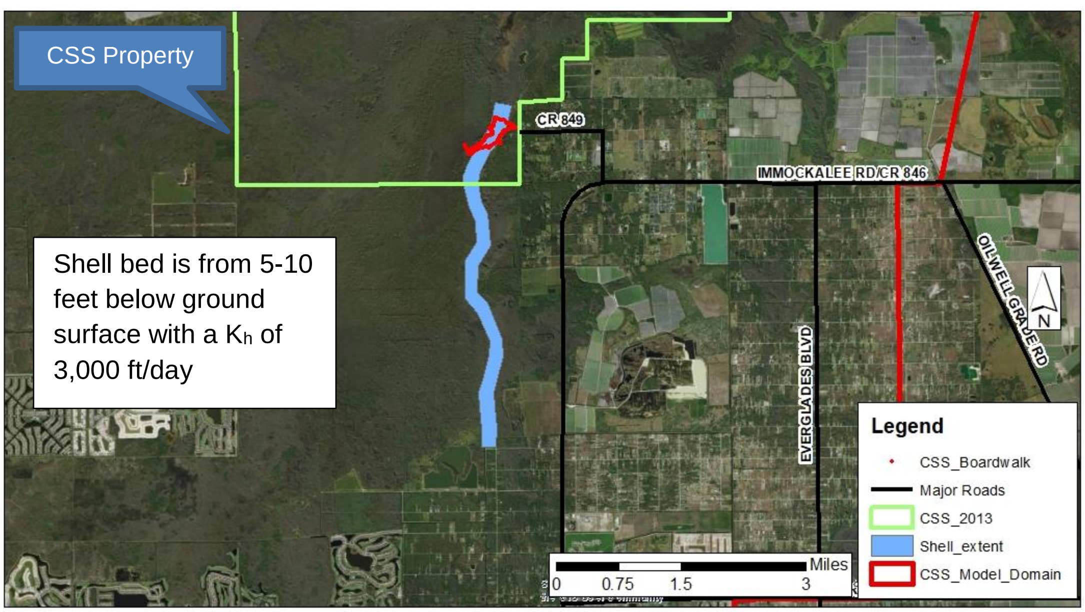


Figure A3-5 - Horizontal Extent of Shell Layer Used in the Model

The Shell layer was simulated as a geologic lens. Background of the shell bed was provided in the calibration report and is described below.

Additional studies conducted at Corkscrew Swamp Sanctuary (Duever, personal communication) identified an area of shell deposits that are close to ground, as shown in **Figure A.3-5** (see **figures below** for additional information). The hydrogeologic data set was revised to incorporate this area of higher transmissivity into the modeling framework. Water Science staff identified deposits of shelly sand below 5 feet of muck in the middle of old growth bald cypress swamps.

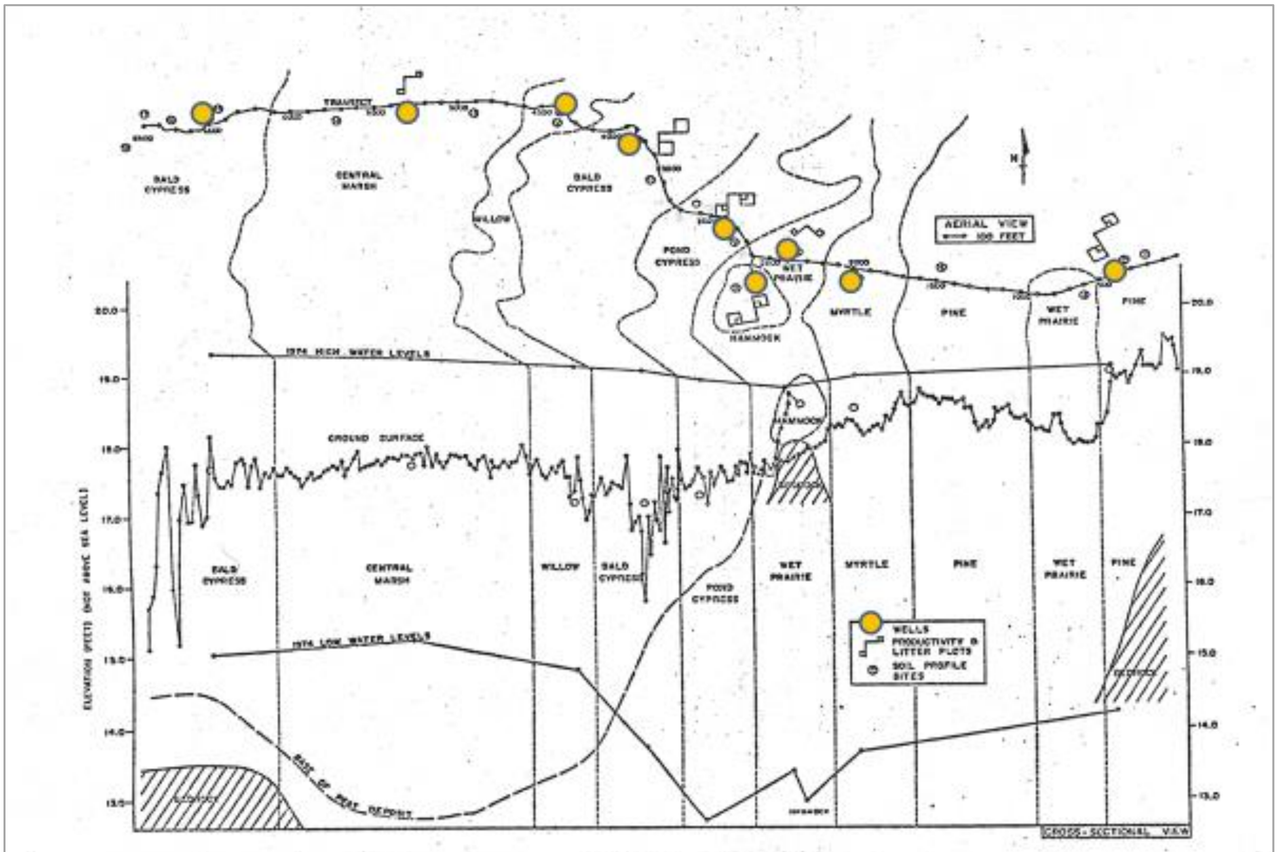
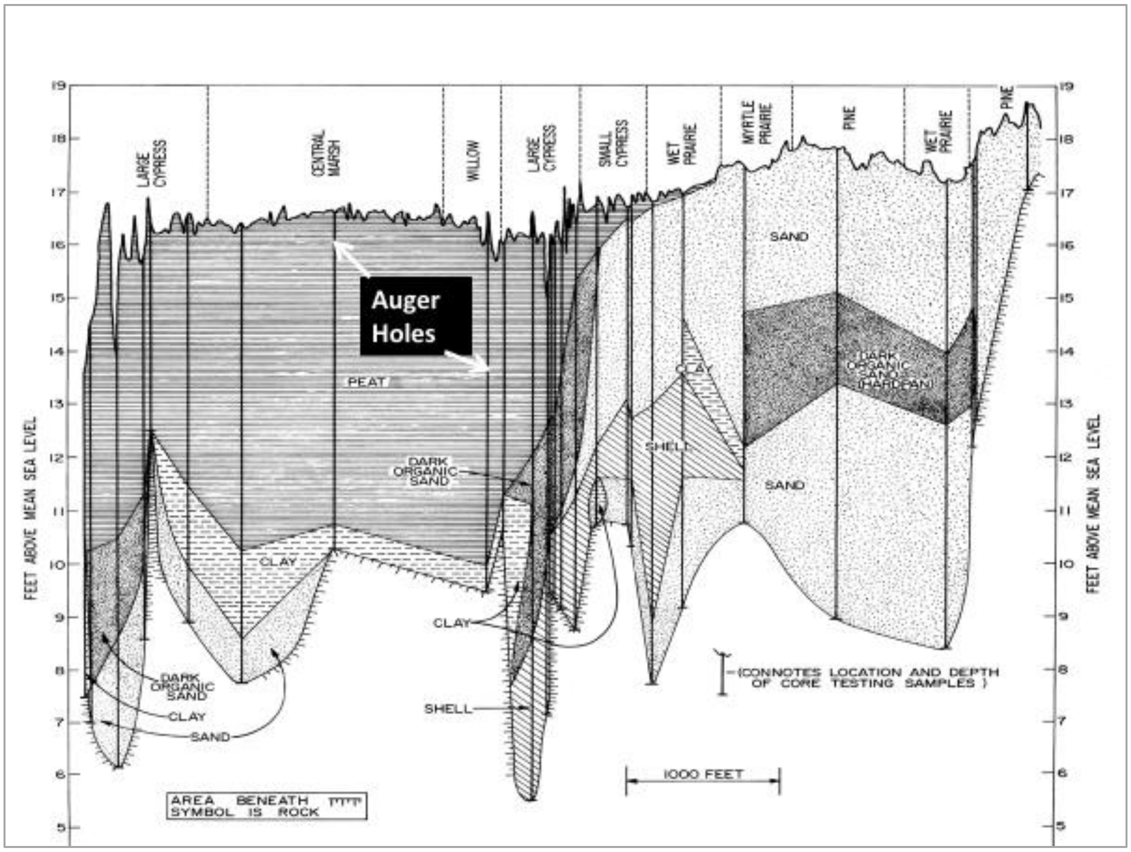


FIGURE 4

CENTRAL MARSH TRANSECT, CORKSCREW SWAMP SANCTUARY



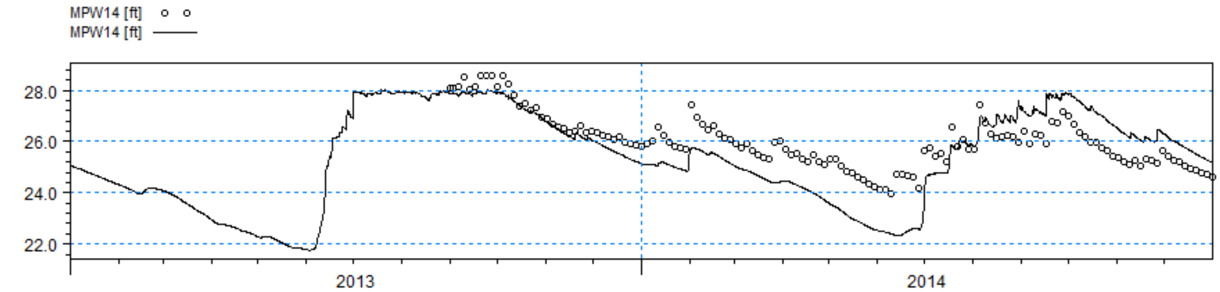
LARGE CYPRESS
CENTRAL MARSH
WILLOW
LARGE CYPRESS
SMALL CYPRESS
WET PRAIRIE
MYRTLE PRAIRIE
PINE
WET PRAIRIE
PINE
Auger Holes
PEAT
SAND
CLAY
SHELL
DARK ORGANIC SAND (HARDPAN)
DARK ORGANIC SAND
CLAY
SAND
(CONNOTES LOCATION AND DEPTH OF CORE TESTING SAMPLES)
1000 FEET
AREA BENEATH SYMBOL IS ROCK
FEET ABOVE MEAN SEA LEVEL

ATTACHMENT 4

Calibration Plots for August 14, 2020 Simulation, 2013 – 2014

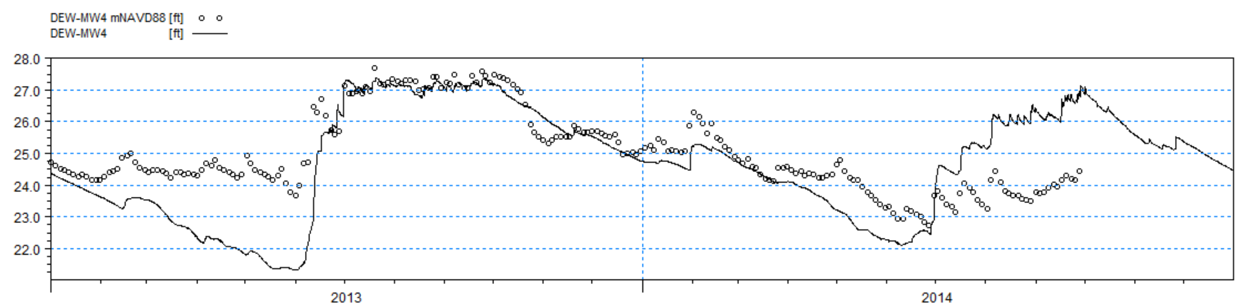
Attachment 4 – Calibration Plots for August 14, 2020 Simulation, 2013 – 2014

Stations North of Corkscrew Road

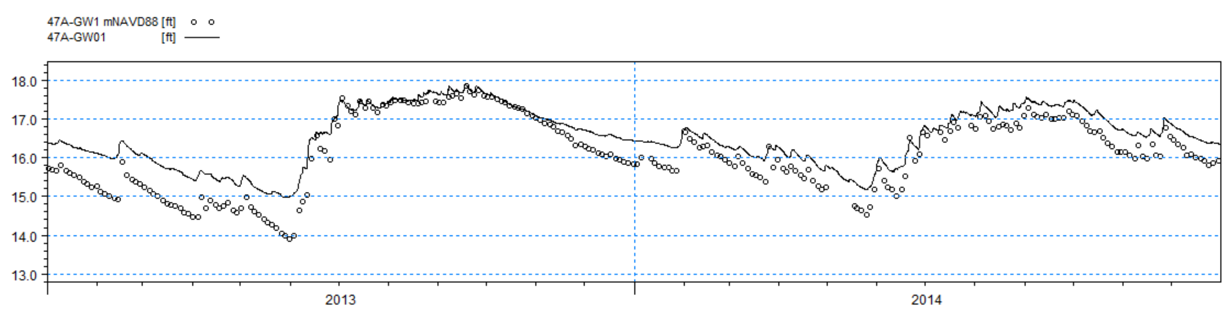


ME=0.362419
MAE=0.894035
RMSE=1.03821
STDres=0.972903
R(Correlation)=0.782603
R2(Nash_Sutcliffe)=-0.0335835

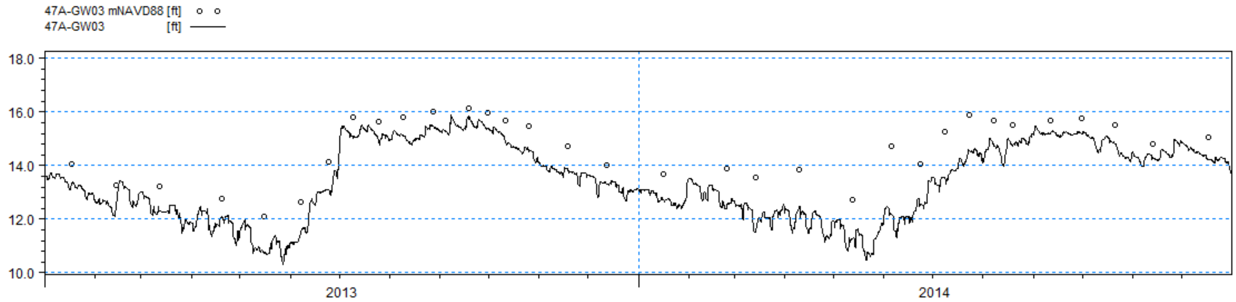
DEW-MW4 is 2000 ft west of MPW14. Summer 2014 stages are 2 ft lower than at MPW14. Influence of nearby mining pit is suspected at DEW-MW4



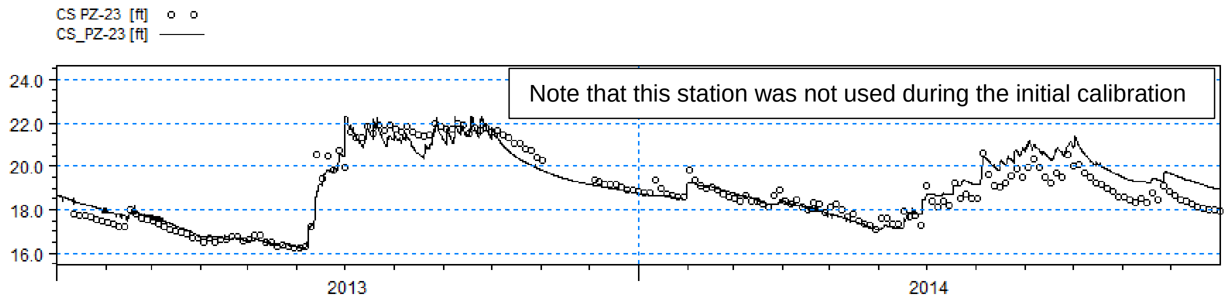
ME=0.357414
MAE=0.975256
RMSE=1.3185
STDres=1.26913
R(Correlation)=0.692179
R2(Nash_Sutcliffe)=-0.124177



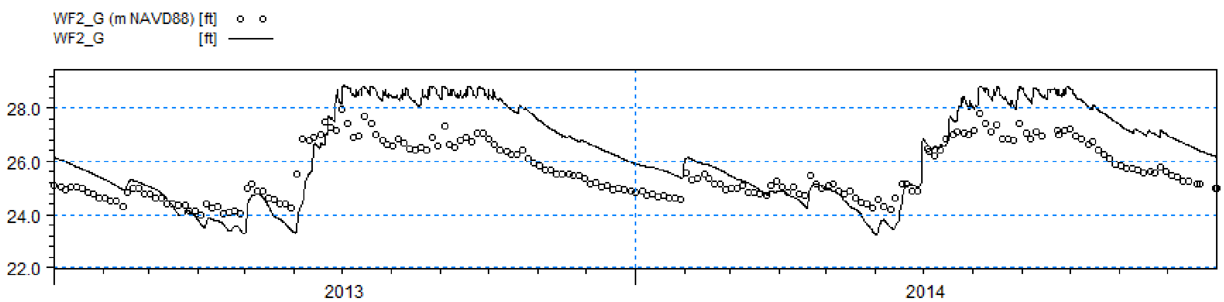
ME=-0.432959
MAE=0.43511
RMSE=0.513705
STDres=0.276477
R(Correlation)=0.982833
R2(Nash_Sutcliffe)=0.708508



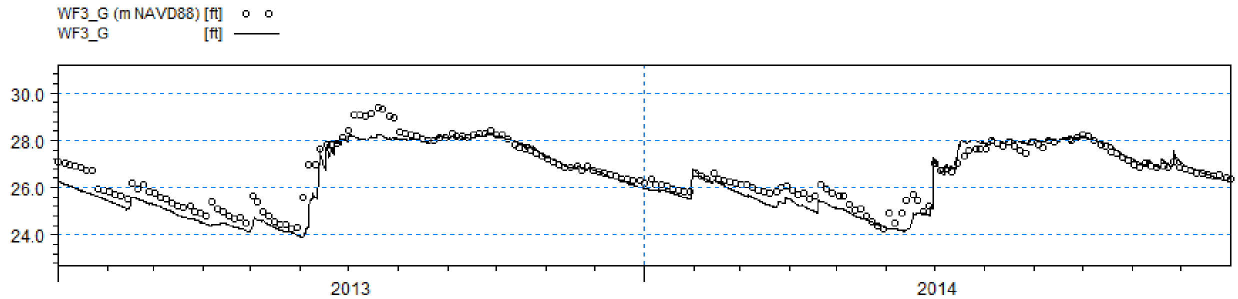
ME=0.996624
MAE=0.996624
RMSE=1.0945
STDres=0.452404
R(Correlation)=0.953669
R2(Nash_Sutcliffe)=0.114099



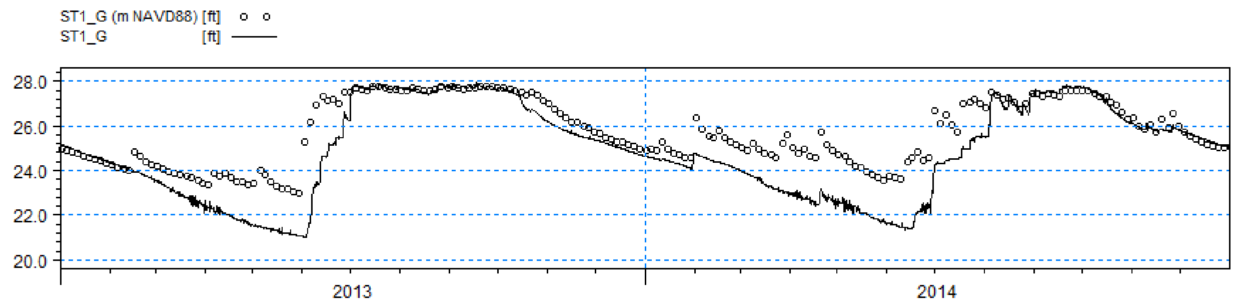
ME=-0.14549
MAE=0.417385
RMSE=0.536236
STDres=0.516121
R(Correlation)=0.944763
R2(Nash_Sutcliffe)=0.883322



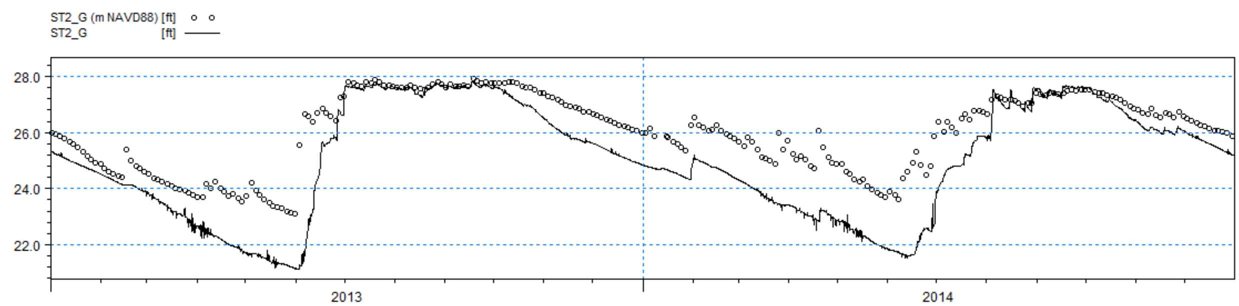
ME=-0.712964
MAE=0.993402
RMSE=1.14956
STDres=0.901754
R(Correlation)=0.896306
R2(Nash_Sutcliffe)=-0.282574



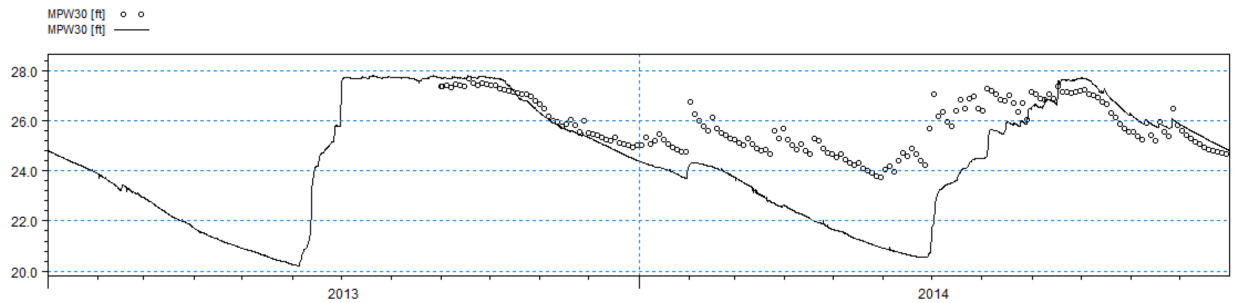
ME=0.254829
MAE=0.343433
RMSE=0.481843
STDres=0.408944
R(Correlation)=0.954699
R2(Nash_Sutcliffe)=0.839012



