Seepage Investigation of the Caulkins Water Farm Pilot Project - First Annual Report

Martin County, Florida

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Executive Summary

The Caulkins Water Farm Pilot Project, part of the South Florida Water Management District's (SFWMD's) Dispersed Water Management Program, consists of a surface water reservoir of approximately 414 acres adjacent to the C-44 Canal (St. Lucie River) in southern Martin County. In the first year of operation (February 10, 2014 through January 31, 2015) the water farm diverted 11,680 acre-feet of water from the C-44 Canal.

This investigation was conducted to characterize the seepage quantity and flow direction from the water farm using residuals estimated from a surface water budget for calibration. The average daily seepage estimated from the surface water budget was matched with lateral and vertical seepage estimates developed using the Darcy general equation for groundwater flow, relative groundwater and surface water levels, and a range of hydraulic conductivity estimates obtained from on-site testing and published values from nearby aquifer tests. As part of this investigation, six surface water stage monitoring stations and 14 groundwater monitoring wells were installed in October and November 2014 and February 2015, within and adjacent to the Caulkins Water Farm Pilot Project area to further qualify and quantify the overall water budget for the water farm. Each station was fitted with continuous data loggers recording data at 15-minute intervals, each surface water and groundwater station is downloaded monthly for data evaluation. Groundwater monitoring wells were installed within the surficial aquifer system from depths between 9 and 130 feet below land surface. Data from a stage and rain monitoring station installed within the water farm in February 2014 by the Caulkins Citrus Company Ltd. were also used. Site specific surveys, including transects across the water farm and the C-44 Canal, were completed by SFWMD. These surveys, along with existing landowner survey data and SFWMD light detection and radar (LIDAR) data, were used for development of a stage-storage relationship used for the surface water budget and seepage analysis.

Seepage estimates were developed using a period of record from November 13, 2014, (initial installation of the data loggers) through December 27, 2014, after which the water levels in the water farm had substantially subsided. Surrogate water levels were developed for the center well cluster (CAU-1), which had not been constructed during the period of record, using a correlation of surface water levels and groundwater levels in CAU-1 in March and February 2015.

The seepage estimate of 34 acre-feet per day, based on the residuals value presented in the surface water budget for the period of record, was used to calibrate an Excel spreadsheet seepage model for generation of average daily seepage estimates over the period of record. This seepage estimate is consistent with hydraulic conductivity ranges used in the model, which provides a qualitative confirmation of the seepage estimate developed using the surface water budget.

A range of hydraulic conductivities from 15 to 48 feet per day in the shallow surficial aquifer system, and anisotropy ratios (vertical hydraulic conductivity divided by horizontal hydraulic conductivity) between 0.01 and 0.50, yielded seepage results that satisfied the constraints of the surface water budget seepage estimate. Estimated downward seepage ranged from 11 to 27 acre-feet per day, or 32 to 79% of total seepage. Based on a surface area of 414 acres, the downward seepage rate ranged from 0.027 feet per day (0.83 centimeters per day) to 0.065 feet per day (1.98 centimeters per day). Using a best estimate of 15 feet per day for horizontal hydraulic conductivity, the best downward seepage estimate is on the upper end of the range of 27 acre-feet per day (0.065 feet per day), or 79% of total seepage. An estimated 7 to 23 acre-feet per day (21 to 68%) seeped to perimeter canals on the east, south and west sides and the adjacent shallow aquifer to the north. The best estimate horizontal hydraulic conductivity value of 15 feet per day yields an estimated 7 acre-feet (21%) of seepage laterally. Additional short-term aquifer performance tests of the shallow surficial aquifer system within and adjacent to the Caulkins Water Farm Pilot Project reservoir may narrow the range of estimated horizontal and vertical hydraulic conductivity values and therefore the ranges of estimated downward and lateral seepage.