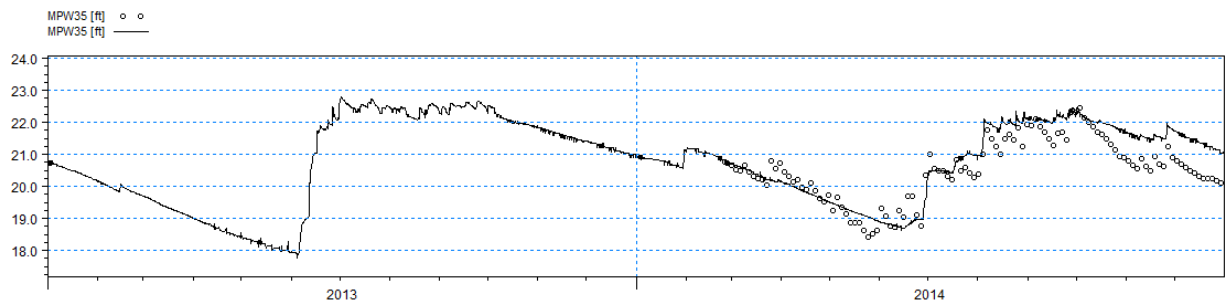
ME=0.863301
MAE=0.907073
RMSE=1.29902
STDres=0.97065
R(Correlation)=0.902536
R2(Nash_Sutcliffe)=0.198111



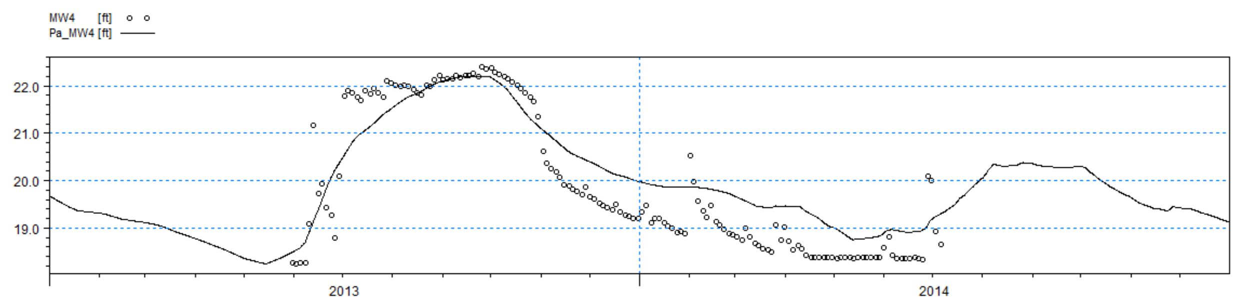
ME=1.02291
MAE=1.02996
RMSE=1.33285
STDres=0.854482
R(Correlation)=0.937722
R2(Nash_Sutcliffe)=0.0154015



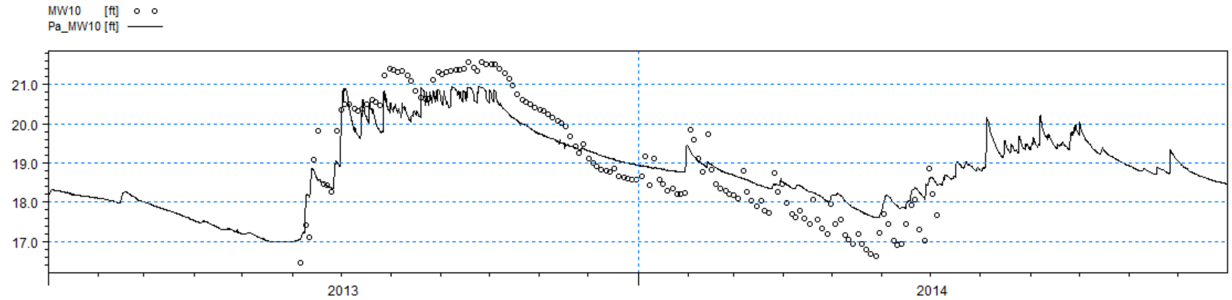
ME=1.08709
MAE=1.31621
RMSE=1.79913
STDres=1.43357
R(Correlation)=0.793493
R2(Nash_Sutcliffe)=-2.05377



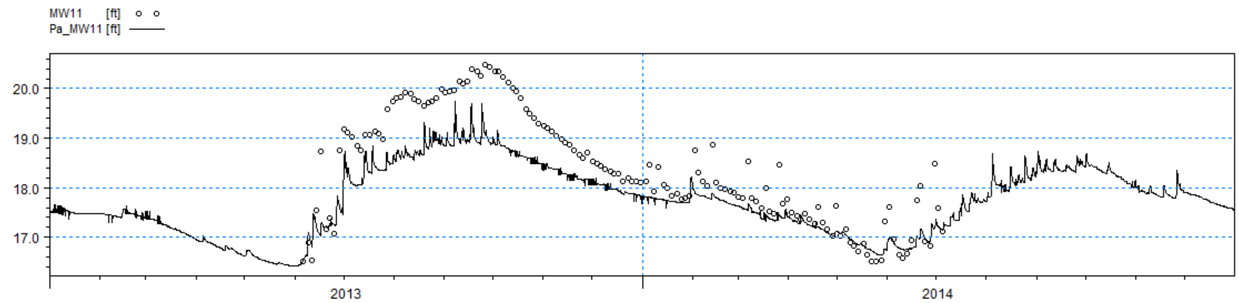
ME=-0.276832
MAE=0.452912
RMSE=0.558921
STDres=0.485548
R(Correlation)=0.905306
R2(Nash_Sutcliffe)=0.654934



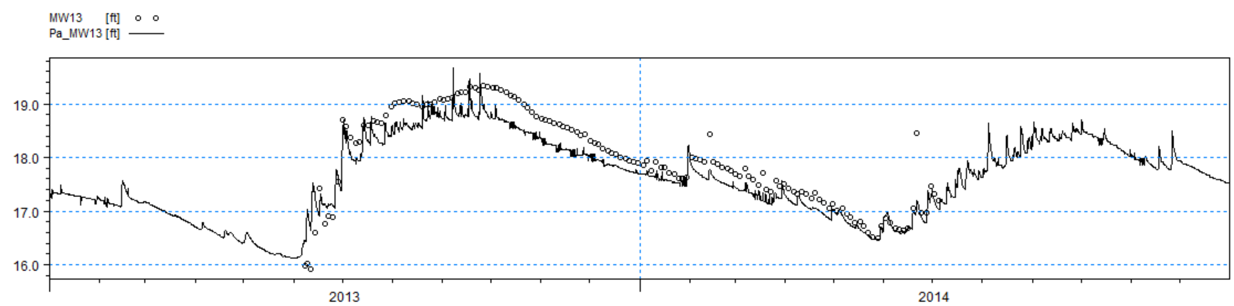
ME=-0.284231
MAE=0.561229
RMSE=0.641518
STDres=0.575116
R(Correlation)=0.938813
R2(Nash_Sutcliffe)=0.811093



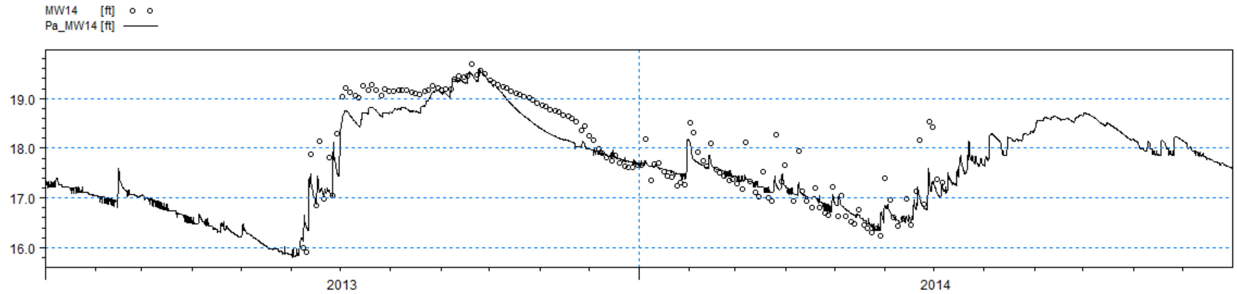
ME=-0.0320187
MAE=0.534071
RMSE=0.598219
STDres=0.597361
R(Correlation)=0.970002
R2(Nash_Sutcliffe)=0.835711



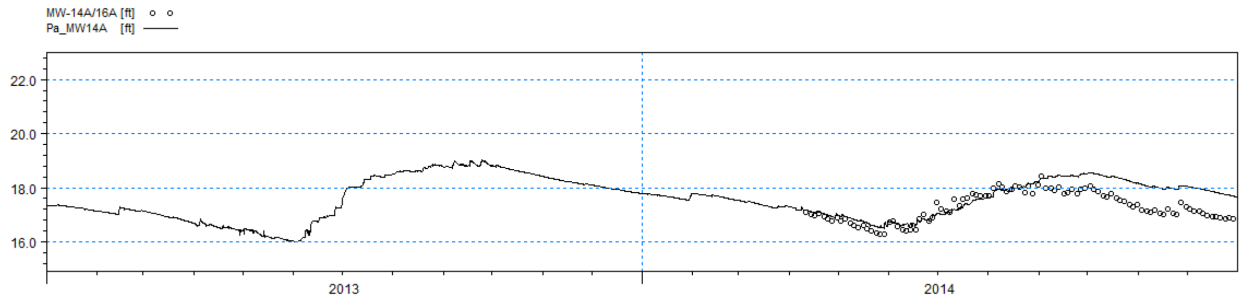
ME=0.514438
MAE=0.542548
RMSE=0.689273
STDres=0.458749
R(Correlation)=0.968931
R2(Nash_Sutcliffe)=0.61382



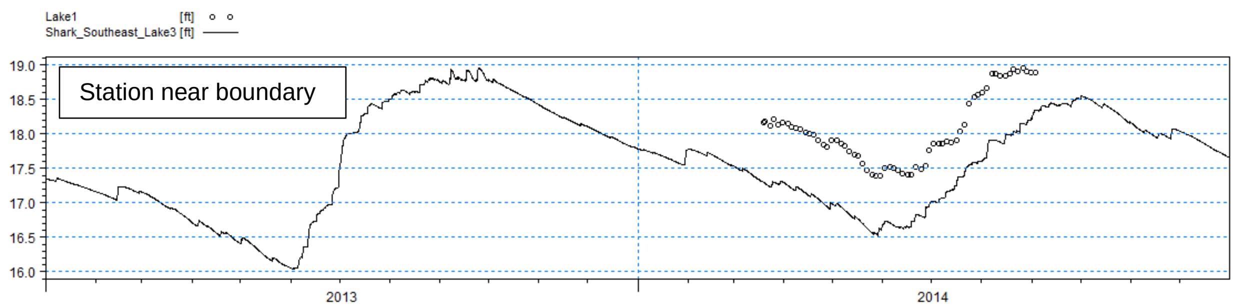
ME=0.235715
MAE=0.283558
RMSE=0.332602
STDres=0.234654
R(Correlation)=0.972963
R2(Nash_Sutcliffe)=0.848833



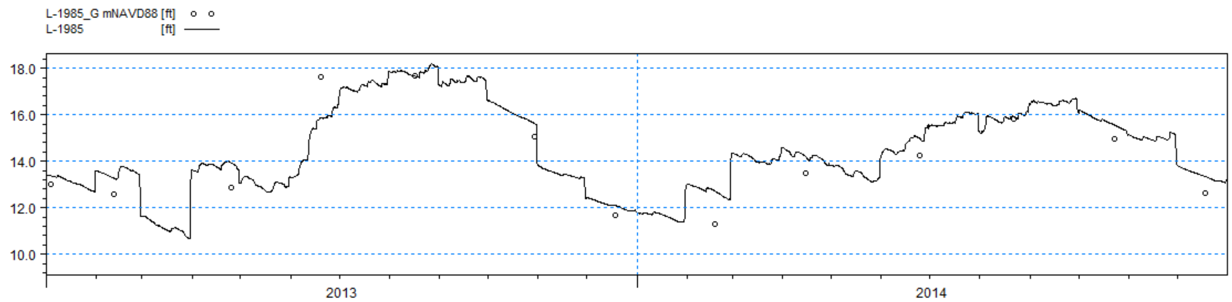
ME=0.181783
MAE=0.266137
RMSE=0.351946
STDres=0.301365
R(Correlation)=0.957799
R2(Nash_Sutcliffe)=0.876444



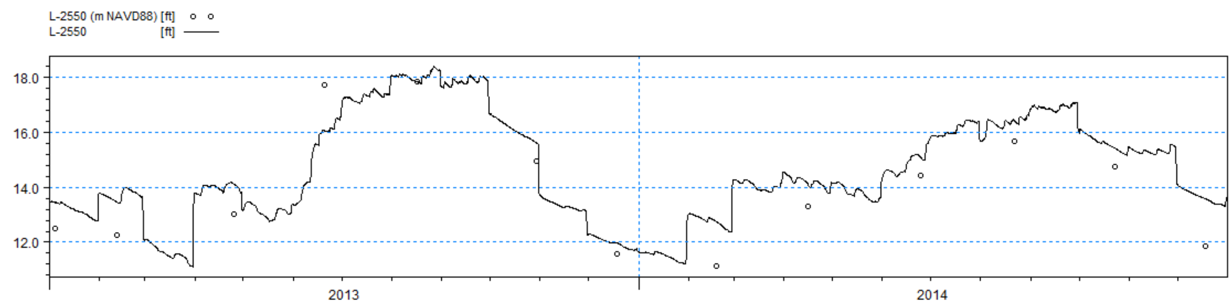
ME=-0.346492
MAE=0.422524
RMSE=0.533524
STDres=0.405698
R(Correlation)=0.776521
R2(Nash_Sutcliffe)=-0.0120375



ME=0.842796
MAE=0.842796
RMSE=0.847669
STDres=0.0907643
R(Correlation)=0.983108
R2(Nash_Sutcliffe)=-1.96036

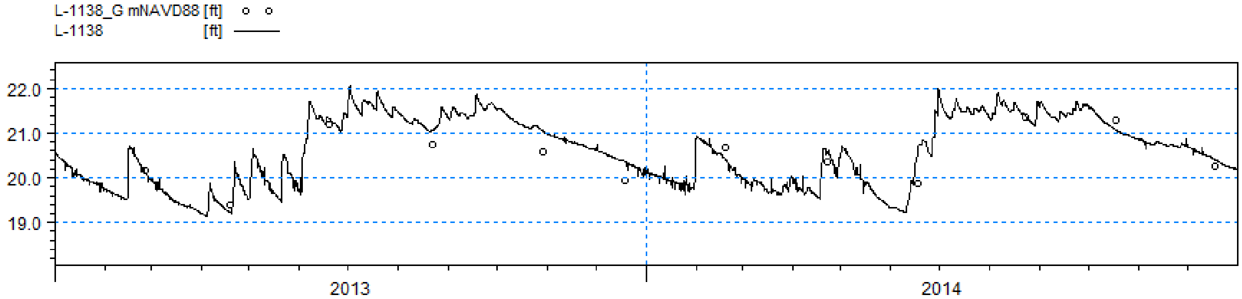


ME=-0.43133
MAE=0.702167
RMSE=0.838428
STDres=0.718969
R(Correlation)=0.949707
R2(Nash_Sutcliffe)=0.821325



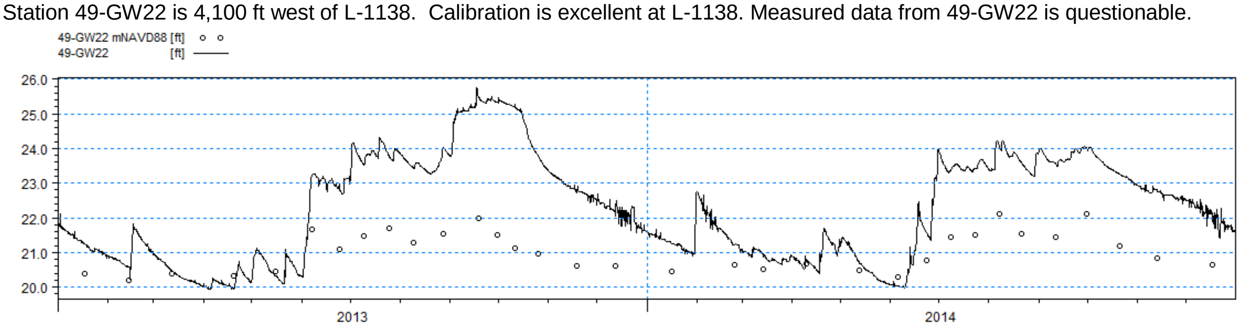
ME=-0.678405
MAE=0.941028
RMSE=1.05912
STDres=0.813323
R(Correlation)=0.944942
R2(Nash_Sutcliffe)=0.749458

Stations South of Corkscrew Road

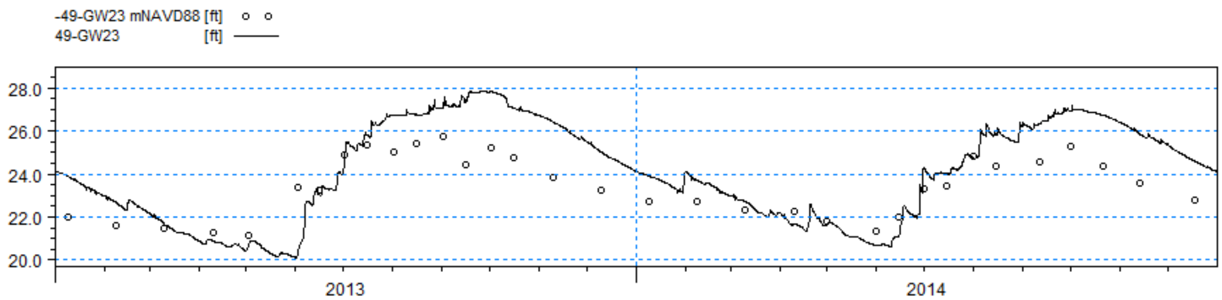


ME=-0.149188
MAE=0.268887
RMSE=0.327371
STDres=0.291402
R(Correlation)=0.874573
R2(Nash_Sutcliffe)=0.678866

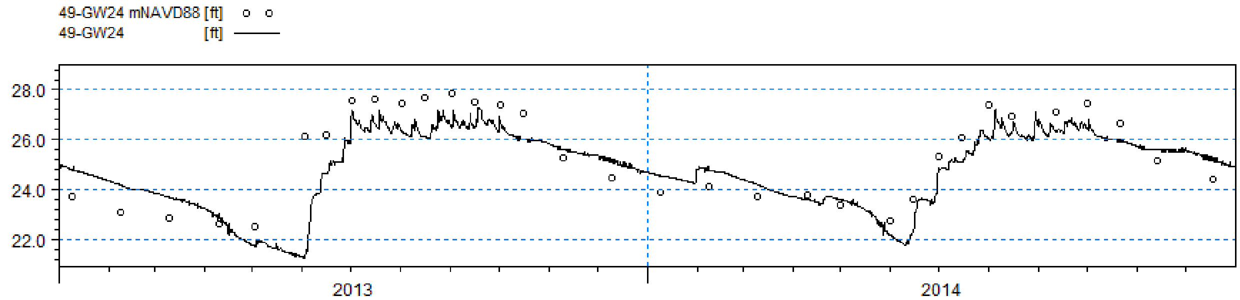
Station 49-GW22 is 4,100 ft west of L-1138. Calibration is excellent at L-1138. Measured data from 49-GW22 is questionable.



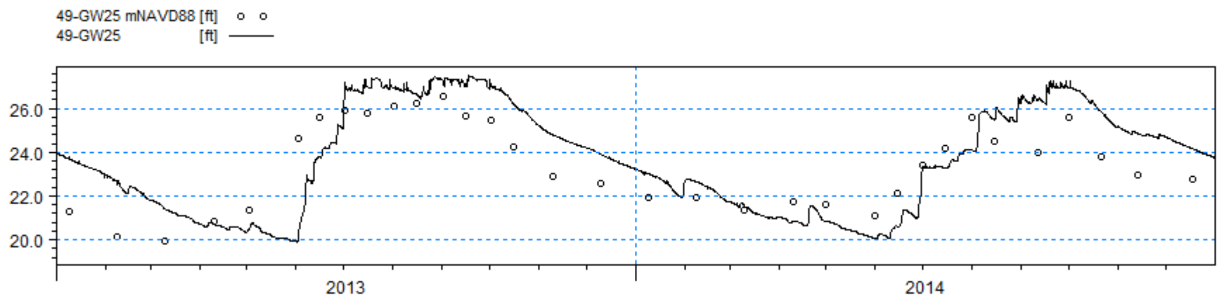
ME=-1.53945
MAE=1.58434
RMSE=1.90291
STDres=1.11855
R(Correlation)=0.860891
R2(Nash_Sutcliffe)=-10.4534



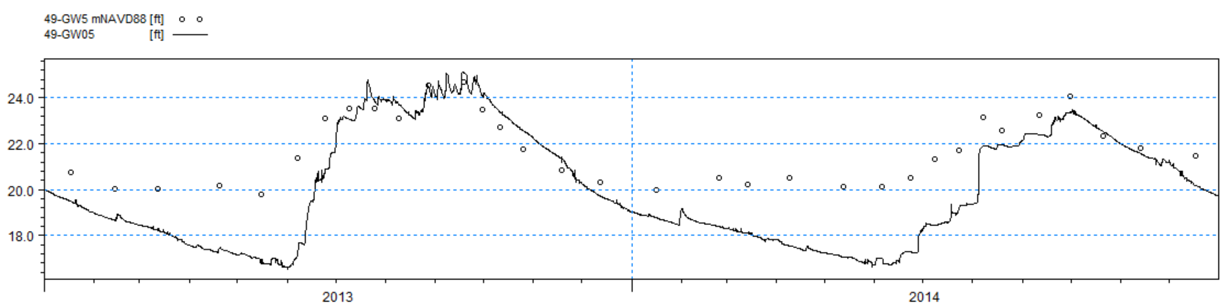
ME=-0.884764
MAE=1.29548
RMSE=1.56528
STDres=1.29124
R(Correlation)=0.864729
R2(Nash_Sutcliffe)=-0.257029



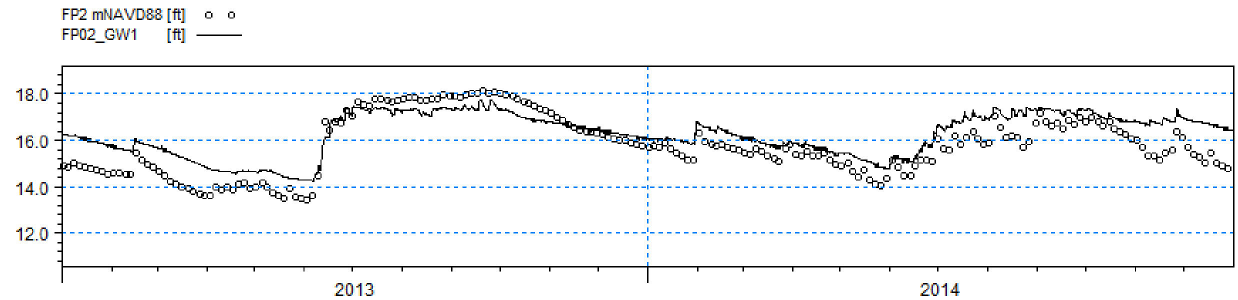
ME=0.473829
MAE=0.943193
RMSE=1.22276
STDres=1.12722
R(Correlation)=0.786917
R2(Nash_Sutcliffe)=0.547567



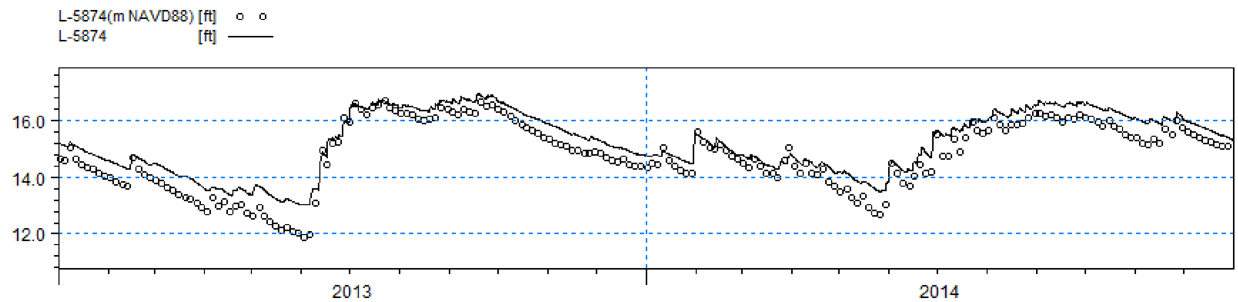
ME=-0.498542
MAE=1.36679
RMSE=1.61194
STDres=1.53291
R(Correlation)=0.774977
R2(Nash_Sutcliffe)=0.31779



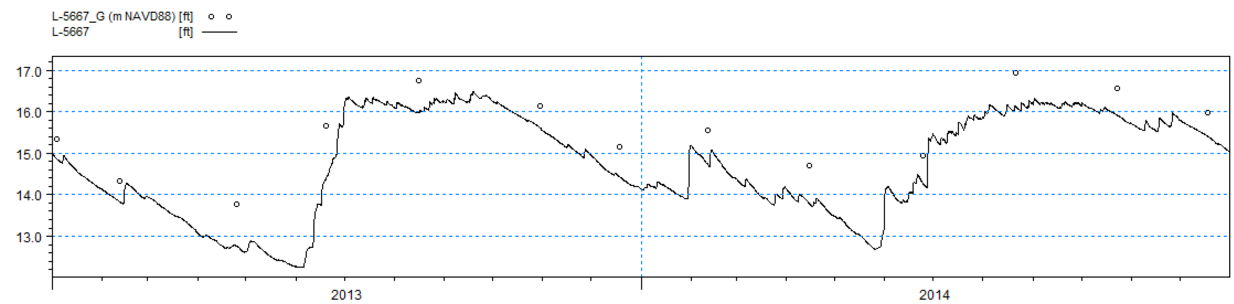
ME=1.2742
MAE=1.509
RMSE=1.88522
STDres=1.38941
R(Correlation)=0.903699
R2(Nash_Sutcliffe)=-0.611942



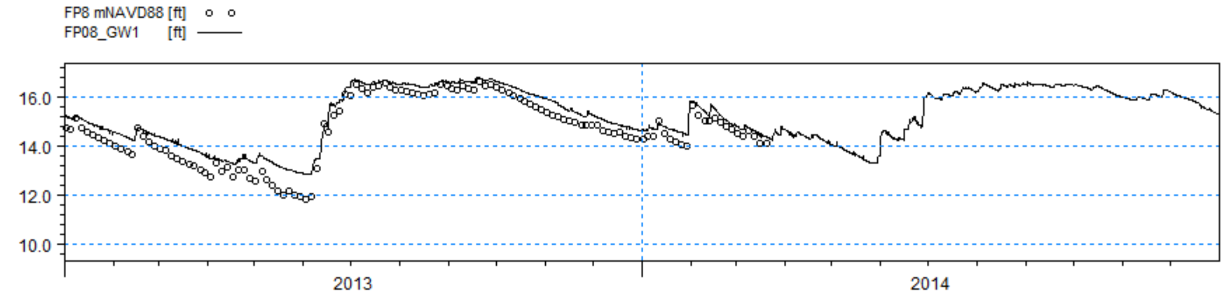
ME=-0.47635
MAE=0.676912
RMSE=0.77625
STDres=0.612907
R(Correlation)=0.892639
R2(Nash_Sutcliffe)=0.618952



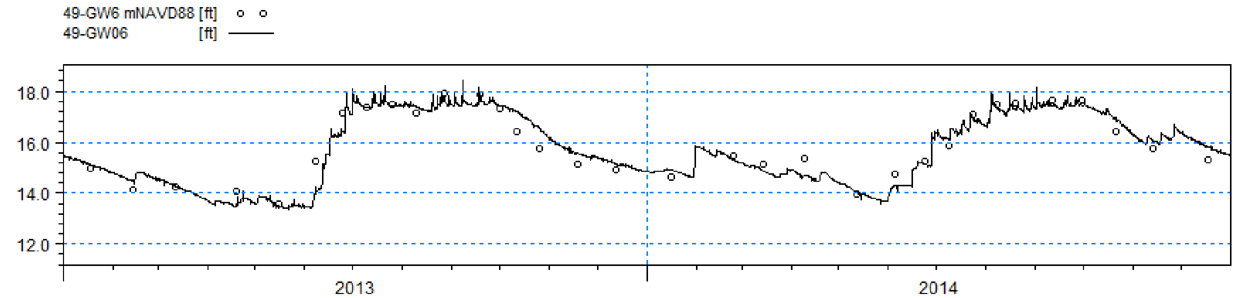
ME=-0.430533
MAE=0.440331
RMSE=0.49615
STDres=0.246589
R(Correlation)=0.981646
R2(Nash_Sutcliffe)=0.822966



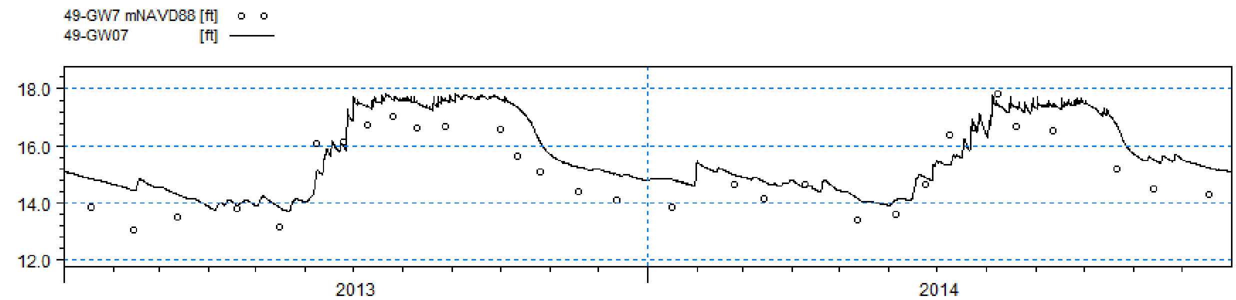
ME=0.744016
MAE=0.744016
RMSE=0.774146
STDres=0.213875
R(Correlation)=0.976164
R2(Nash_Sutcliffe)=0.294608



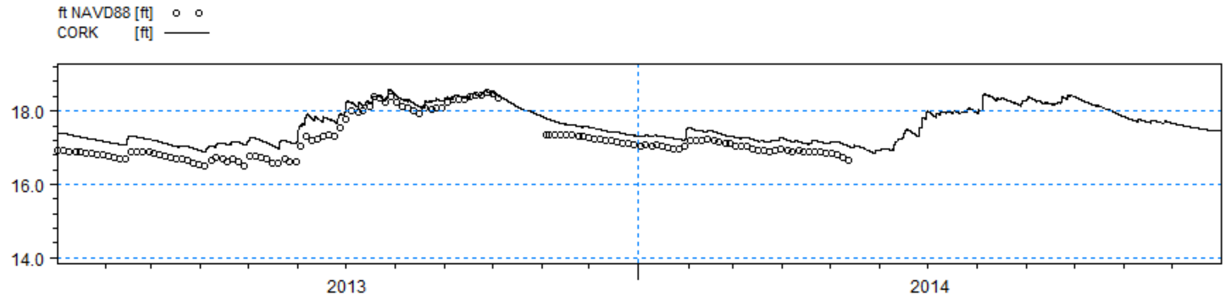
ME=-0.401819
MAE=0.408035
RMSE=0.463232
STDres=0.230489
R(Correlation)=0.989853
R2(Nash_Sutcliffe)=0.871892



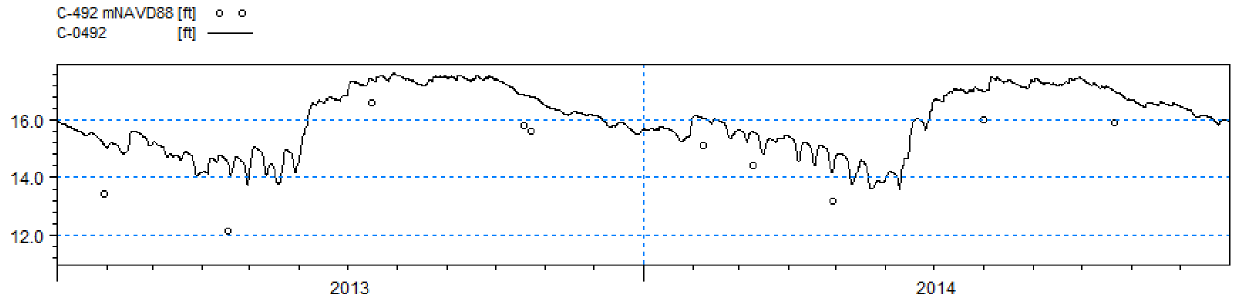
ME=0.0205066
MAE=0.329244
RMSE=0.424106
STDres=0.42361
R(Correlation)=0.949069
R2(Nash_Sutcliffe)=0.895841



ME=-0.588479
MAE=0.775647
RMSE=0.872517
STDres=0.644189
R(Correlation)=0.882961
R2(Nash_Sutcliffe)=0.582299

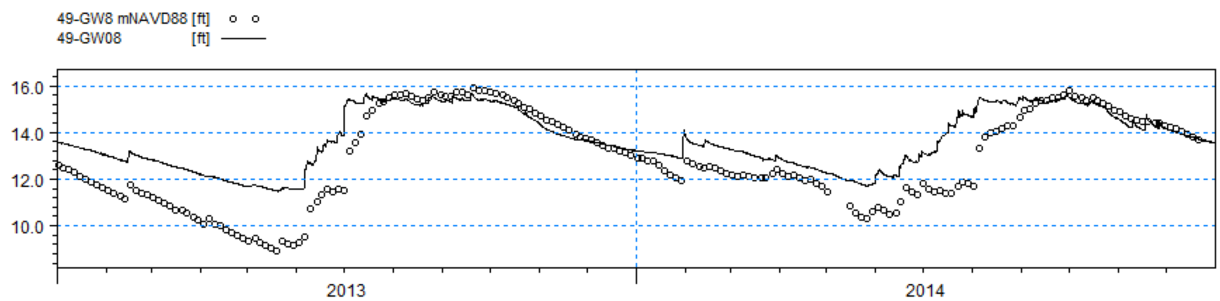


ME=-0.301765
MAE=0.302247
RMSE=0.329337
STDres=0.131912
R(Correlation)=0.983179
R2(Nash_Sutcliffe)=0.655022

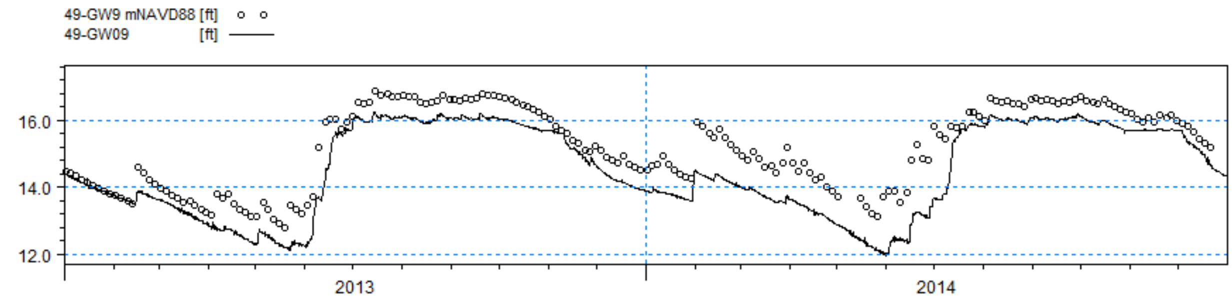


ME=-1.22628
MAE=1.22628
RMSE=1.292
STDres=0.406819
R(Correlation)=0.969176
R2(Nash_Sutcliffe)=0.0607437

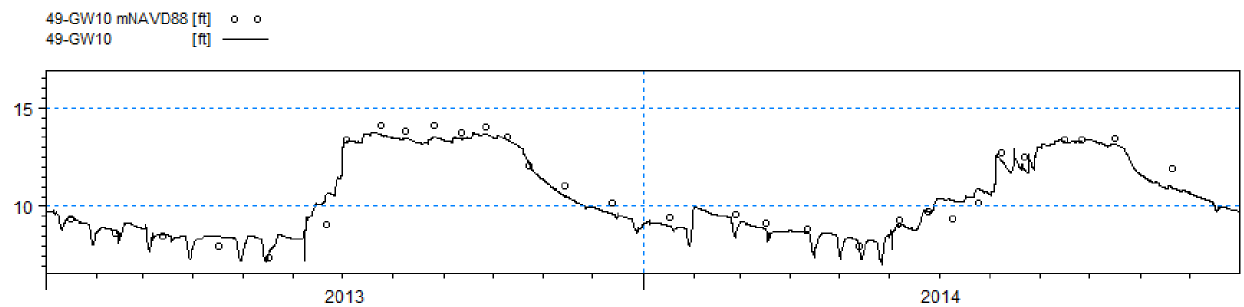
Stations in Imperial River Headwaters



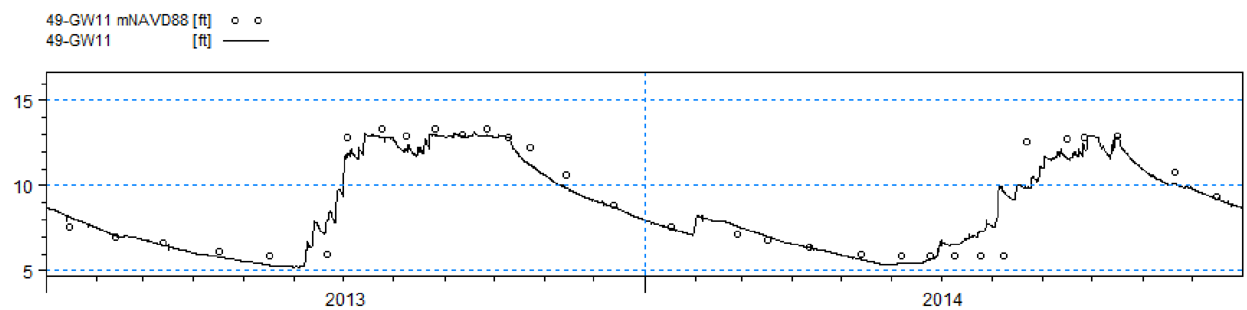
ME=-0.839697
MAE=0.990582
RMSE=1.27721
STDres=0.962383
R(Correlation)=0.916192
R2(Nash_Sutcliffe)=0.574037



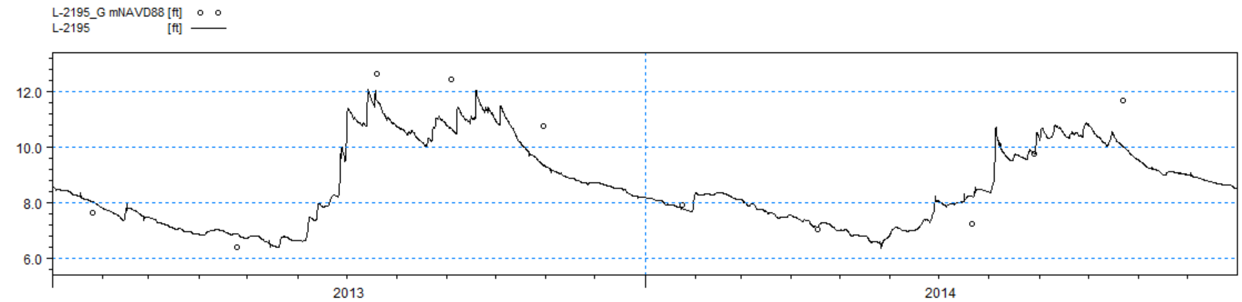
ME=0.695446
MAE=0.696414
RMSE=0.816577
STDres=0.427964
R(Correlation)=0.947393
R2(Nash_Sutcliffe)=0.536074



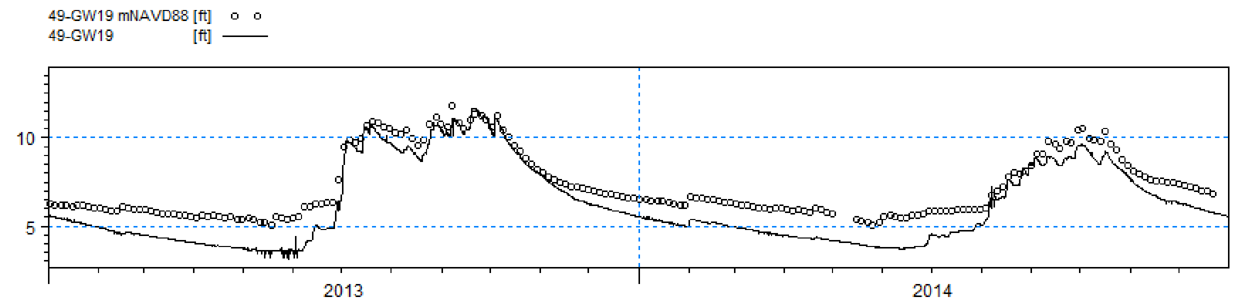
ME=0.136668
MAE=0.42437
RMSE=0.551517
STDres=0.534315
R(Correlation)=0.970747
R2(Nash_Sutcliffe)=0.937384



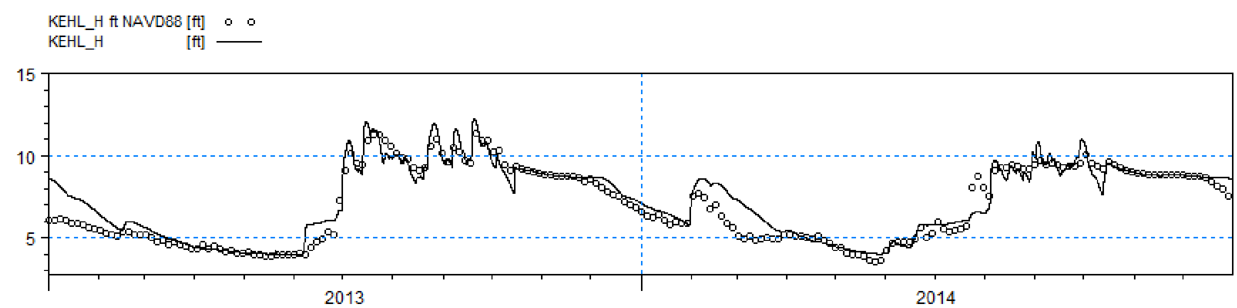
ME=0.104331
MAE=0.674912
RMSE=1.04674
STDres=1.04153
R(Correlation)=0.943223
R2(Nash_Sutcliffe)=0.88297



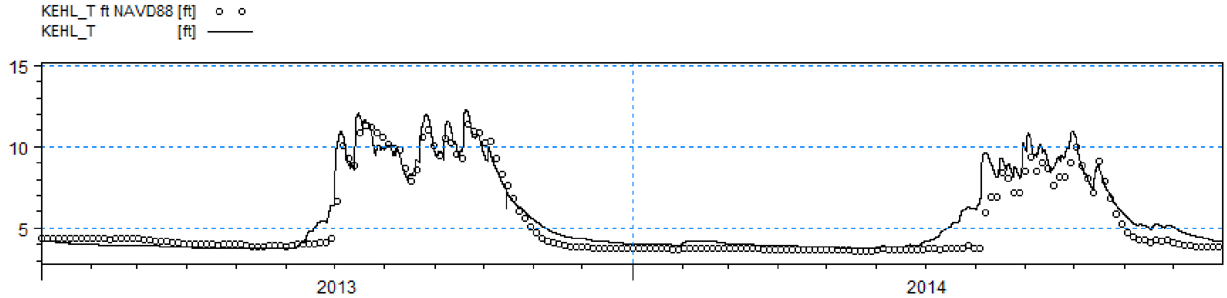
ME=0.398571
MAE=0.79098
RMSE=1.00762
STDres=0.925435
R(Correlation)=0.957978
R2(Nash_Sutcliffe)=0.801372



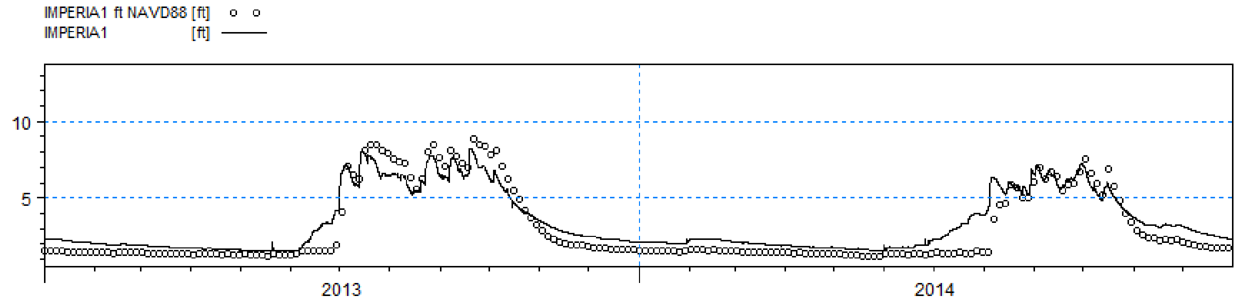
ME=1.06064
MAE=1.06634
RMSE=1.17193
STDres=0.498447
R(Correlation)=0.988214
R2(Nash_Sutcliffe)=0.591005



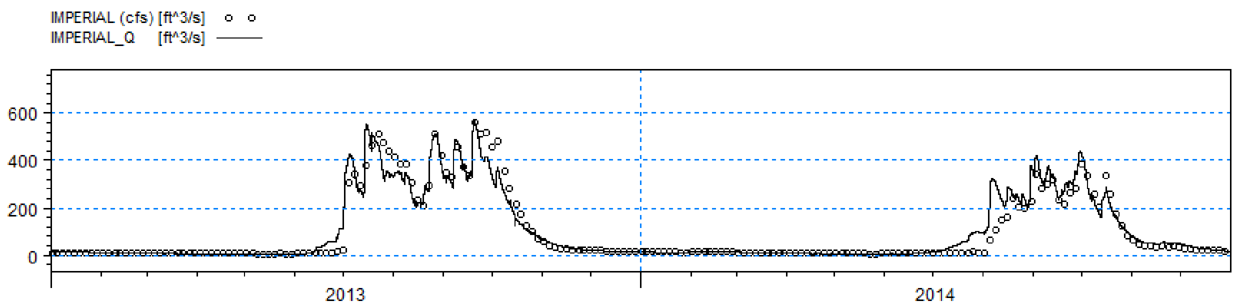
ME=-0.268245
MAE=0.495982
RMSE=0.732797
STDres=0.681936
R(Correlation)=0.953381
R2(Nash_Sutcliffe)=0.894844