Groundwater flow from the Caulkins Water Farm Pilot Project was downward into deeper portions of the aquifer and outward into perimeter canals to the east, south, and west, and the shallow aquifer to the north. Groundwater from the shallow aquifer flowed downward to the base of the surficial aquifer system and then southerly towards the C-44 Canal. In the vicinity of the C-44 Canal, upward groundwater flow from the deep surficial aquifer system towards the C-44 Canal is indicated by an upward hydraulic gradient between the deep wells and the C-44 Canal.

Approximately 90% of lateral seepage was to the west, towards the west perimeter canal, which was nearly dry during the period of record, and to the north into the shallow surficial aquifer system. Since the ultimate disposition of the water that flows to the west perimeter canal is assumed to seep into the shallow surficial aquifer system, approximately 90% of the lateral seepage eventually flowed into the surficial aquifer system.

Lithology of the shallow sediments includes thin, sandy clay and clayey sand interbeds from approximately 4 to 13 feet below land surface, which appears to be discontinuous and at variable depths. The presence of these lower permeability clayey zones may attenuate downward seepage from the water farm, and increase seepage to perimeter canals.

Average groundwater flow velocities from the surface reservoir to the C-44 Canal were calculated based on the assumption that most of the flow toward the C-44 Canal occurred through the deepest portion of the surficial aquifer system. Based on horizontal hydraulic conductivity values of 50 feet per day, representing the high end estimated horizontal hydraulic conductivity ranges, and using a distance of 900 feet from the southern edge of the water farm to the C-44 Canal, the resultant velocity and travel time estimate is 0.9 feet per day and 2.7 years, respectively. This travel time may help nutrient reduction efforts by absorbing nutrient pulses within the C-44 Canal and normalizing discharge back to the C-44 Canal over a period of years, and by providing residence time within the surficial aquifer system to facilitate nutrient adsorption.

Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

ac-ft	acre-feet
ac-ft/d	acre-feet per day
ACT	time composite autosampler
APT	aquifer performance test
bls	below land surface
Caulkins Citrus Grove	Caulkins Citrus Company Ltd. grove
CV	control volume
ET	evapotranspiration
ft/d	feet per day
ft/ft	feet per foot
FWMC	flow-weighted mean concentration
GIS	geographic information system
gpm	gallons per minute
K	hydraulic conductivity
Kh	horizontal hydraulic conductivity
Kv	vertical hydraulic conductivity
LIDAR	light detection and radar
MG	million gallons
MGD	million gallons per day
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
POR	period of record
PVC	polyvinyl casing
SAS	surficial aquifer system
SFWMD	South Florida Water Management District
TOTN	total nitrogen
TPO4	total phosphorus
TSS	total suspended solids
WFPP	Water Farm Pilot Project

Conversions

NGDV29 = NAVD88 + 1.40 feet
1 acre-feet per day = 0.3259 million gallons per day
1 acre-feet per day = 0.5042 cubic feet per second

1

Introduction

1.1 Background

The Caulkins Water Farm Pilot Project (WFPP) is located in the southwestern portion of the Caulkins Citrus Company Ltd. grove (Caulkins Citrus Grove), 7801 SW Citrus Boulevard (County Road 726), in Martin County, Florida (**Figure 1**). The WFPP was designed and constructed as part of the South Florida Water Management District (SFWMD) Dispersed Water Management Program to evaluate the ability to reduce flow and nutrient loads from the C-44 Canal (St. Lucie River). The C-44 Canal conveys water from local basin runoff and from Lake Okeechobee, approximately 16 miles to the west, and flows into the St. Lucie Estuary, which is approximately 14 miles east of the WFPP. This investigation was conducted to characterize the quantity and direction of seepage from the WFPP using surface and groundwater levels during the first year of operation. Integral to this effort is the total seepage estimate independently developed from the surface water budget, a summary of which is provided in **Appendix A**. In addition, water quality samples representative of water pumped into the WFPP were collected, the results of which are also presented in **Appendix A**. Evaluation of water quality is included in the scope of this report. A more comprehensive evaluation will be included in the second annual report.