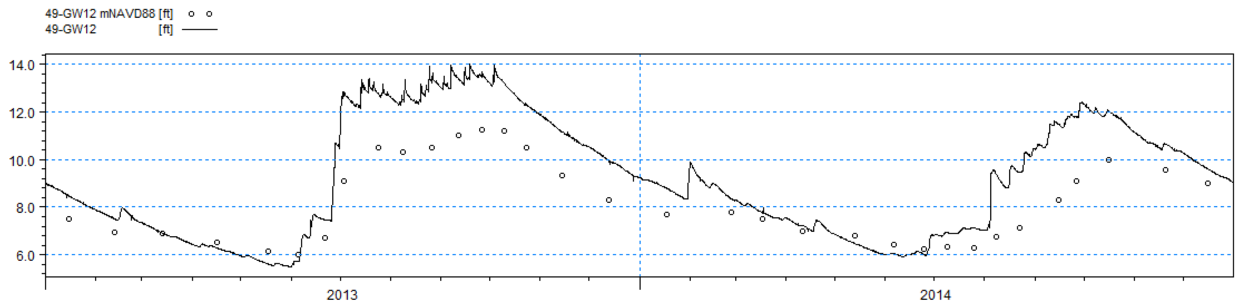
ME=-0.345988
MAE=0.533559
RMSE=0.747842
STDres=0.662993
R(Correlation)=0.962727
R2(Nash_Sutcliffe)=0.900337



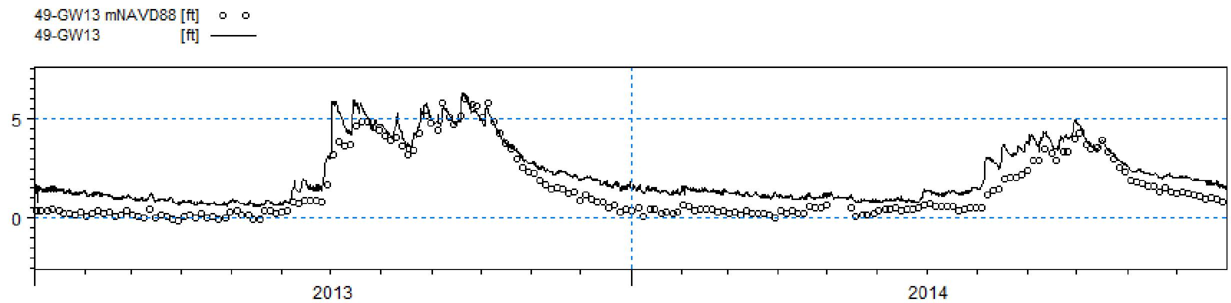
ME=-0.385915
MAE=0.684363
RMSE=0.834477
STDres=0.73988
R(Correlation)=0.961372
R2(Nash_Sutcliffe)=0.873513



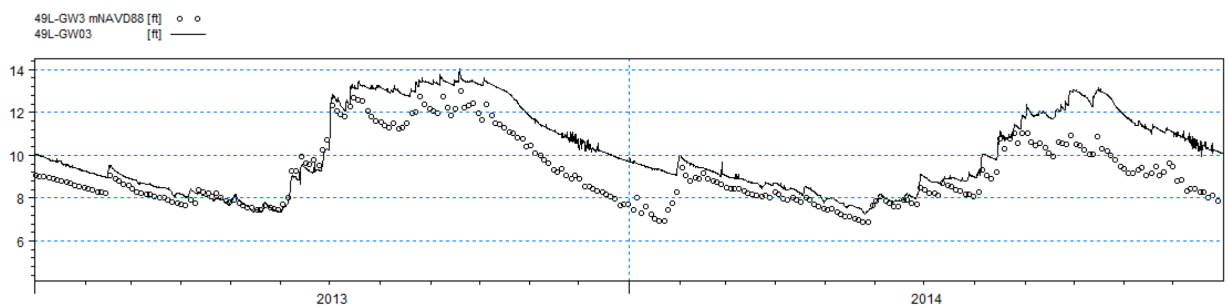
ME=-3.47926
MAE=20.3305
RMSE=40.169
STDres=40.018
R(Correlation)=0.961716
R2(Nash_Sutcliffe)=0.924326



ME=-1.25562
MAE=1.37713
RMSE=1.7131
STDres=1.16539
R(Correlation)=0.948643
R2(Nash_Sutcliffe)=-0.0262767

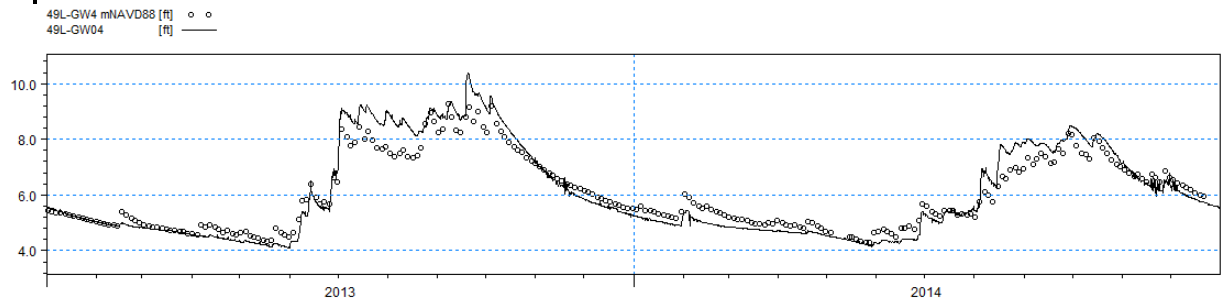


ME=-0.701991
MAE=0.722537
RMSE=0.795783
STDres=0.374807
R(Correlation)=0.975213
R2(Nash_Sutcliffe)=0.754364

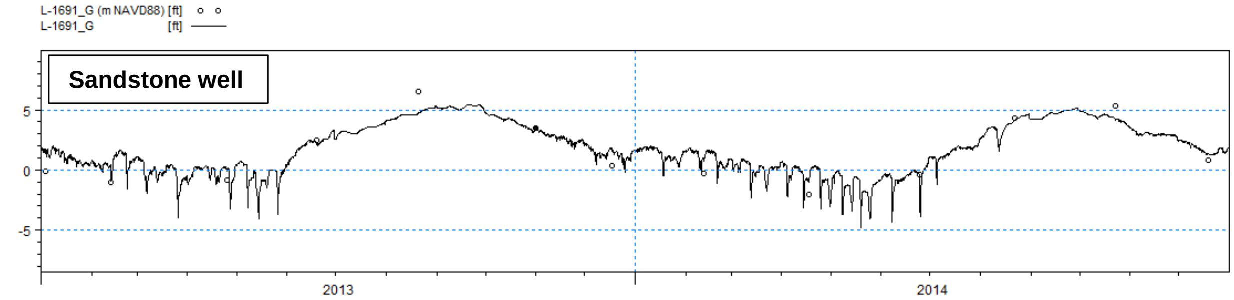


ME=-0.975755
MAE=1.02139
RMSE=1.2633
STDres=0.802393
R(Correlation)=0.907916
R2(Nash_Sutcliffe)=0.321078

Imperial River Watershed Stations West of I-75

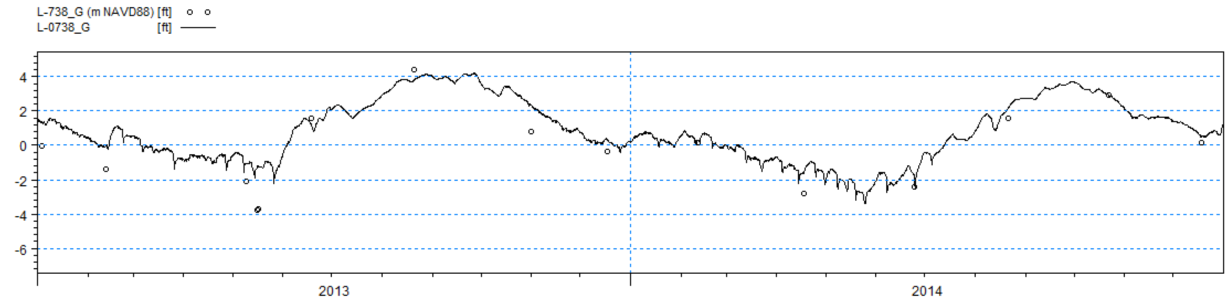


ME=-0.0203139
MAE=0.346504
RMSE=0.441562
STDres=0.441094
R(Correlation)=0.980619
R2(Nash_Sutcliffe)=0.880103

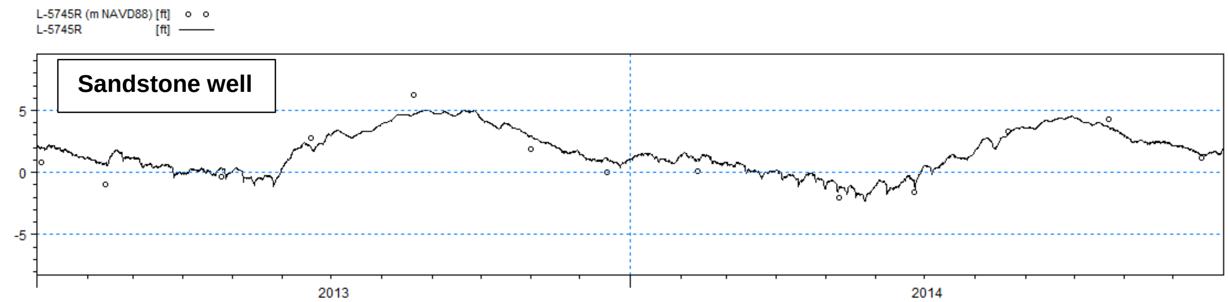


ME=-0.0524513
MAE=1.02826
RMSE=1.27382
STDres=1.27274
R(Correlation)=0.872309
R2(Nash_Sutcliffe)=0.759782

L-738 is a sandstone well located west of I-75 and is 1000 ft south of Imperial River

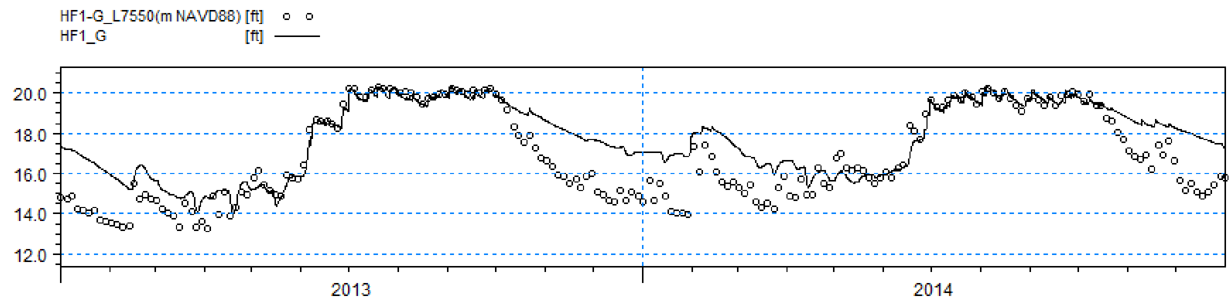


ME=-1.01302
MAE=1.1174
RMSE=1.37421
STDres=0.928567
R(Correlation)=0.948372
R2(Nash_Sutcliffe)=0.671542

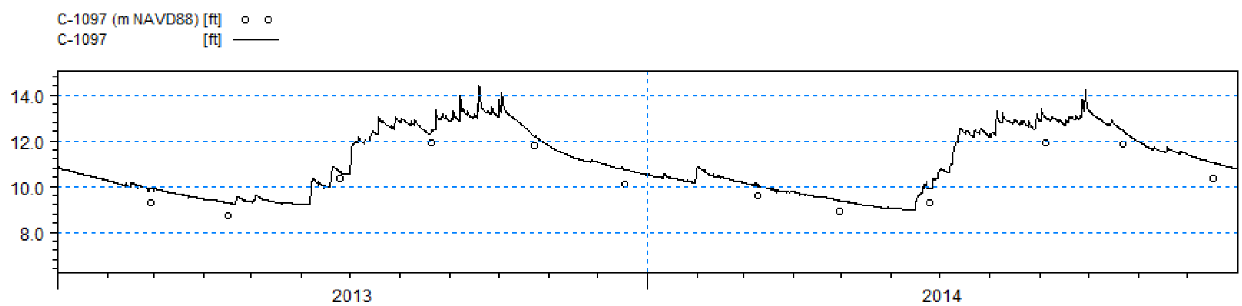


ME=-0.424494
MAE=0.918662
RMSE=1.01104
STDres=0.917614
R(Correlation)=0.955365
R2(Nash_Sutcliffe)=0.810475

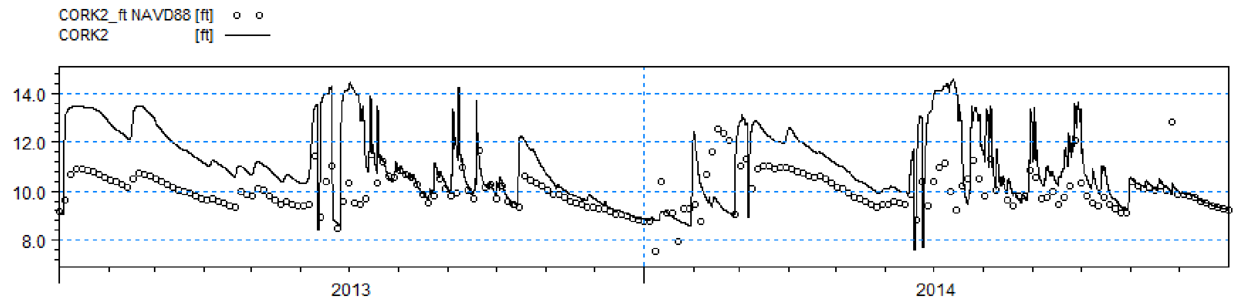
Stations South of Imperial River and South of Corkscrew Swamp Sanctuary



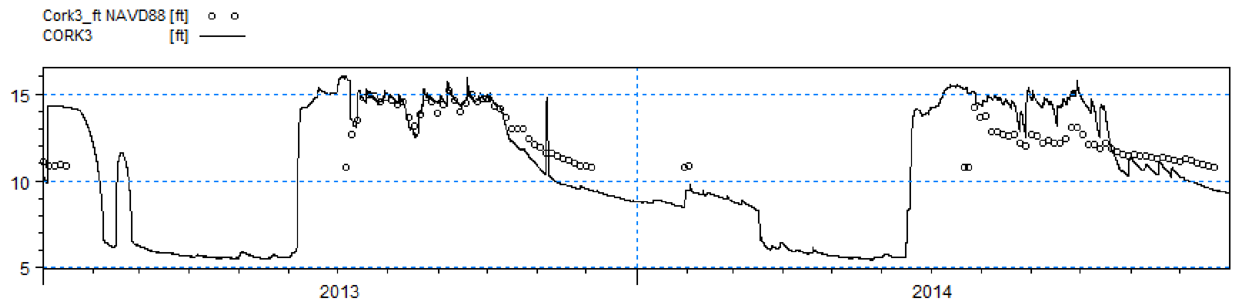
ME=-0.855637
MAE=1.023
RMSE=1.3828
STDres=1.08629
R(Correlation)=0.881769
R2(Nash_Sutcliffe)=0.617901



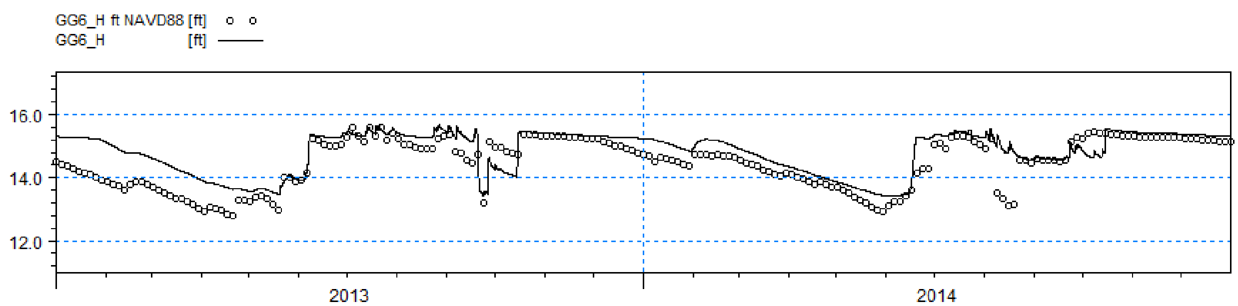
ME=-0.571887
MAE=0.571887
RMSE=0.600222
STDres=0.182239
R(Correlation)=0.989556
R2(Nash_Sutcliffe)=0.745842



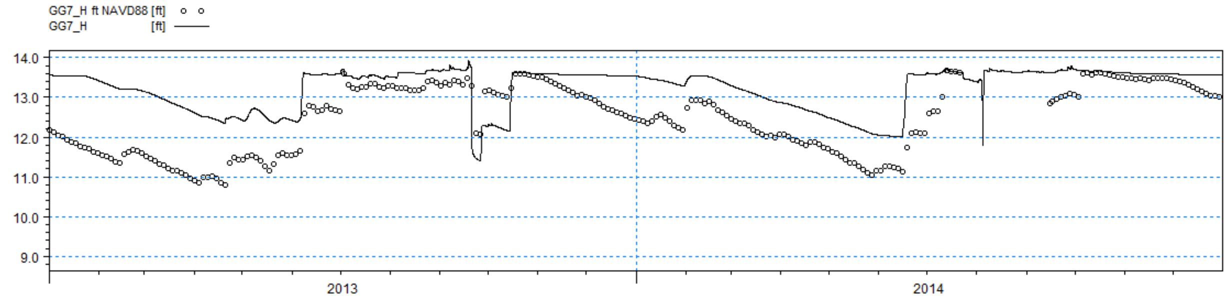
ME=-0.964538
MAE=1.13432
RMSE=1.55419
STDres=1.21868
R(Correlation)=0.53906
R2(Nash_Sutcliffe)=-3.3477



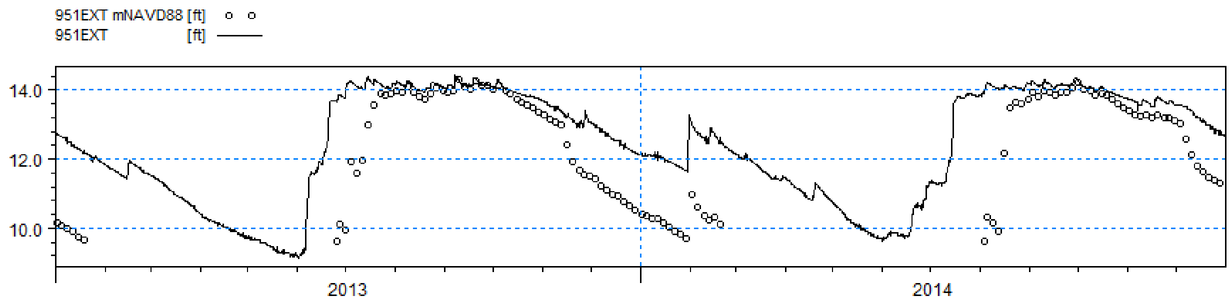
ME=-0.318281
MAE=1.11763
RMSE=1.43433
STDres=1.39857
R(Correlation)=0.72935
R2(Nash_Sutcliffe)=-0.112586



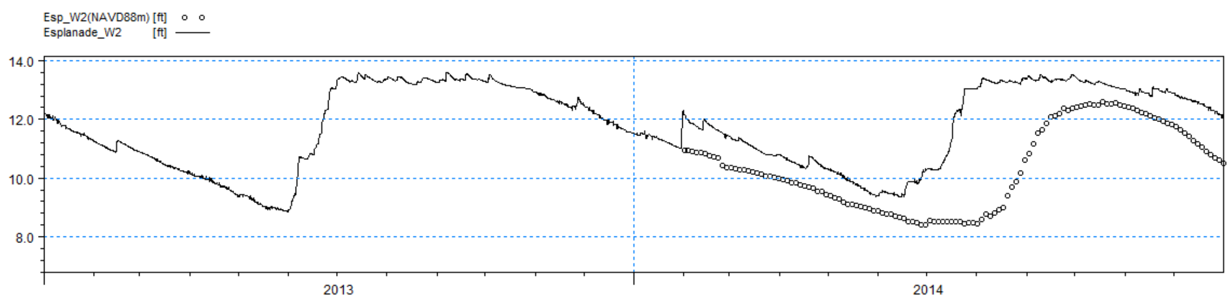
ME=-0.342083
MAE=0.411254
RMSE=0.543651
STDres=0.422535
R(Correlation)=0.838541
R2(Nash_Sutcliffe)=0.508565



ME=-0.737082
MAE=0.792891
RMSE=0.943579
STDres=0.589111
R(Correlation)=0.720525
R2(Nash_Sutcliffe)=-0.254206



ME=-1.03161
MAE=1.03216
RMSE=1.46241
STDres=1.03655
R(Correlation)=0.822727
R2(Nash_Sutcliffe)=0.11551



ME=-1.45673
MAE=1.45673
RMSE=1.85353
STDres=1.14608
R(Correlation)=0.660445
R2(Nash_Sutcliffe)=-0.743196

ATTACHMENT 5

Model Performance for the Validation Period

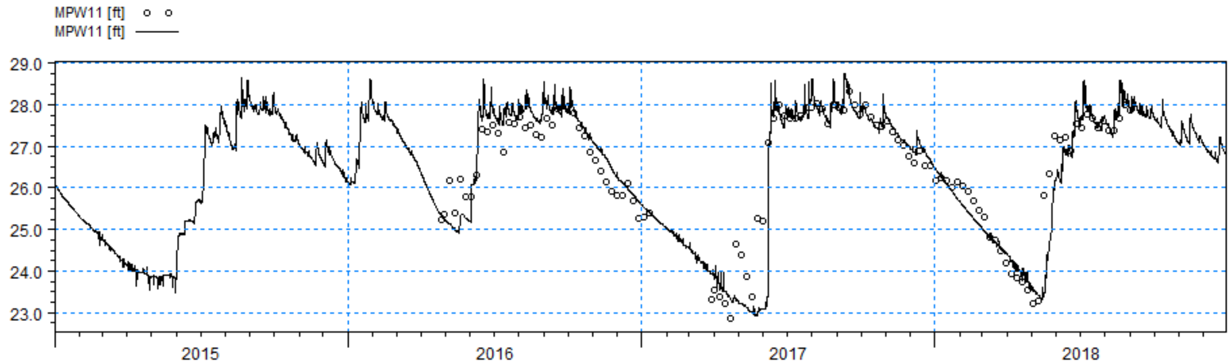
Attachment 5 – Model Performance for the Validation Period

Name	Data_type	Layer	ME	MAE	RMSE	STDres	R_Correlat	R2_Nash_Su
47A-GW01	head elevation in saturated zone	3	-0.66	0.66	0.70	0.23	0.99	0.61
47A-GW03	head elevation in saturated zone	3	1.17	1.18	1.30	0.57	0.94	-0.19
49-GW06	head elevation in saturated zone	1	0.42	0.48	0.75	0.63	0.92	0.74
49-GW07	head elevation in saturated zone	1	-0.19	0.90	1.16	1.15	0.70	0.31
49-GW08	head elevation in saturated zone	1	-0.45	0.49	0.61	0.41	0.98	0.88
49-GW09	head elevation in saturated zone	1	0.81	0.84	0.99	0.56	0.95	0.48
49-GW10	head elevation in saturated zone	1	1.50	1.64	1.74	0.89	0.91	0.35
49-GW11	head elevation in saturated zone	1	0.92	1.35	1.75	1.49	0.81	0.54
49-GW12	head elevation in saturated zone	1	-0.93	1.13	1.41	1.06	0.92	-0.18
49-GW13	head elevation in saturated zone	1	-2.28	2.29	2.93	1.84	0.71	-0.33
49-GW19	head elevation in saturated zone	1	1.25	1.27	1.35	0.50	0.98	0.49
49-GW22	head elevation in saturated zone	1	-1.84	1.85	2.07	0.93	0.79	-16.69
49-GW23	head elevation in saturated zone	1	-0.35	1.02	1.25	1.19	0.87	0.36
49-GW24	head elevation in saturated zone	1	0.74	0.92	1.05	0.75	0.92	0.66
49-GW25	head elevation in saturated zone	1	-0.19	0.86	1.02	1.01	0.91	0.75
49L-GW03	head elevation in saturated zone	1	-0.82	1.10	1.35	1.07	0.90	0.67
49L-GW04	head elevation in saturated zone	1	0.07	0.26	0.34	0.33	0.98	0.95
951EXT	head elevation in saturated zone	1	-1.11	1.11	1.44	0.92	0.83	0.09
BRDROOK_SW	head elevation in saturated zone	1	-0.85	0.88	0.96	0.45	0.96	0.65
C-0492	head elevation in saturated zone	3	-1.09	1.09	1.16	0.40	0.97	0.44
C-1097	head elevation in saturated zone	1	-0.55	0.55	0.61	0.28	0.98	0.83
CRKSWPS	head elevation in saturated zone	1	-0.55	0.60	0.86	0.66	0.97	0.59
FP02_GW1	head elevation in saturated zone	1	-0.23	0.56	0.69	0.64	0.92	0.77
FP11	head elevation in saturated zone	3	-0.94	1.07	1.24	0.80	0.84	0.30
HF1_G	head elevation in saturated zone	1	-1.18	1.26	1.69	1.21	0.90	0.50
HF6_G	head elevation in saturated zone	3	-3.24	3.28	4.67	3.36	0.85	0.05
L-0738_G	head elevation in saturated zone	3	-1.07	1.09	1.26	0.65	0.99	0.86
L-1138	head elevation in saturated zone	1	0.06	0.29	0.36	0.36	0.92	0.83
L-1691_G	head elevation in saturated zone	3	-0.64	1.18	1.46	1.31	0.95	0.83
L-1985	head elevation in saturated zone	3	0.62	0.82	1.10	0.91	0.89	0.66
L-2195	head elevation in saturated zone	1	0.75	0.78	0.98	0.63	0.97	0.67
L-2550	head elevation in saturated zone	3	0.24	0.74	1.00	0.97	0.84	0.68
L-5667	head elevation in saturated zone	3	1.01	1.01	1.04	0.27	0.98	0.30
L-5745R	head elevation in saturated zone	3	-0.64	1.27	1.75	1.63	0.94	0.77
L-5874	head elevation in saturated zone	3	-0.12	0.31	0.44	0.42	0.95	0.89
Pa_MW14A	head elevation in saturated zone	3	1.03	1.28	1.59	1.21	0.61	-0.08
SOCREW1	head elevation in saturated zone	1	-0.01	0.34	0.43	0.43	0.97	0.93
SOCREW2	head elevation in saturated zone	1	-0.05	0.42	0.60	0.60	0.93	0.80
ST1_G	head elevation in saturated zone	1	0.93	0.95	1.38	1.02	0.91	0.20
ST2_G	head elevation in saturated zone	1	1.13	1.13	1.48	0.96	0.92	-0.06
WF2_G	head elevation in saturated zone	1	-0.61	1.04	1.16	0.99	0.93	0.04
WF3_G	head elevation in saturated zone	1	0.62	0.65	0.85	0.58	0.93	0.71
Esplanade_W2	head elevation in saturated zone	1	-1.68	1.69	1.80	0.64	0.97	-0.04
CS_PZ-23	head elevation in saturated zone	1	0.59	0.87	1.16	1.00	0.86	0.64
MPW11	head elevation in saturated zone	1	-0.07	0.39	0.54	0.54	0.92	0.79
MPW14	head elevation in saturated zone	1	0.59	1.01	1.31	1.17	0.87	-0.01
MPW30	head elevation in saturated zone	1	1.06	1.20	1.78	1.42	0.88	-0.47
MPW33	head elevation in saturated zone	1	2.01	2.01	2.29	1.10	0.91	-1.31
MPW35	head elevation in saturated zone	1	0.36	0.48	0.67	0.56	0.92	0.77

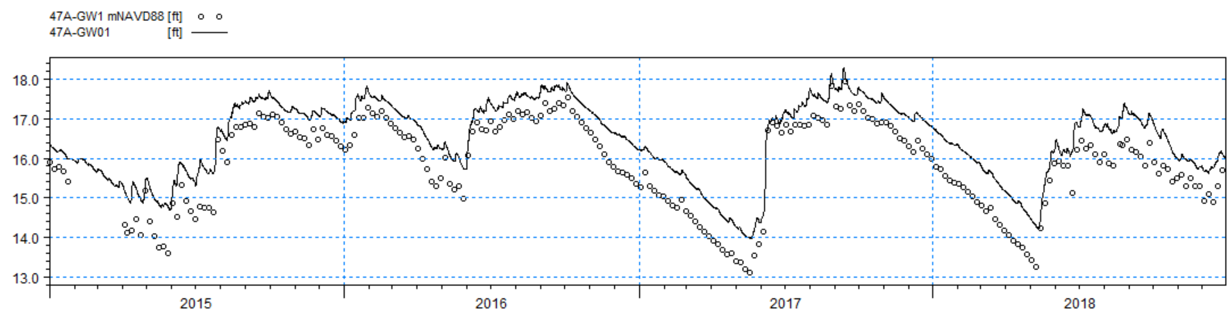
Name	Data_type	Layer	ME	MAE	RMSE	STDres	R_Correlat	R2_Nash_Su
CORK2	water level in river h-point	0	-0.40	1.17	2.09	2.06	0.27	-2.44
CORK3	water level in river h-point	0	0.91	1.72	2.21	2.01	0.56	-1.64
GG6_H	water level in river h-point	0	-0.72	0.76	0.98	0.67	0.67	-0.26
GG7_H	water level in river h-point	0	-0.82	0.83	1.06	0.66	0.72	-0.25
IMPERIAL_H	water level in river h-point	0	0.00	0.76	1.00	1.00	0.96	0.87
KEHL_H	water level in river h-point	0	0.39	0.78	1.10	1.03	0.90	0.77
KEHL_T	water level in river h-point	0	-0.16	0.51	0.72	0.70	0.97	0.93
IMPERIAL_Q	discharge in river q-point	0	22.33	35.84	70.78	67.17	0.96	0.88

Validation Plots

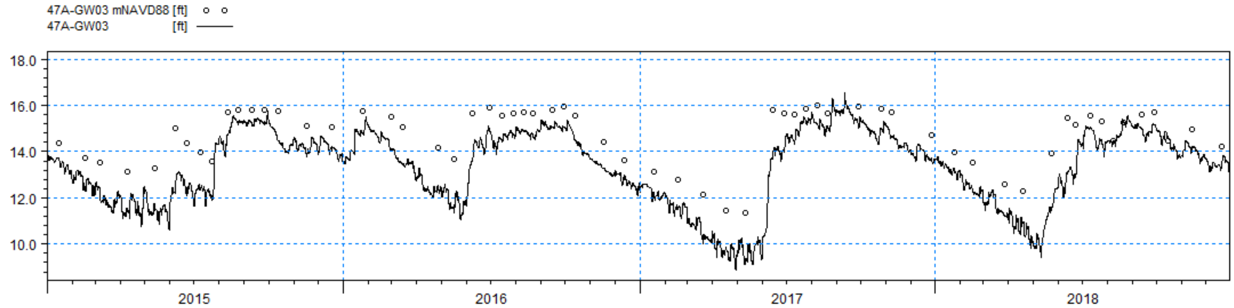
Stations North of Corkscrew Road



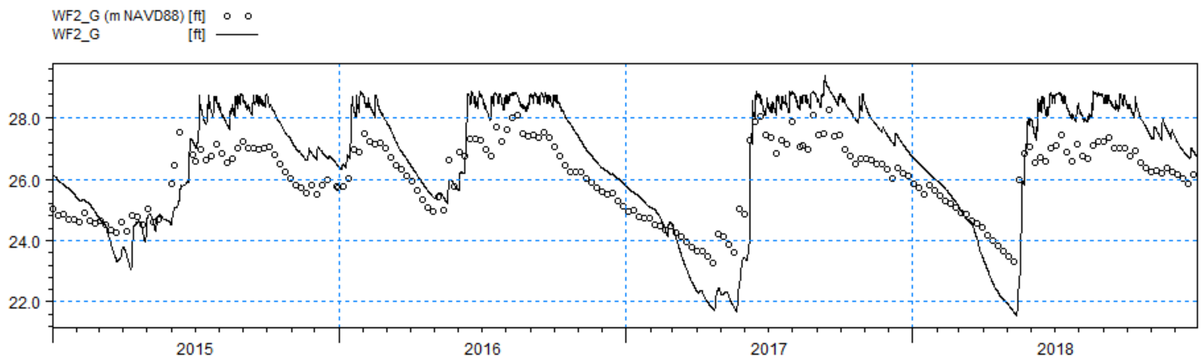
ME=-0.0658994
MAE=0.385674
RMSE=0.540834
STDres=0.536804
R(Correlation)=0.924596
R2(Nash_Sutcliffe)=0.787953



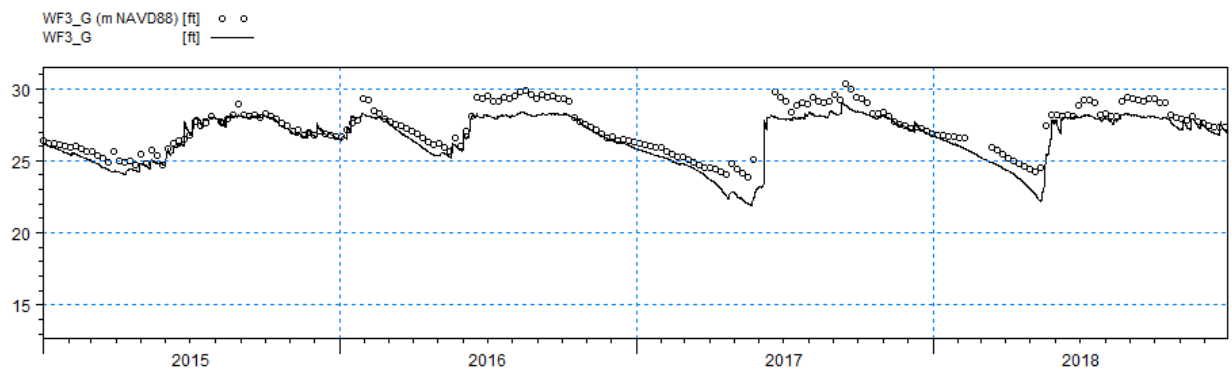
ME=-0.659834
MAE=0.660808
RMSE=0.699876
STDres=0.233337
R(Correlation)=0.985454
R2(Nash_Sutcliffe)=0.611603



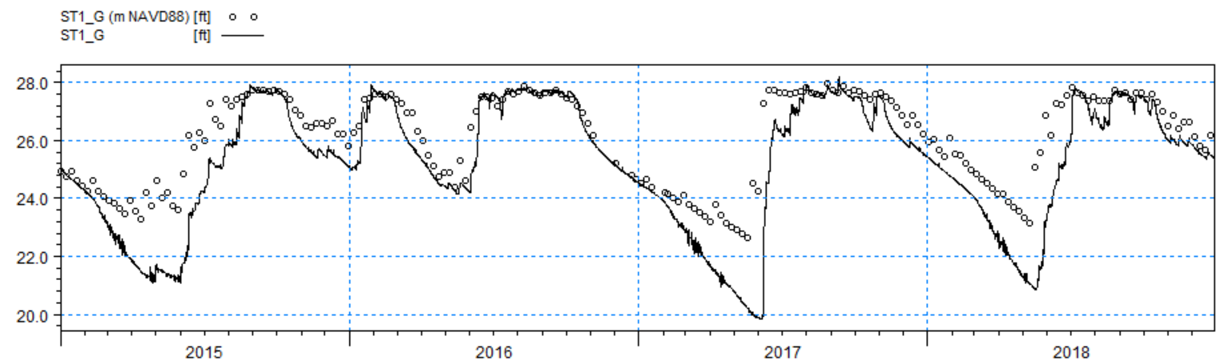
ME=1.17329
MAE=1.17779
RMSE=1.30288
STDres=0.566456
R(Correlation)=0.936981
R2(Nash_Sutcliffe)=-0.189098



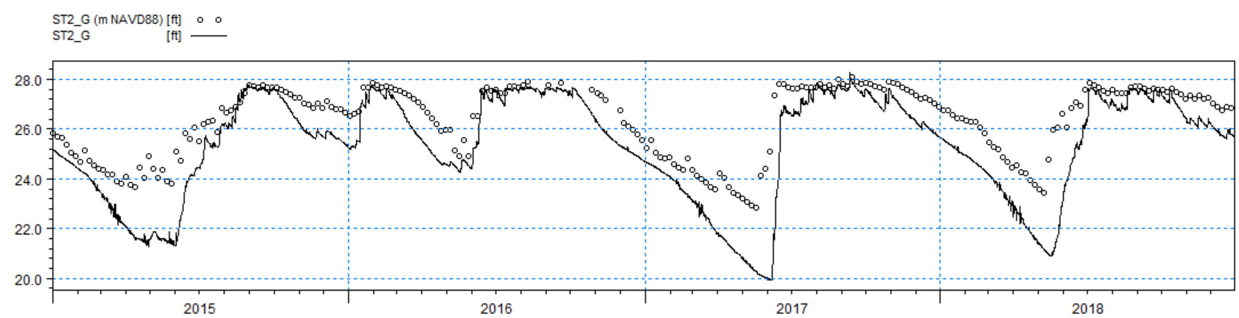
ME=-0.61096
MAE=1.04314
RMSE=1.16383
STDres=0.99057
R(Correlation)=0.928407
R2(Nash_Sutcliffe)=0.0351183



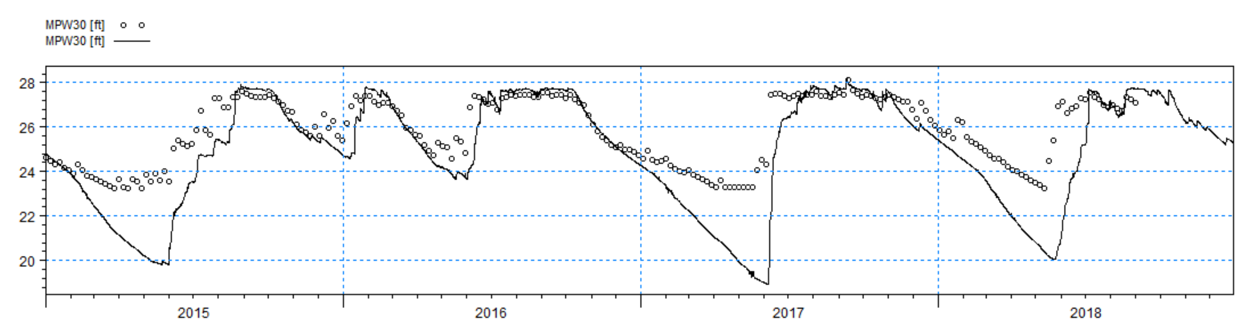
ME=0.620521
MAE=0.647252
RMSE=0.850841
STDres=0.582138
R(Correlation)=0.933965
R2(Nash_Sutcliffe)=0.70716



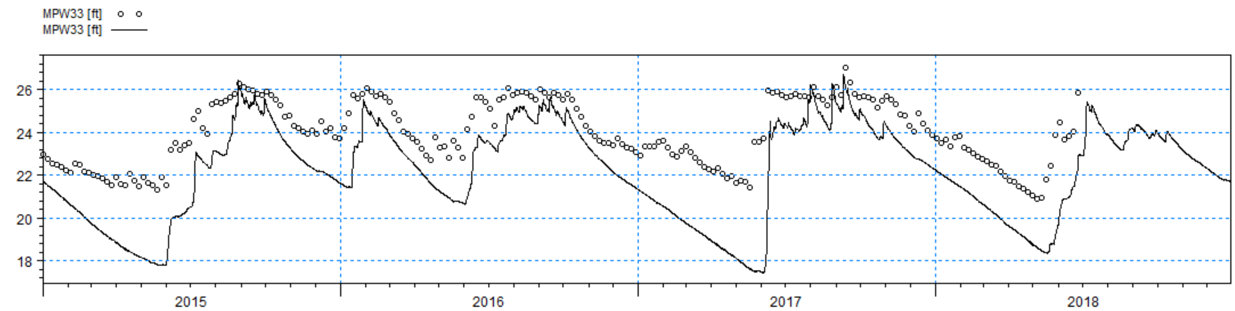
ME=0.930586
MAE=0.947002
RMSE=1.37808
STDres=1.01643
R(Correlation)=0.909172
R2(Nash_Sutcliffe)=0.200029



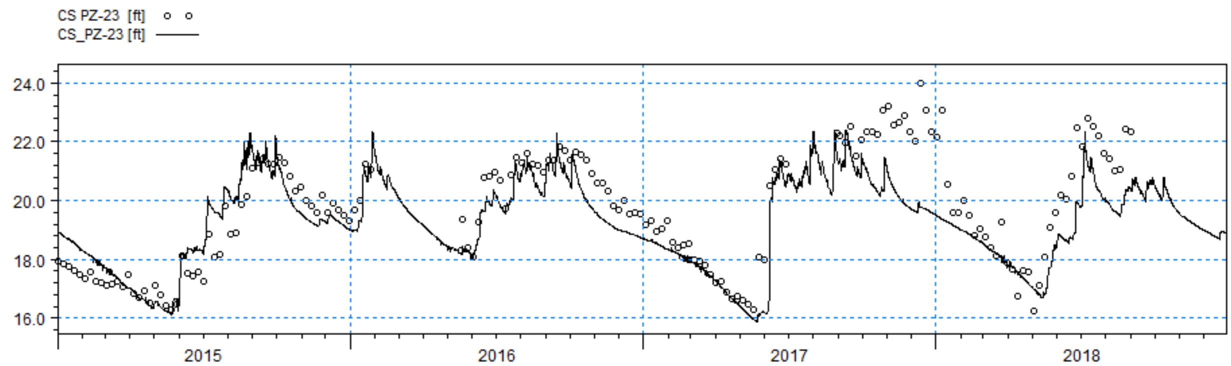
ME=1.12959
MAE=1.13175
RMSE=1.48068
STDres=0.957297
R(Correlation)=0.924667
R2(Nash_Sutcliffe)=-0.0628411



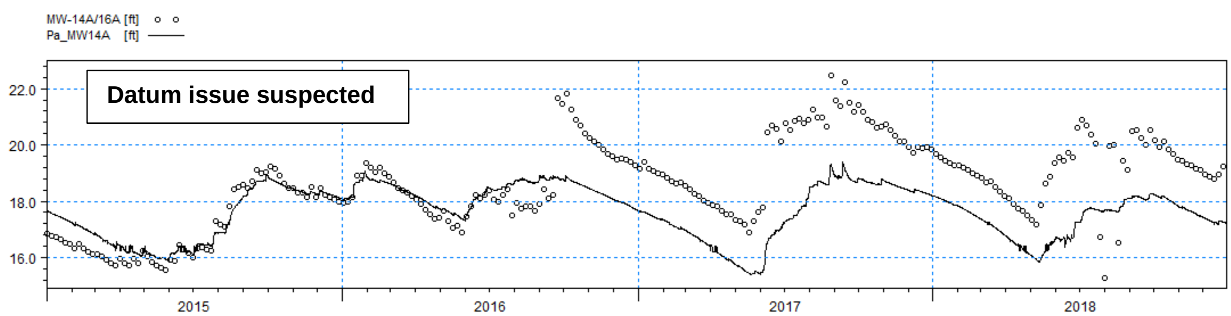
ME=1.06289
MAE=1.19817
RMSE=1.77677
STDres=1.4238
R(Correlation)=0.878422
R2(Nash_Sutcliffe)=-0.471375



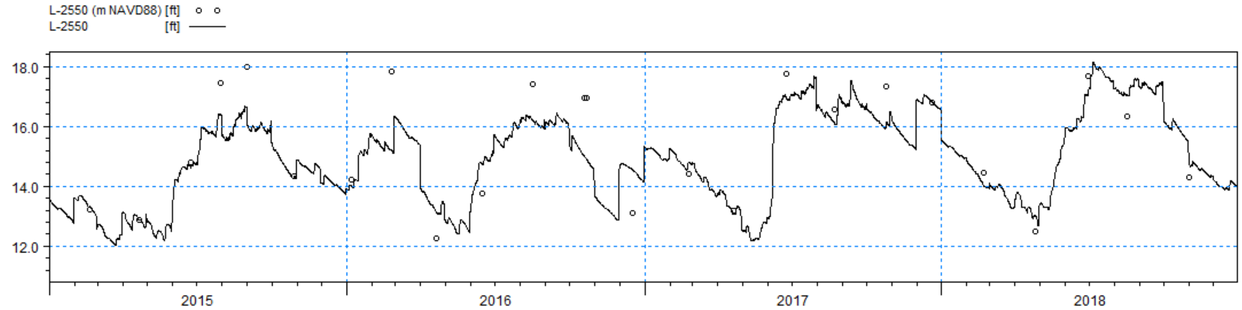
ME=2.00682
MAE=2.00693
RMSE=2.28875
STDres=1.10048
R(Correlation)=0.913033
R2(Nash_Sutcliffe)=-1.31212



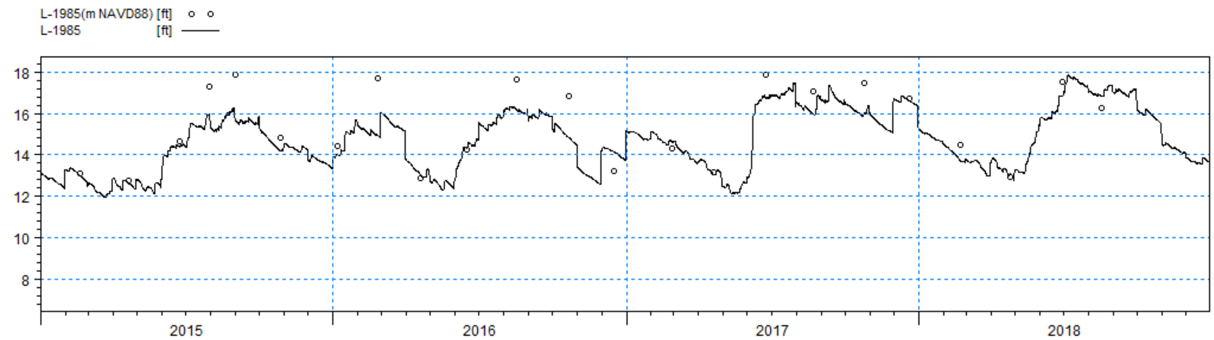
ME=0.591895
MAE=0.872886
RMSE=1.16478
STDres=1.00318
R(Correlation)=0.860477
R2(Nash_Sutcliffe)=0.639906



ME=1.03314
MAE=1.27799
RMSE=1.59055
STDres=1.20932
R(Correlation)=0.611102
R2(Nash_Sutcliffe)=-0.08393

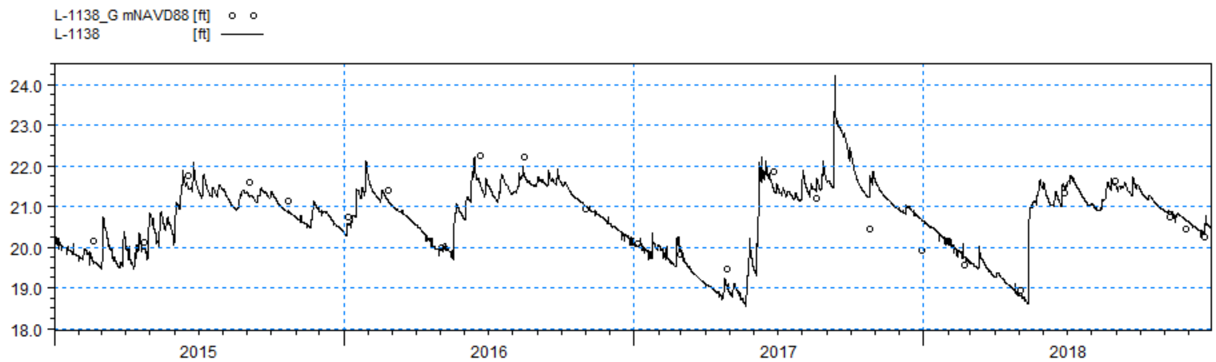


ME=0.237374
MAE=0.743144
RMSE=1.00141
STDres=0.972873
R(Correlation)=0.844766
R2(Nash_Sutcliffe)=0.684349