The WFPP was constructed from August through December 2013, and pumping into the reservoir began February 5, 2014. Pump inflow, surface water stage and rain (one station) have been monitored in the WFPP since initial pumping. From September 2014 through February 2015, 14 groundwater monitoring wells and 6 stage monitoring stations were constructed within and adjacent to the WFPP for monitoring surface and groundwater levels and estimation of seepage/groundwater flow. This pilot project is scheduled to run for two years through January 2016. This report is the first annual report covering the period from February 2014 through January 2015.

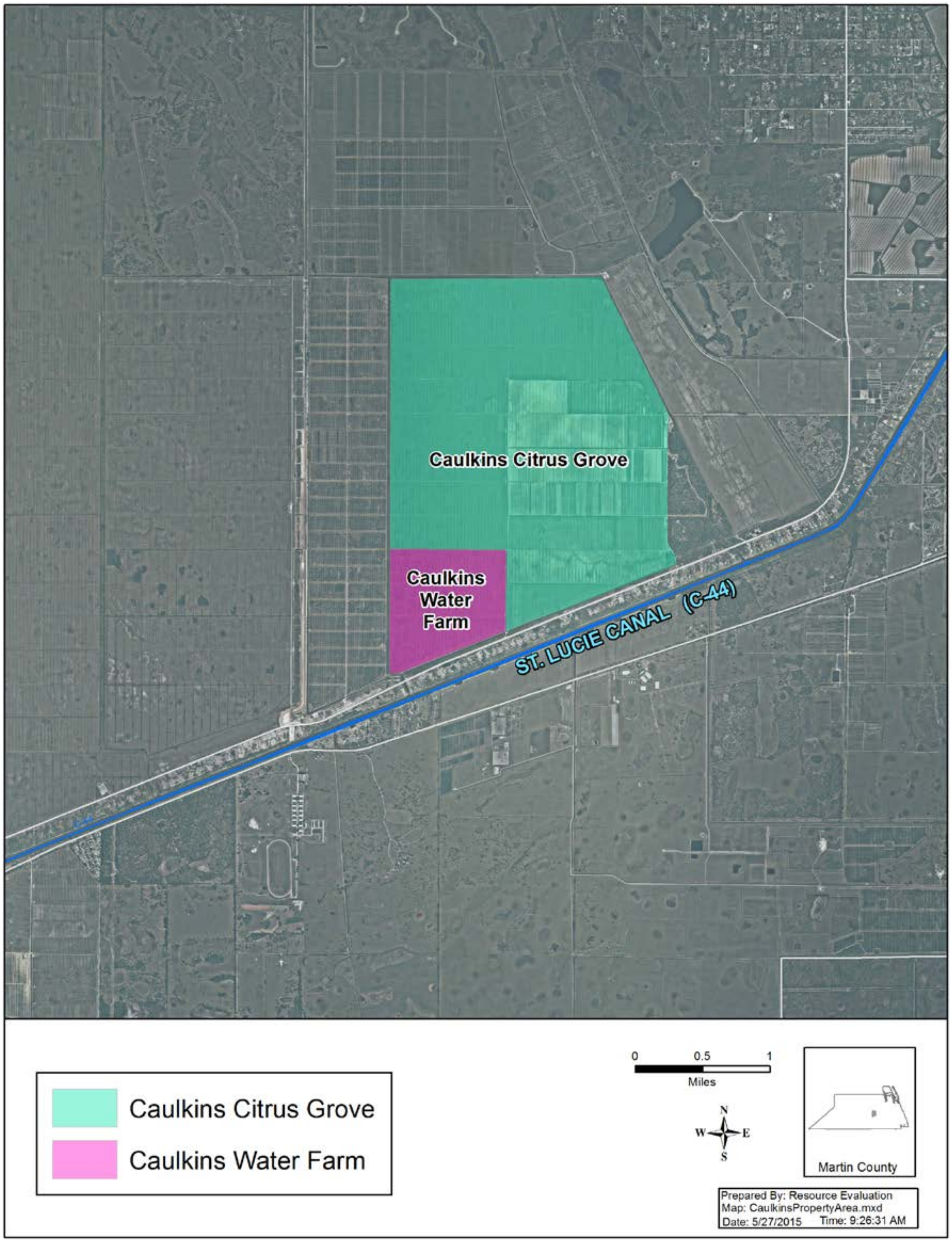

Figure 1. Location of Caulkins WFPP within Caulkins Citrus Grove.

2

Site Setting and Description

2.1 Site Setting

The Caulkins Citrus Grove is comprised of approximately 3,275 acres of former groves and agricultural property, and is bordered by groves/agricultural land to the north, east and west, and to the south by County Highway 726 (Citrus Boulevard), south of which is undeveloped land and the C-44 Canal. Approximately one-third of the farm is actively leased for corn, pepper, cabbage, lettuce and spinach farming, and approximately two-thirds are not farmed. Irrigation is mostly predominantly flood irrigation via a network of three north-south and six east-west irrigation canals, with a small amount of overhead irrigation pumped from irrigation canals (personal communication, Ron Hataway, Caulkins Citrus Company Ltd.). Flow between irrigation canals is controlled by vertical riser, with stop logs and at least one portable pump.