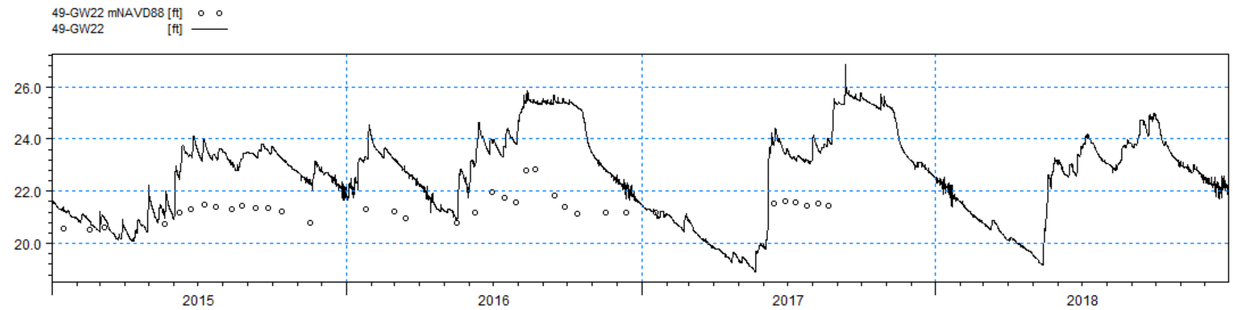
ME=0.624957
MAE=0.816836
RMSE=1.10442
STDres=0.910592
R(Correlation)=0.892473

Stations South of Corkscrew Road

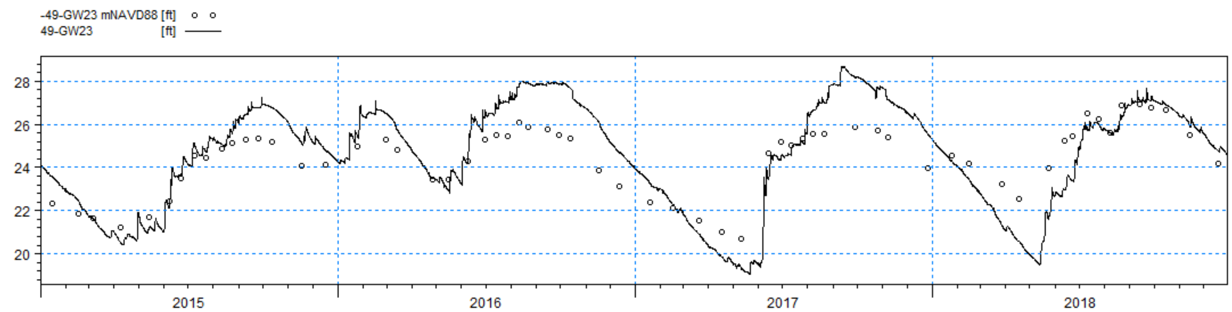


ME=0.0563351
MAE=0.28929
RMSE=0.359398
STDres=0.354956
R(Correlation)=0.915221
R2(Nash_Sutcliffe)=0.833365

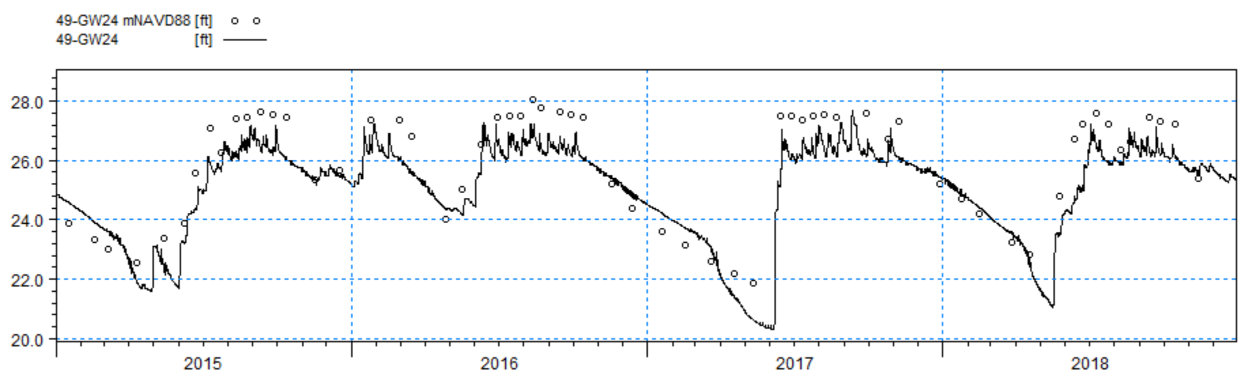
Station 49-GW22 is 4,100 ft west of L-1138. Calibration is excellent at L-1138. Measured data from 49-GW22 is questionable.



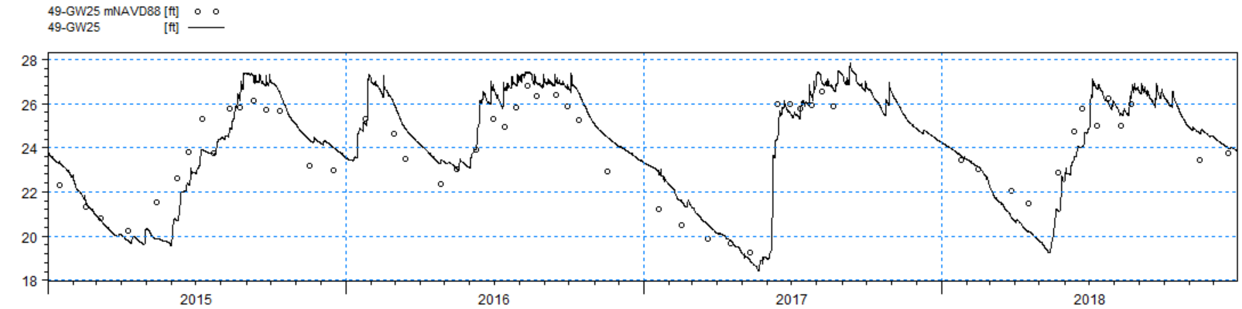
ME=-1.84453
MAE=1.84512
RMSE=2.06639
STDres=0.931494
R(Correlation)=0.787168
R2(Nash_Sutcliffe)=-16.6907



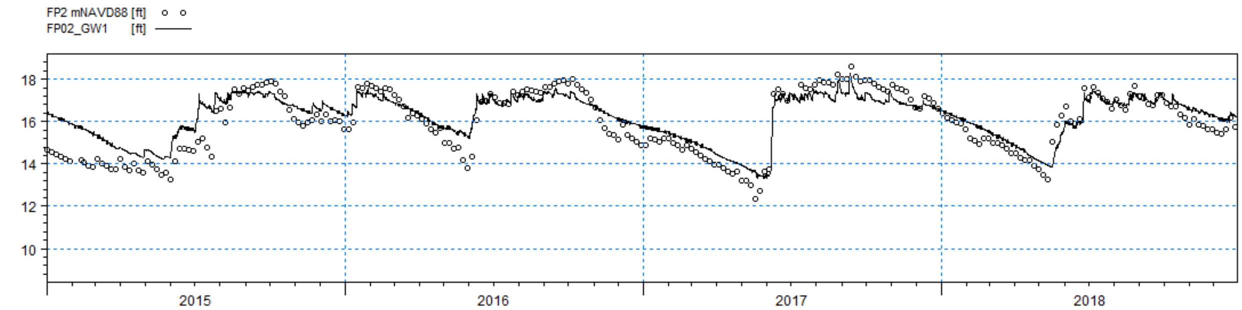
ME=-0.352846
MAE=1.01519
RMSE=1.24572
STDres=1.1947
R(Correlation)=0.865665
R2(Nash_Sutcliffe)=0.36182



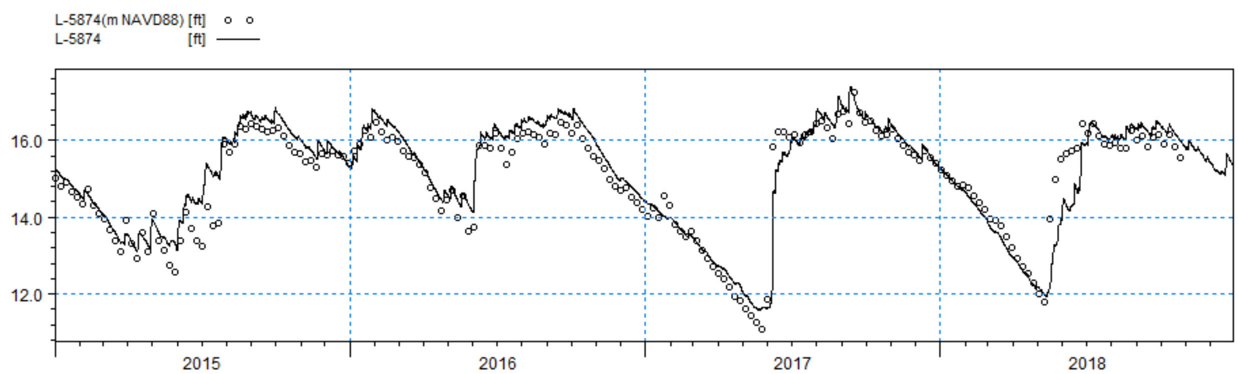
ME=0.744004
MAE=0.920995
RMSE=1.05447
STDres=0.747237
R(Correlation)=0.921089
R2(Nash_Sutcliffe)=0.658445



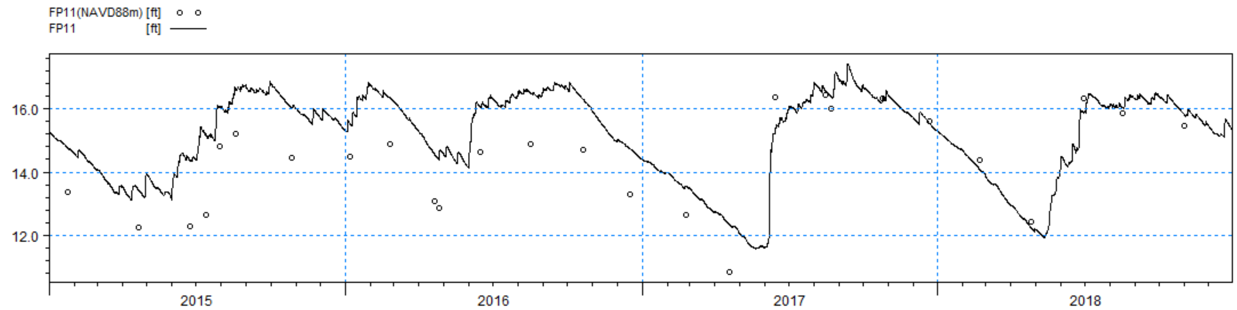
ME=-0.193408
MAE=0.860869
RMSE=1.02347
STDres=1.00503
R(Correlation)=0.905495
R2(Nash_Sutcliffe)=0.7502



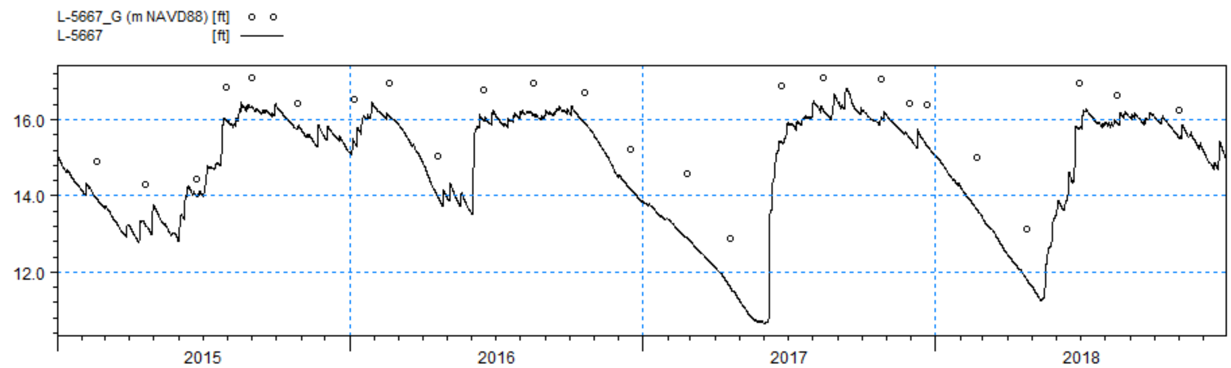
ME=-0.232743
MAE=0.556612
RMSE=0.685086
STDres=0.64434
R(Correlation)=0.915361
R2(Nash_Sutcliffe)=0.772757



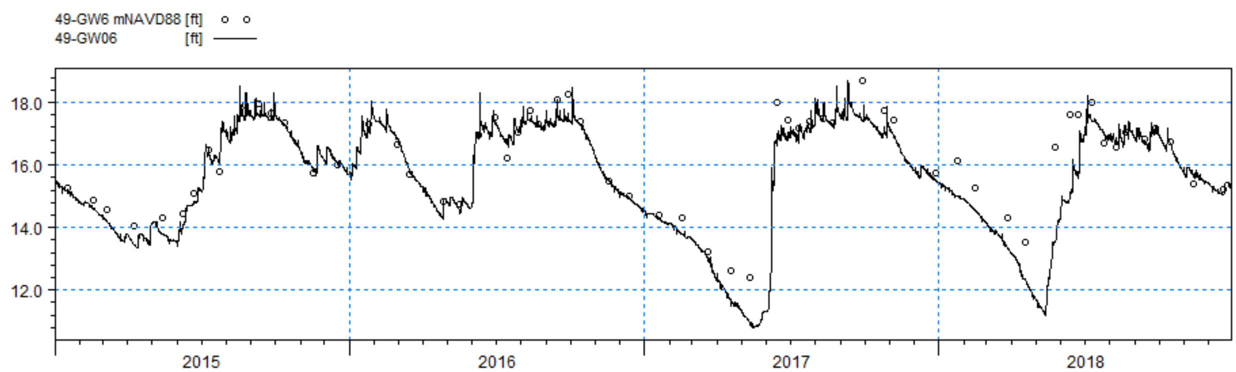
ME=-0.116217
MAE=0.307184
RMSE=0.440517
STDres=0.42491
R(Correlation)=0.952176
R2(Nash_Sutcliffe)=0.894031



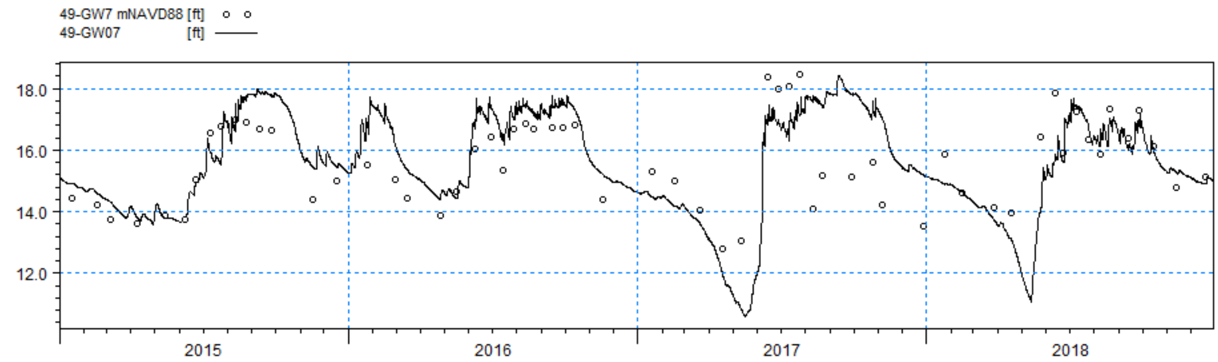
ME=-0.944464
MAE=1.07061
RMSE=1.2403
STDres=0.80395
R(Correlation)=0.840462
R2(Nash_Sutcliffe)=0.300728



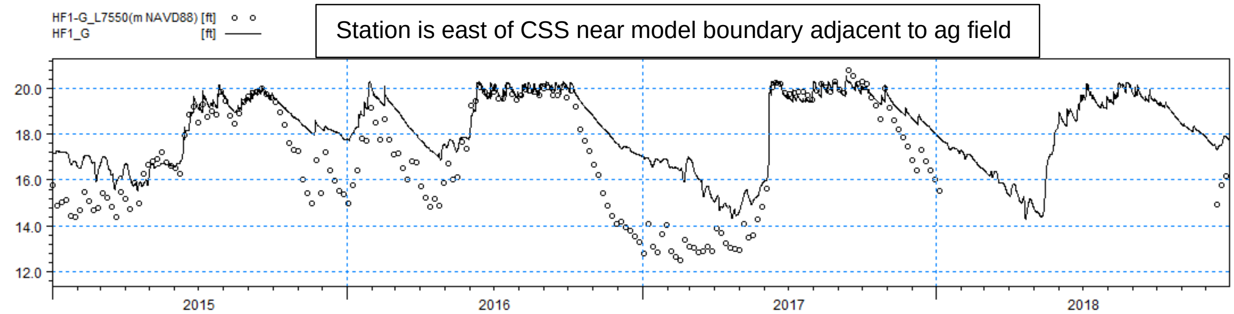
ME=1.00587
MAE=1.00587
RMSE=1.04186
STDres=0.271479
R(Correlation)=0.982751
R2(Nash_Sutcliffe)=0.303261



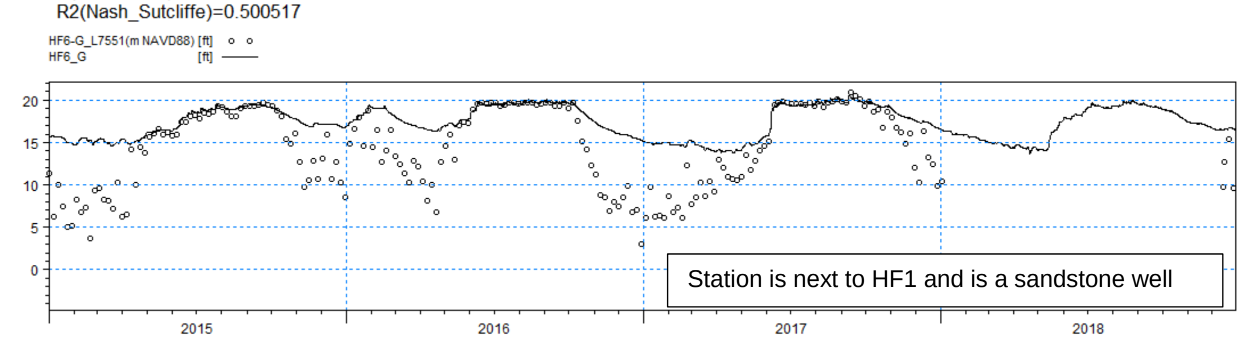
ME=0.415702
MAE=0.483631
RMSE=0.754694
STDres=0.629885
R(Correlation)=0.919817
R2(Nash_Sutcliffe)=0.744867



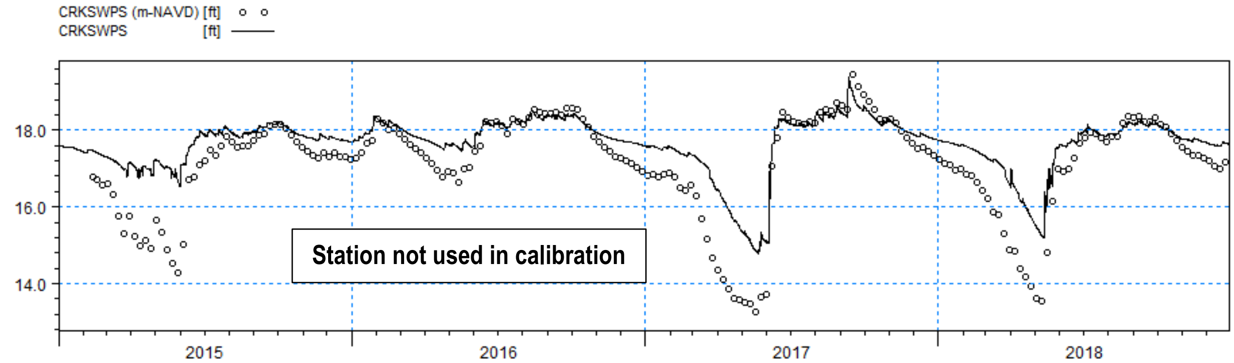
ME=-0.185203
MAE=0.896994
RMSE=1.16398
STDres=1.14915
R(Correlation)=0.697316
R2(Nash_Sutcliffe)=0.309995



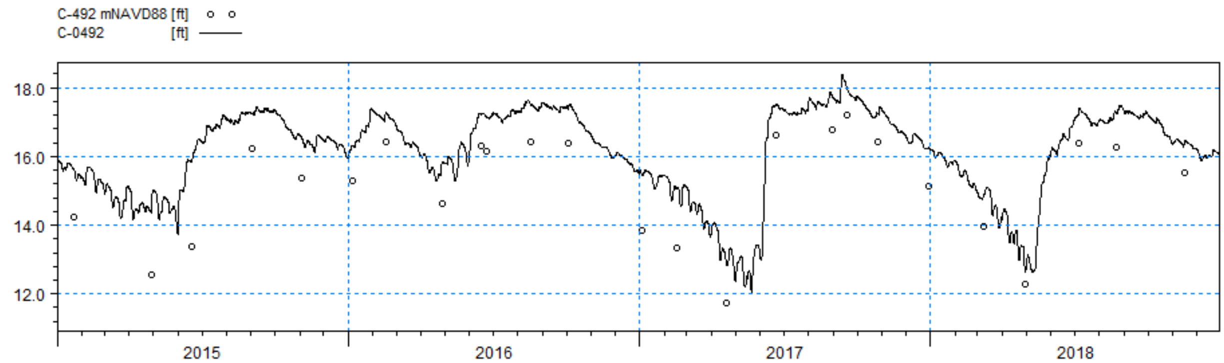
ME=-1.18265
MAE=1.26004
RMSE=1.68858
STDres=1.20525
R(Correlation)=0.901182
R2(Nash_Sutcliffe)=0.500517



ME=-3.2363
MAE=3.28387
RMSE=4.66513
STDres=3.36003
R(Correlation)=0.847574
R2(Nash_Sutcliffe)=0.0502364

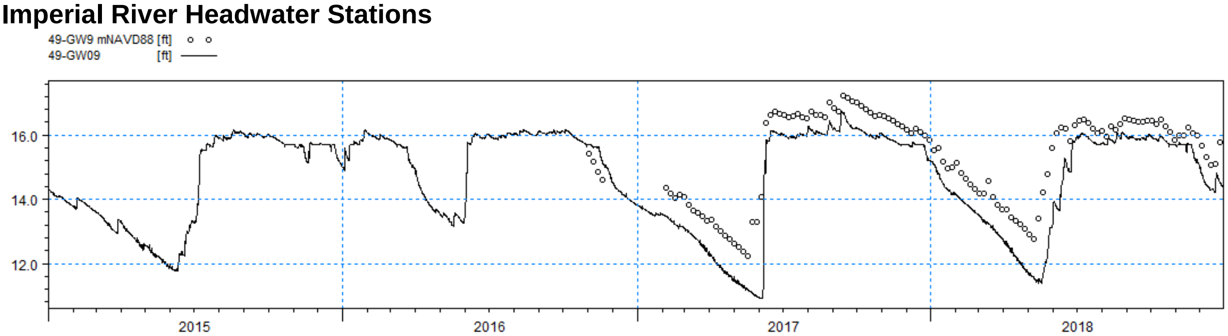


ME=-0.547312
MAE=0.603812
RMSE=0.860322
STDres=0.663779
R(Correlation)=0.967323
R2(Nash_Sutcliffe)=0.586248