The citrus grove withdraws irrigation supply water via two canal pumps that lift water from the C-444 Canal (connected to the C-44 Canal) in a pump station approximately 300 feet southeast of the southwestern portion of the Caulkins WFPP (**Figure 2**). Through October 2014, the pumps consisted of one 100-horsepower diesel and one 100-horsepower electric pump. Each operated at a flow rate of approximately 15,000 gallons per minute (gpm). In October 2014, the diesel pump was replaced by a 200-horsepower electric pump operated at a flow rate of approximately 30,000 gpm. The pump station pumps water into the southernmost irrigation canal that borders the southern edge of the farm, also known as the feeder canal. The pump station can also receive water from the grove via the westernmost irrigation canal, also known as the drainage canal, which borders the west edge of the farm. Four 54-inch gates with stop logs at the pump station connect to the C-444 Canal, feeder canal, and drainage canal and control flow to/from the three canals. Discharge from the drainage canal to the C-444 Canal is not recorded; however, the gates that control water from the drainage canal have been closed during the period of record (POR) of this investigation (personal communication, Ron Hataway, Caulkins Citrus Company Ltd.).

The grove discharges water from the irrigation network to the C-44 Canal from the southeastern corner via irrigation canals on the eastern side of the grove. Based on discussion with SFWMD regulatory personnel, the discharge amounts are not recorded.

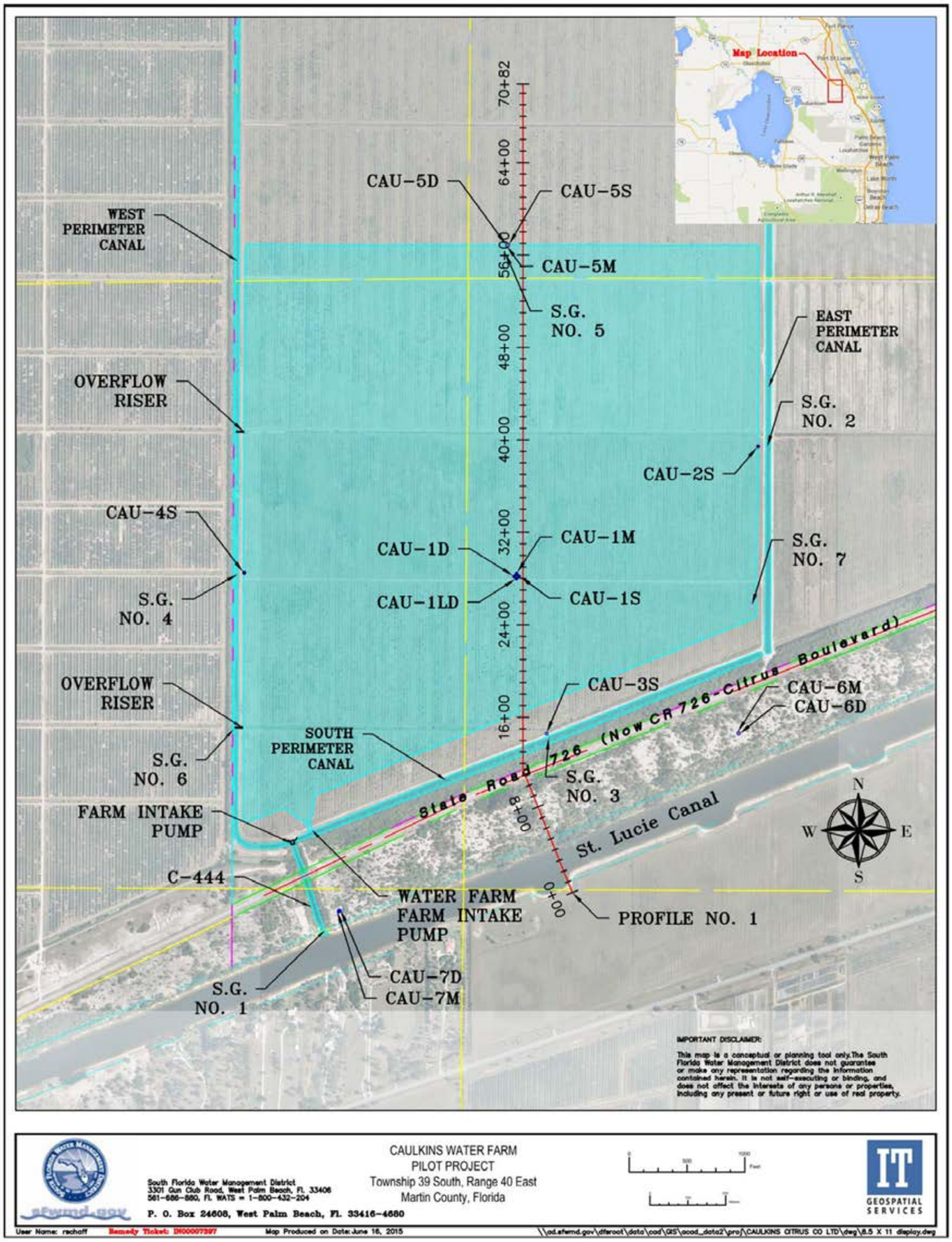

Figure 2. Site diagram showing the WFPP, monitoring stations and adjacent canals.

2.2 Water Farm Description and Operation

The WFPP area consists of a four-sided polygon with an exterior earthen levee approximately 7 feet above grade that enclose approximately 414 acres (**Figure 2**). The interior of the water farm was previously a citrus grove with associated beds, furrows and irrigation canals. Abandoned citrus trees and overgrowth are present within the project interior. Borrow ditches, approximately 5 to 7 feet below grade, border the interior of each levee and were excavated to provide fill. Ground elevations range from approximately +21.4 feet National Geodetic Vertical Datum of 1929 (NGVD29) at the bottom of the ditches, to approximately +23.4 to +26.4 feet NGVD29 at the interior of the water farm, to +32.4 feet NGVD29 at the top of the levees. The WFPP is approximately 350 feet north of the feeder canal (south perimeter canal), 70 feet west of the main north-south irrigation canal (east perimeter canal), and 70 feet east of the drainage canal (west perimeter canal). The adjacent canals are approximately 40 feet wide and 10 to 15 feet deep. The lowest measurable water level elevation within the control volume (CV) is approximately +23.5 feet NGVD29 as measured at SG-7. The stage elevation of 23.5 feet NGVD29 at SG-7 represents the bottom of the pressure transducer and the ability to record any further data. The control elevation for the WFPP is 29.4 feet NGVD29, which is controlled by 2 riser culverts on the west side of the farm and discharge (when needed) to the west perimeter ditch. Operationally, the WFPP is maintained at 28.9 feet NGVD29 to allow 0.5 foot of freeboard for storm event contingency. Based on the stage-storage relationship developed to facilitate the water budget (Section 4.5), the WFPP contains approximately 27 acre-feet (ac-ft) of water at a minimal water level of +23.4 feet NGVD29, and approximately 1,280 ac-ft of water at a maximum water level of +28.9 feet NGVD29.