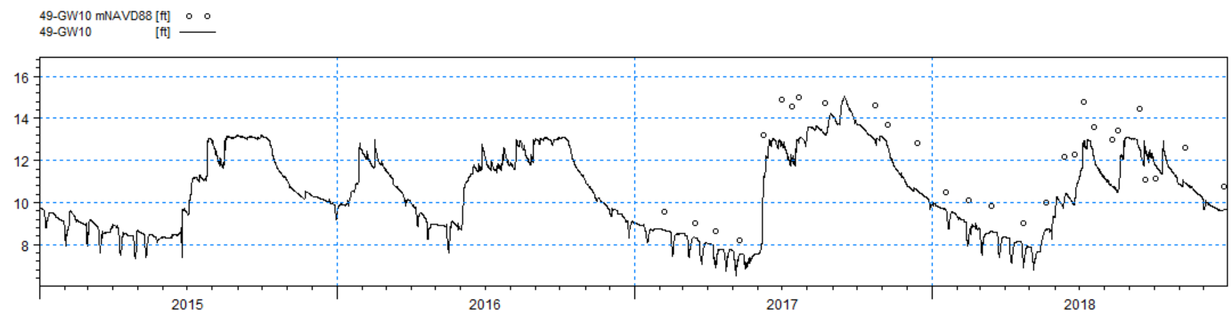


ME=-1.08885
MAE=1.08885
RMSE=1.16148
STDres=0.404267
R(Correlation)=0.967559
R2(Nash_Sutcliffe)=0.439729

Imperial River Headwater Stations

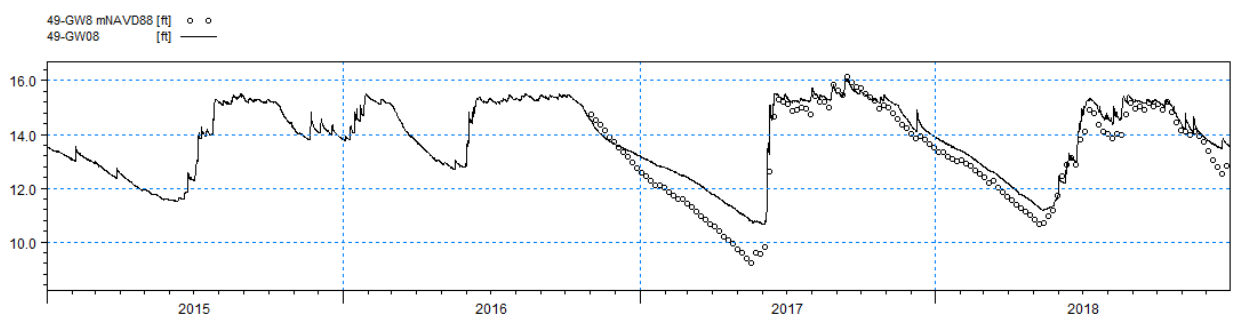


ME=0.812507
MAE=0.842765
RMSE=0.988402
STDres=0.562824
R(Correlation)=0.950207
R2(Nash_Sutcliffe)=0.479957

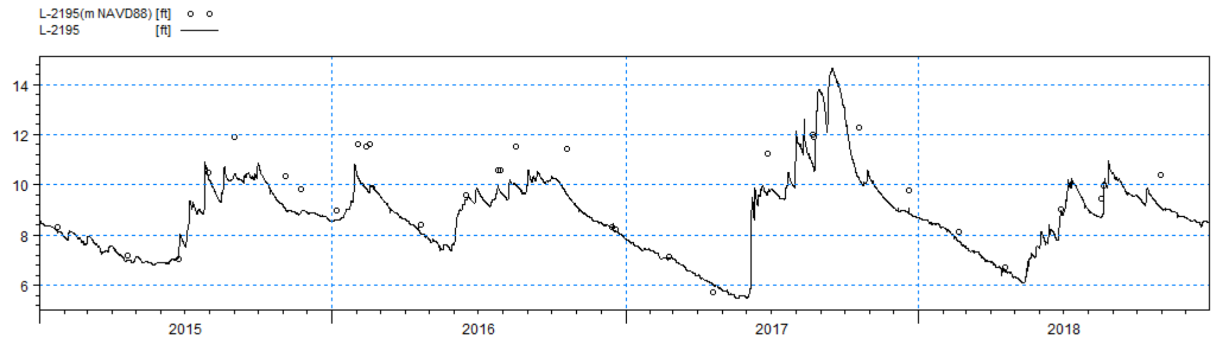


ME=1.49685
MAE=1.63759
RMSE=1.74241
STDres=0.891879
R(Correlation)=0.910691
R2(Nash_Sutcliffe)=0.346531

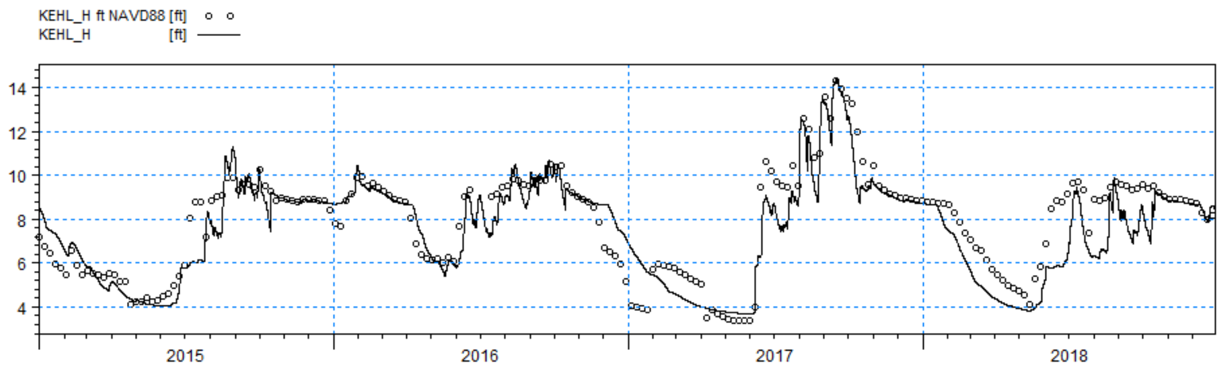
ME=0.920788
MAE=1.34584
RMSE=1.75361
STDres=1.49241
R(Correlation)=0.814692
R2(Nash_Sutcliffe)=0.535283



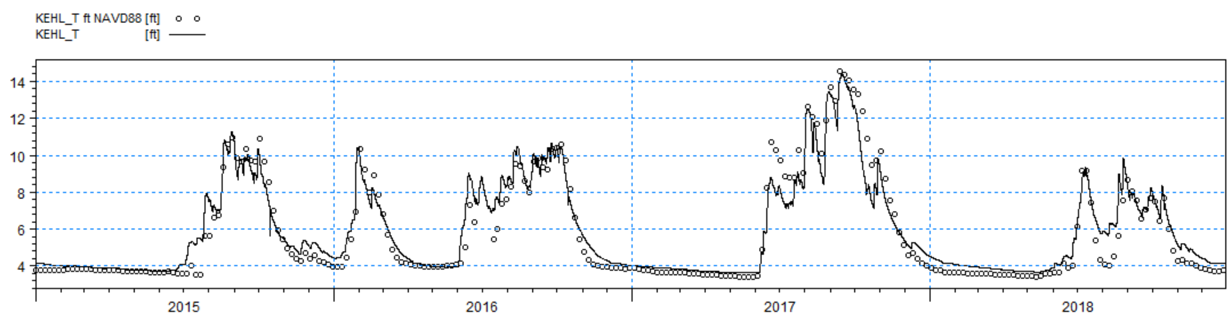
ME=-0.449403
MAE=0.489843
RMSE=0.611515
STDres=0.414713
R(Correlation)=0.982331
R2(Nash_Sutcliffe)=0.87714



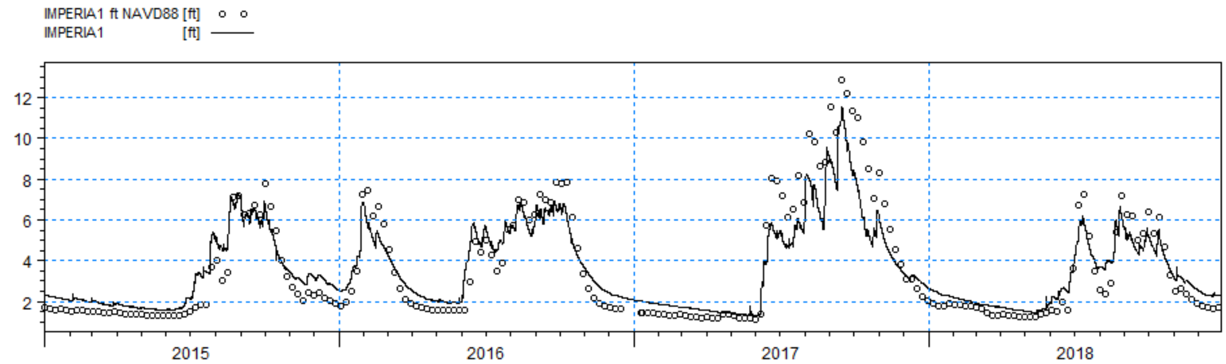
ME=0.750705
MAE=0.779234
RMSE=0.979452
STDres=0.629101
R(Correlation)=0.965109



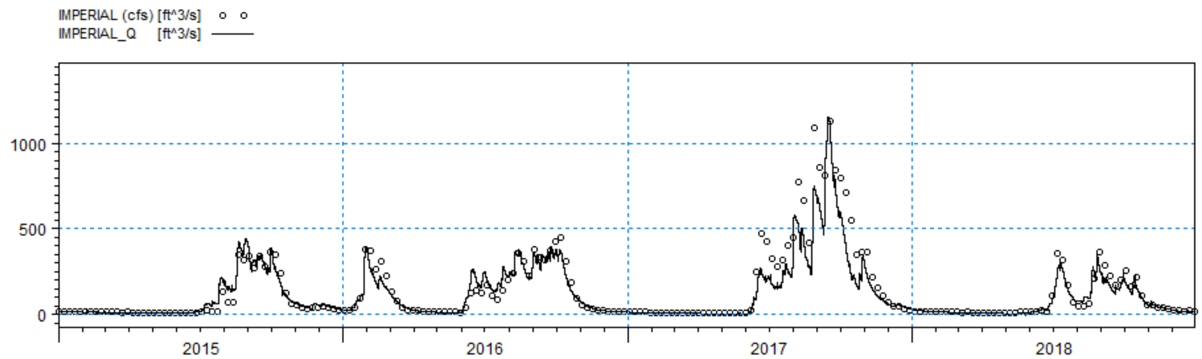
ME=0.390181
MAE=0.780418
RMSE=1.09992
STDres=1.02838
R(Correlation)=0.898441
R2(Nash_Sutcliffe)=0.773567



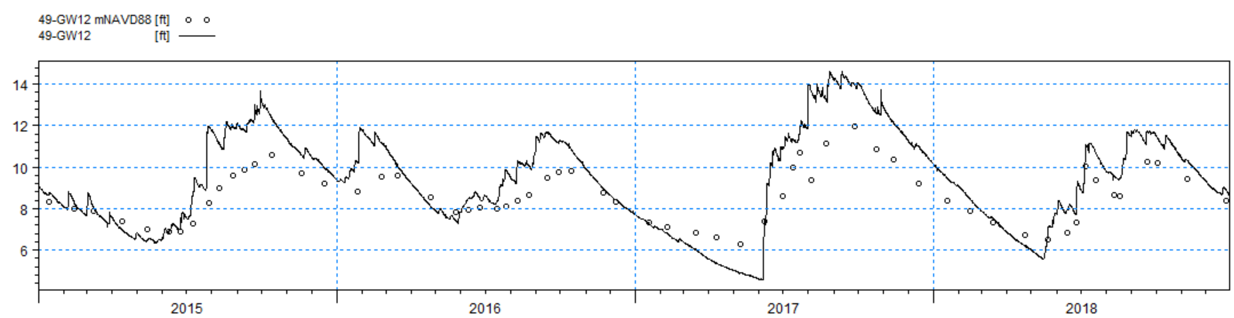
ME=-0.156897
MAE=0.513134
RMSE=0.715104
STDres=0.69768
R(Correlation)=0.972044
R2(Nash_Sutcliffe)=0.933732



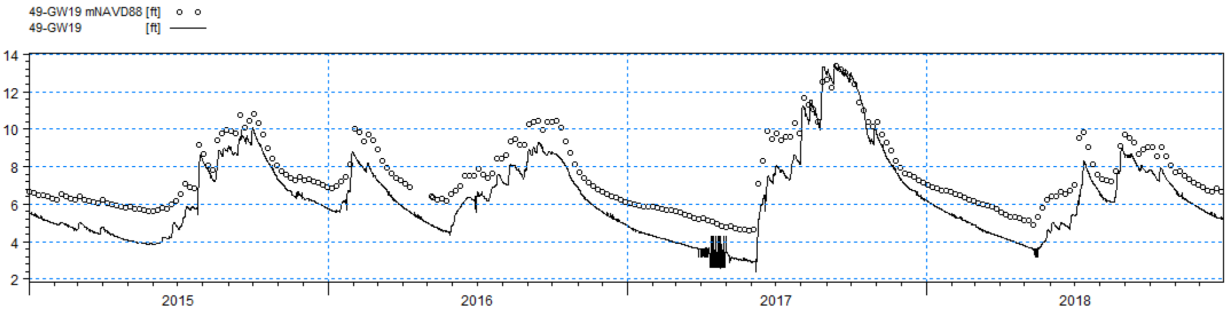
ME=0.00484379
MAE=0.764444
RMSE=0.996955
STDres=0.996943
R(Correlation)=0.963199
R2(Nash_Sutcliffe)=0.865104



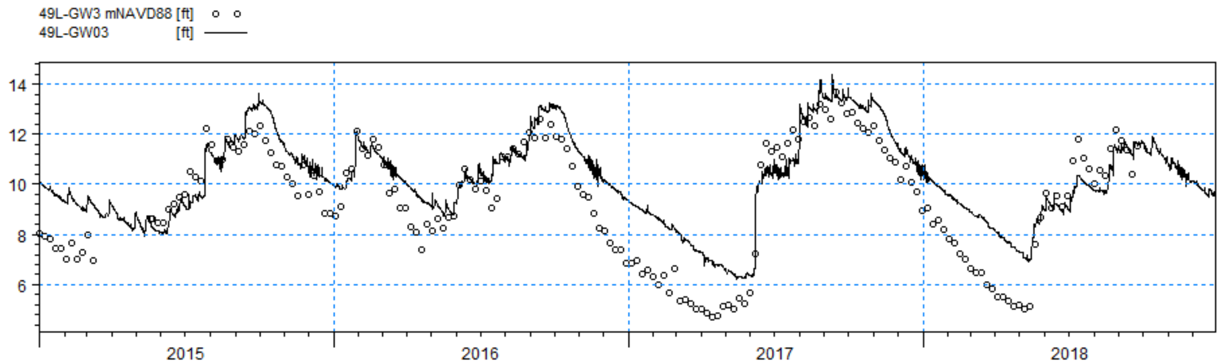
ME=22.3254
MAE=35.8444
RMSE=70.7803
STDres=67.1671
R(Correlation)=0.960188
R2(Nash_Sutcliffe)=0.876648



ME=-0.932584
MAE=1.13337
RMSE=1.41113
STDres=1.05904
R(Correlation)=0.920333
R2(Nash_Sutcliffe)=-0.17772

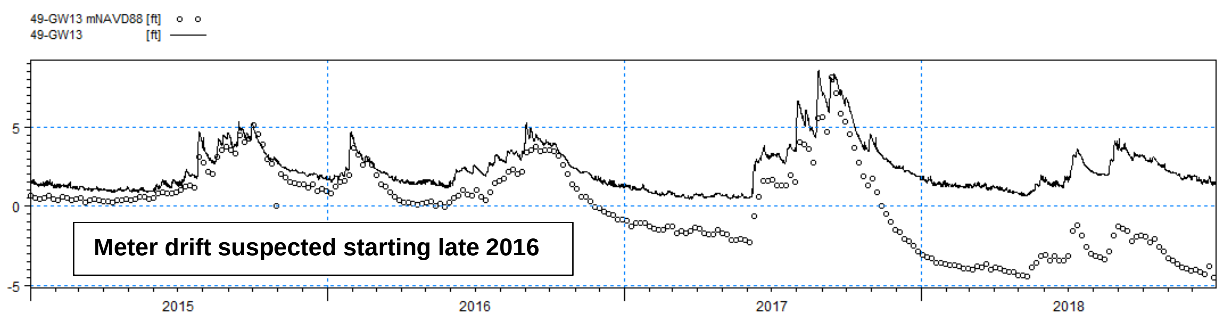


ME=1.2549
MAE=1.27078
RMSE=1.35149
STDres=0.501732
R(Correlation)=0.979232
R2(Nash_Sutcliffe)=0.491268

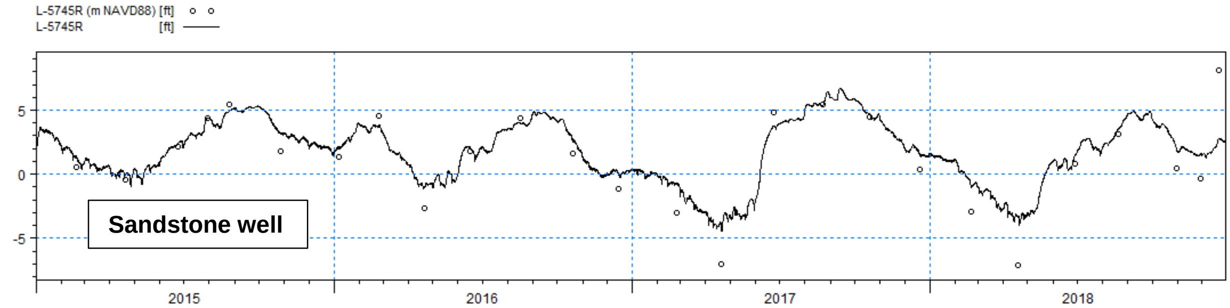


ME=-0.818779
MAE=1.09841
RMSE=1.34759
STDres=1.07033
R(Correlation)=0.899751
R2(Nash_Sutcliffe)=0.665231

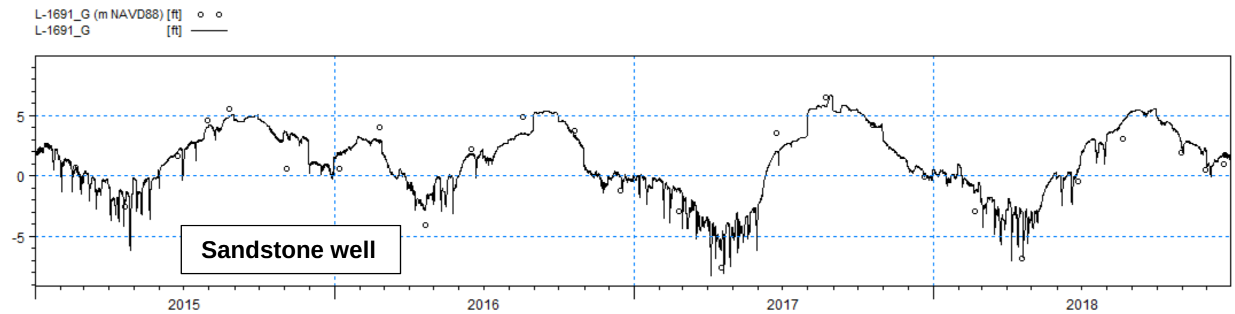
Imperial River Watershed Stations West of I-75



ME=-2.28317
MAE=2.29114
RMSE=2.93066
STDres=1.83736
R(Correlation)=0.706704
R2(Nash_Sutcliffe)=-0.325698

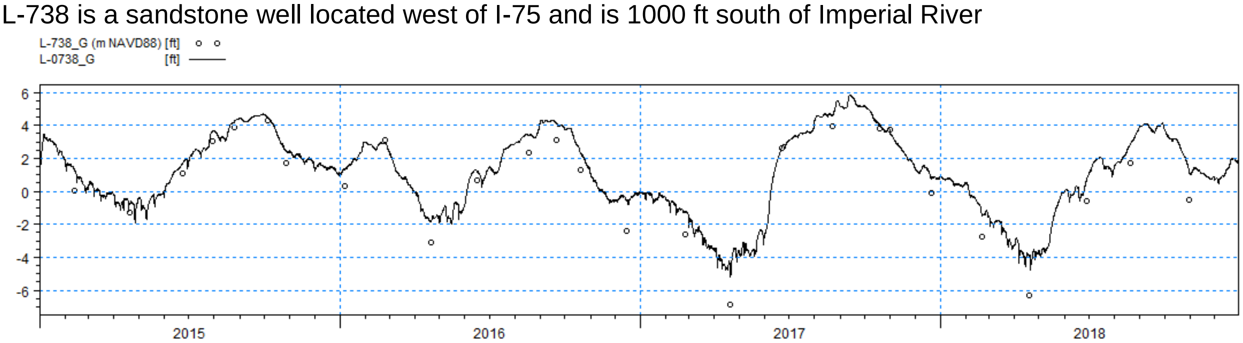


ME=-0.637903
MAE=1.26523
RMSE=1.74938
STDres=1.62893
R(Correlation)=0.937539
R2(Nash_Sutcliffe)=0.768365



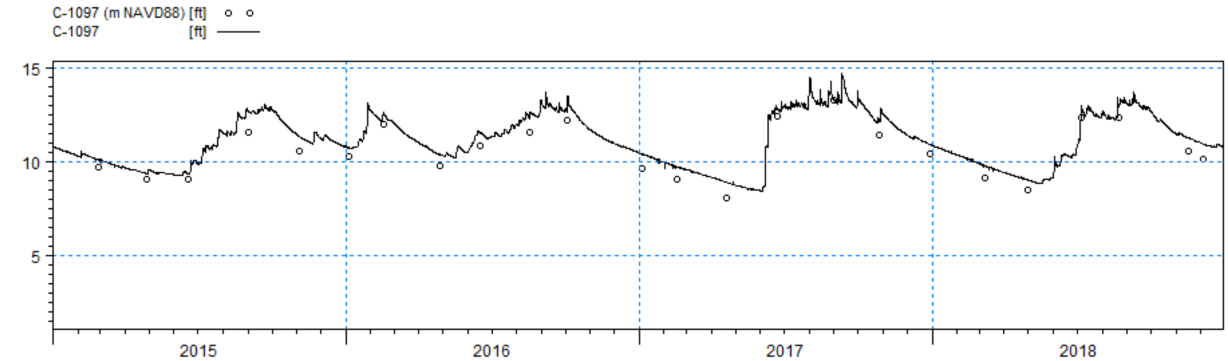
ME=-0.643684
MAE=1.17615
RMSE=1.46322
STDres=1.31403
R(Correlation)=0.9524
R2(Nash_Sutcliffe)=0.834086

L-738 is a sandstone well located west of I-75 and is 1000 ft south of Imperial River

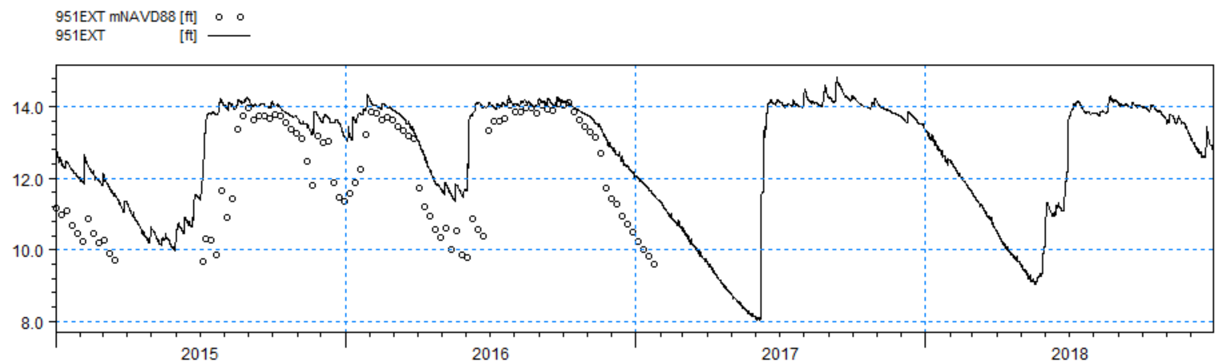


ME=-1.07435
MAE=1.09125
RMSE=1.25685
STDres=0.652271
R(Correlation)=0.991937
R2(Nash_Sutcliffe)=0.861564

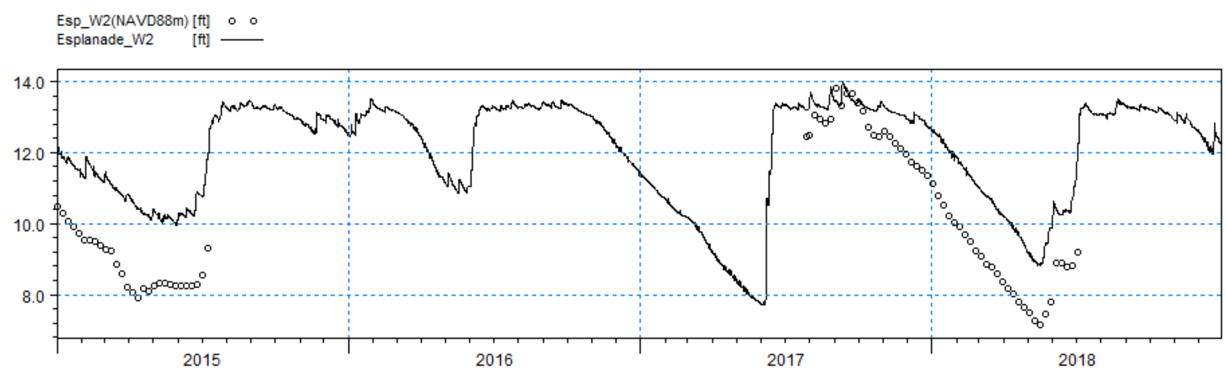
Stations South of Imperial River and South of Corkscrew Swamp Sanctuary



ME=-0.545252
MAE=0.548387
RMSE=0.610805
STDres=0.275286
R(Correlation)=0.982842
R2(Nash_Sutcliffe)=0.825899

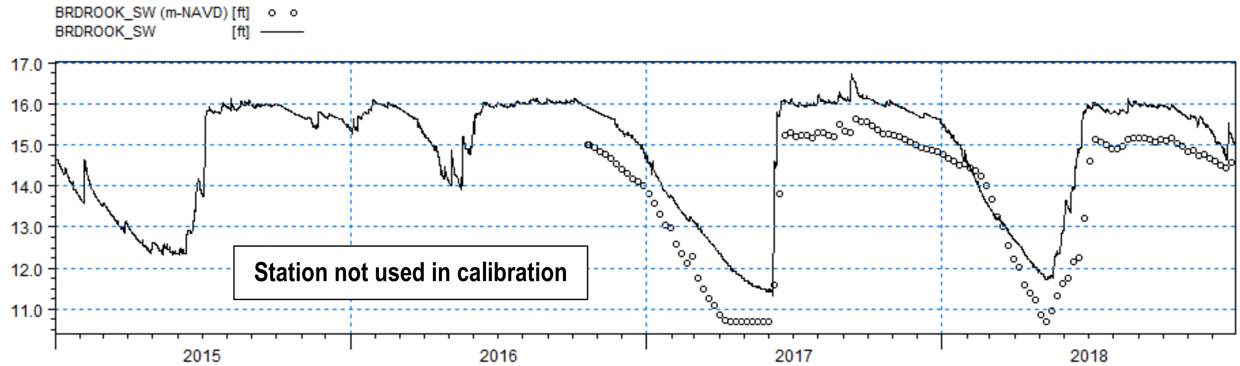


ME=-1.10705
MAE=1.10705
RMSE=1.44153
STDres=0.923273
R(Correlation)=0.829075
R2(Nash_Sutcliffe)=0.0935854

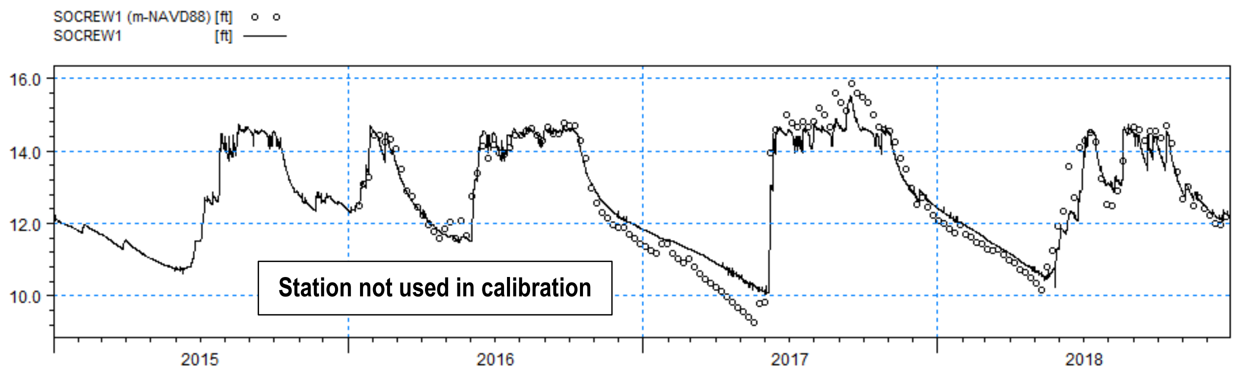


ME=-1.67695
MAE=1.6879
RMSE=1.79523
STDres=0.640863
R(Correlation)=0.967239
R2(Nash_Sutcliffe)=-0.0424985

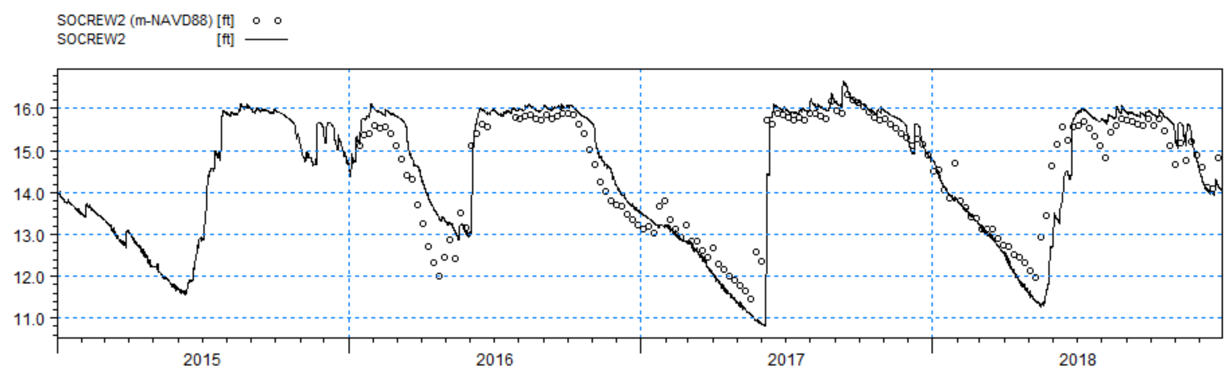
Station not used in calibration, and station is next to lake maintained at elevation below natural ground level



ME=-0.853344
MAE=0.876418
RMSE=0.964724
STDres=0.449994
R(Correlation)=0.9608
R2(Nash_Sutcliffe)=0.645866

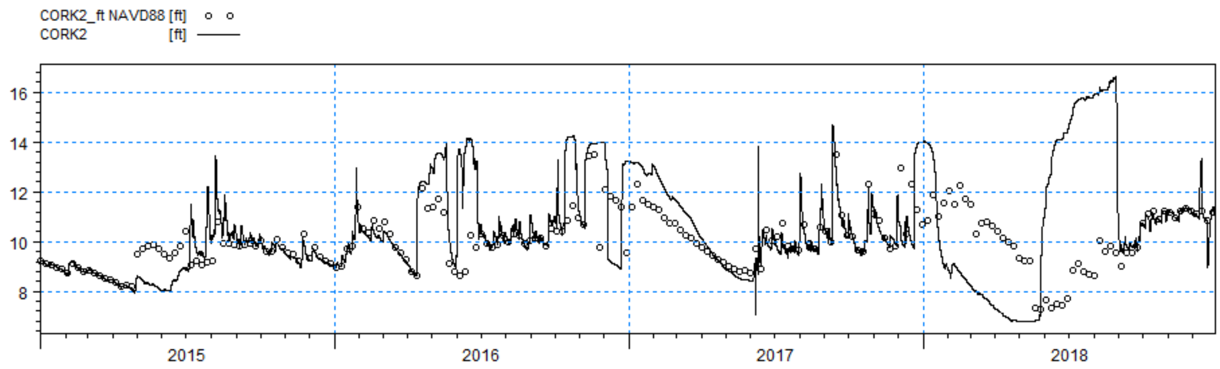


ME=-0.0141378
MAE=0.338273
RMSE=0.431407
STDres=0.431175
R(Correlation)=0.973466
R2(Nash_Sutcliffe)=0.93108

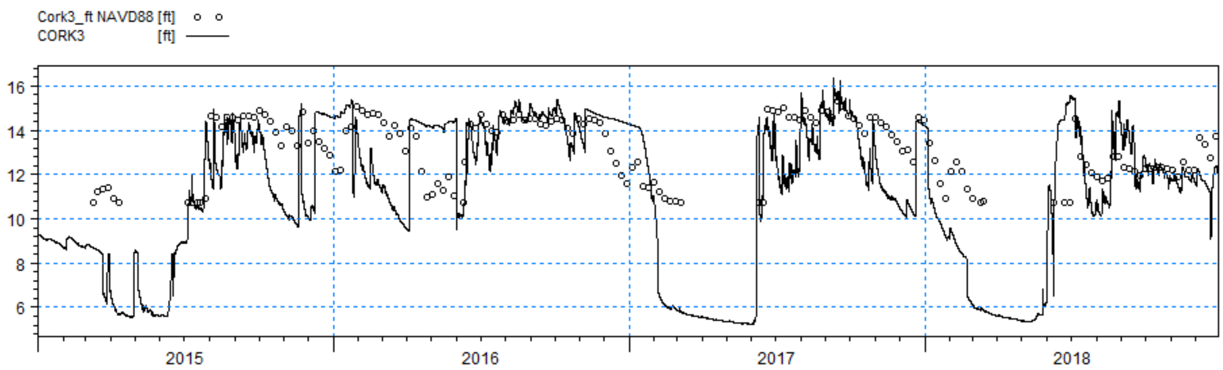


ME=-0.050689
MAE=0.423747
RMSE=0.601638
STDres=0.599499
R(Correlation)=0.928712
R2(Nash_Sutcliffe)=0.798056

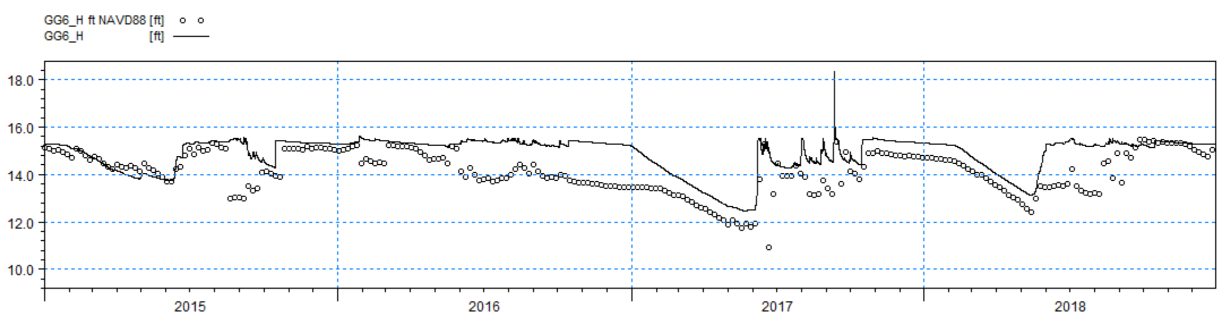
Station not used in calibration



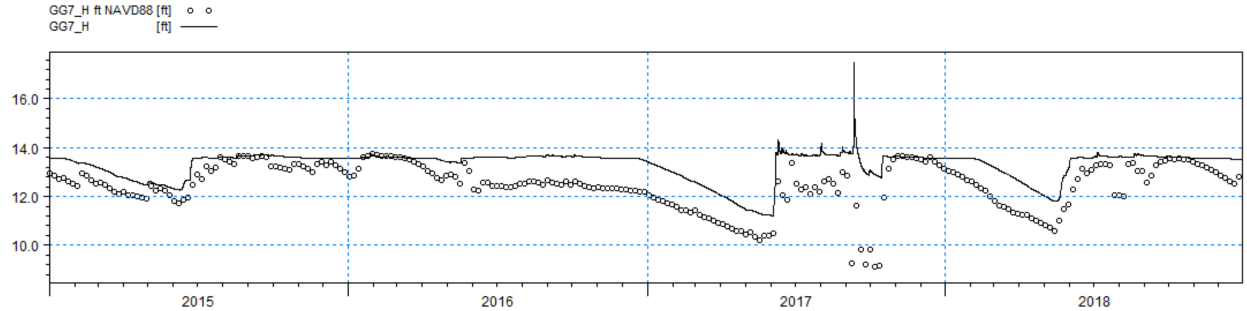
ME=-0.395338
MAE=1.17157
RMSE=2.09372
STDres=2.05605
R(Correlation)=0.268453
R2(Nash_Sutcliffe)=-2.43606



ME=0.908177
MAE=1.72481
RMSE=2.20533
STDres=2.00965
R(Correlation)=0.564751
R2(Nash_Sutcliffe)=-1.64107



ME=-0.722332
MAE=0.75999
RMSE=0.984318
STDres=0.668669
R(Correlation)=0.670721
R2(Nash_Sutcliffe)=-0.256291



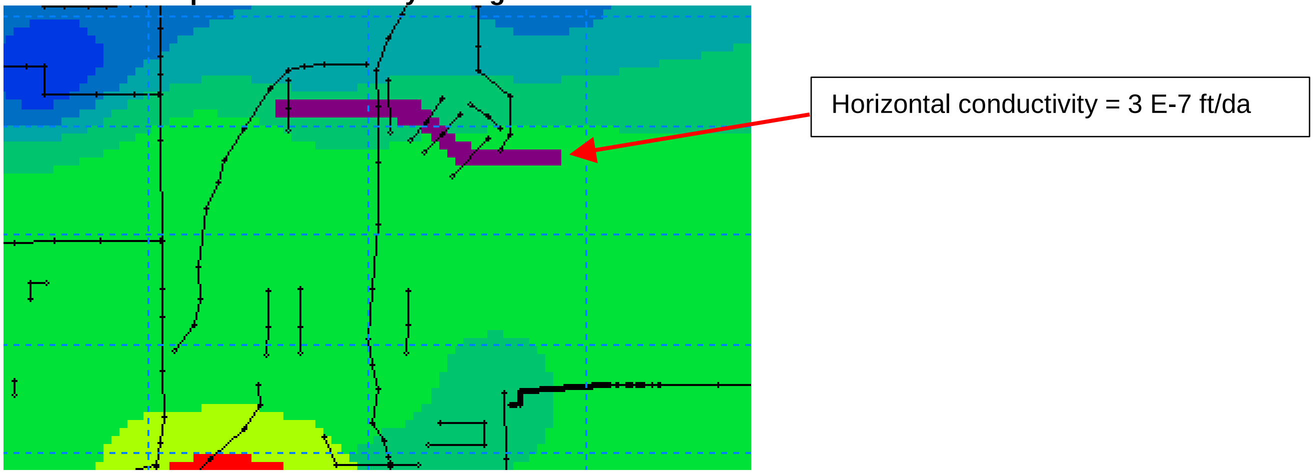
ME=-0.82492
MAE=0.828074
RMSE=1.05581
STDres=0.65897
R(Correlation)=0.723185
R2(Nash_Sutcliffe)=-0.250644

ATTACHMENT 6

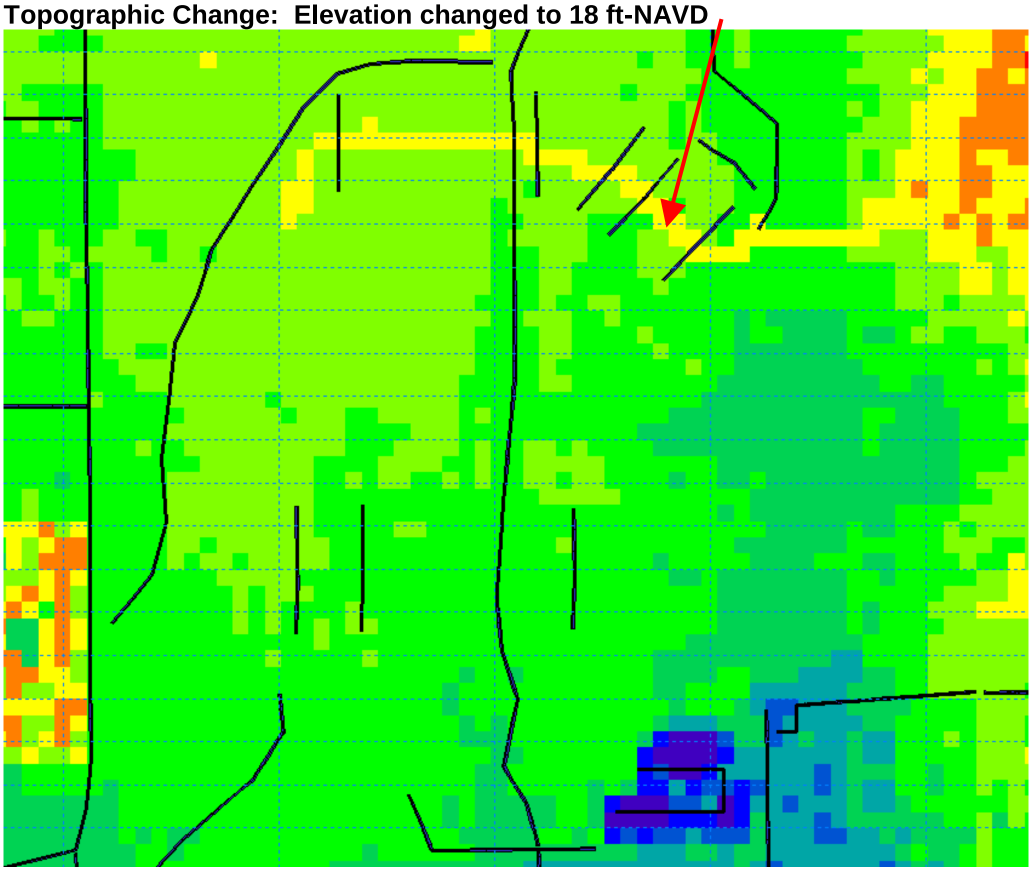
Details on Simulated Structures for Scenario 4

Details on Structures for Scenario 4

Water Table Aquifer conductivity change made to simulate cutoff wall



Topographic Change: Elevation changed to 18 ft-NAVD



Changes made to CSS_20200914_scen_4a3.nwk11

	Chainage	Existing		Proposed	
Branch	**meters**	**Structure**	**Details**	**Structure**	**Details**
Birdrookery_5	365.76	14.272	4' dia	17	2' x 6'
Birdrookery_4(Bridge)	125	no weir		16.5	Weir 16.5@30 ft wide, 17@50 ft wide
Birdrookery_4(Bridge)	365.76	11.4164	Culvert 11.42@15 ft wide, 16.42@25 ft wide	15.5	Culvert 15.5@25 ft wide, 18@30 ft wide
Birdrookery_3	374	12.595	4' dia	17	2' x 6'
Birdrookery_2	374	13.34	4' dia	17	2' x 6'
CorkscrewTrib3	5098	16.4	Weir 16.4@50 ft wide, 17@75 ft, 17.5@1000 ft wide	17	Weir 17@50 ft wide, 17.6@75 ft, 18@1000 ft wide
Branch259	500	no weir		16	Weir 16@20 ft wide, 16.5@35 ft, 17@70 ft wide
Birdrookery_7	150	no weir			Weir 14@20 ft wide, 15@50 ft wide
Birdrookery_7	460.248	11.1536	4' dia	12.1536	1x4' dia
CorkscrewTrib3	8136	16.4	Weir 16.4@100 ft wide, 16.65@300, 16.9@1000 ft wide	17.4	same dimensions but one ft higher overall
Birdrookery_6	150	no weir			Weir 14@30 ft wide, 15@70 ft wide
Birdrookery_6	475.88	11.419	2x4' dia	12.4194	2x4' dia
Birdrookery_8	466.344	11.97577	2x4.5' dia	12.97577	2x4' dia
CorkScewCan	1000	no weir		13	Weir 13@20 ft wide, 14@30 ft, 15@60 ft wide
CorkscrewTrib3	10125	14.7	Weir 14.7@4 ft wide, 15@100 ft, 15.4@300 ft wide	15.7	Weir 15.7@4 ft wide, 16@100 ft, 16.4@300 ft wide
CorkscrewTrib3	10125	14.5	1.5' dia	no flow	culvert left in model, section type is Closed

Changes to Operation of Cork2 and Cork3

Cork2	Open elev. changed from 10.2 to 11.2 ft-NAVD		11.2 to 12.2		
	wet season		**dry season**		
	old	new		old	new
Ctrl Elev	Gate Elev	Gate Elev	Ctrl Elev	Gate Elev	Gate Elev
-100	6.7	-100	-100	6.7	-100
10.25	6.7	11.25	11.25	7.75	12.25
10.5	7	11.5	11.75	8.25	12.75
10.75	7.25	11.75	12.25	8.75	13.25
11	7.5	12	12.75	9.25	13.75
11.5	8	12.5	13.25	9.75	14
12	8.5	13	13.75	10.5	14.15
13	9.5	13.5	14.25	14.2	14.25
14	10.5	14	100	14.2	100
14.75	14.2	14.75			
100	14.2	100			
Cork3	11.2 to 12.2		12.2 to 13.2		
	wet season		**dry season**		
	old	new		old	new
Ctrl Elev	Gate Elev	Gate Elev	Ctrl Elev	Gate Elev	Gate Elev
-100	8.15	-100	-100	8.15	-100
11.2	8.15	12.2	12.2	8.15	13.2
11.7	8.65	12.7	12.7	8.75	13.7
12	9	13	13	9	14
12.25	9.25	13.25	13.25	9.25	14
12.5	9.5	13.5	14	10.95	14
12.75	9.75	13.75	15	10.95	100
13	10	14			
13.25	10.25	14.1			
13.5	10.75	14.2			
100	10.95	100			
Closed priority definitions elevations increased 1 ft.					
Rules usage changed					