One diesel-powered vertical intake pump, located in the western part of the southern feeder canal, pumps water into the southwestern portion of the WFPP. The pump is typically operated at a flow rate of approximately 30,000 gpm. When pumping, the pump is typically operated on a 24-hour basis.

The WFPP began pumping on February 5, 2014, and continued intermittent pumping through May 14, 2014 (operational pumping/test fill), during which time water levels were between approximately +25.4 and +26.9 feet NGVD29. Pumping was initiated again on July 5, 2014 (wet season operations) and continued with intermittent breaks until December 2, 2014, during which time water levels were maintained between approximately +27.9 and +28.9 feet NGVD29. Pumping was not started again through the remainder of the reporting year, and water levels dropped to a level below the lowest stage gauge (approximately +23.4 feet NGVD29) by the end of January 2015.

2.3 Summary of Surface Water Budget

The surface water budget (**Appendix A**) estimates residuals (including subsurface flows, ungauged surface flows and errors) of 11,687 ac-ft by calculating the difference between the sum of the pump inflow and rainfall, and the sum of evapotranspiration (ET) and change in storage for the first reporting year. As errors and ungauged surface flows are not quantified, the residual amount is used as total seepage out in this study. Total seepage accounted for approximately 87% of the total outflow and ET accounted for approximately 13% for the first reporting year. The average seepage rate for the reporting year (using 356 days) was approximately 33 ac-ft per day (ac-ft/d).

2.4 Area Water Use

This section gives a brief overview of permitted water users within a one-mile radius of the Caulkins Citrus Grove. It includes a summary of water use activities (if any) and facilities used to meet demand, together with the reported data for 2014. **Figure 3** shows the locations of SFWMD permitted parcels and the pumps used to extract water from the C-44 Canal. The coordinates of the pumps are listed in **Table 1**. Armstrong Properties and the Box Ranch of Martin County did not withdraw any water from the C-44 Canal during 2014.

The neighboring farms were identified using a SFWMD regulation database geographic information system (GIS). The permits were then downloaded from the District' ePermitting portal and reviewed. The SFWMD Regulation Division provided the monthly reported volumes withdrawn from the C-44 Canal shown in **Table 2**. No data for January 2015 was available at the time of the data request. The first year of the WFPP runs from February 2014 through January 2015. Data reported for January 2014 is included in **Table 2** for completeness. No groundwater use was reported during 2014 by any of the permittees. **Table 3** includes the locations of groundwater wells associated with permits.

The Caulkins Citrus Grove (Permit Number 43-00360-W) is permitted to extract water from the C-44 canal to supplement irrigation demand for small vegetable crops via the pumps, canals and gates discussed in Section 2.1. The total annual allocation for Caulkins Citrus Grove is 2,711 million gallons (MG) or approximately 8,300 ac-ft. The maximum monthly allocation is 521.23 MG (approximately 1,600 ac-ft). There are also four Floridan aquifer wells on the farm that are typically used for freeze protection. These groundwater facilities were not utilized during 2014. The freeze protection allocation is limited to 66.5 million gallons per day (MGD). In 2014, Caulkins Citrus Grove reported surface water pumpage from the C-44 Canal of 5,641 MG (approximately 17,300 ac-ft).

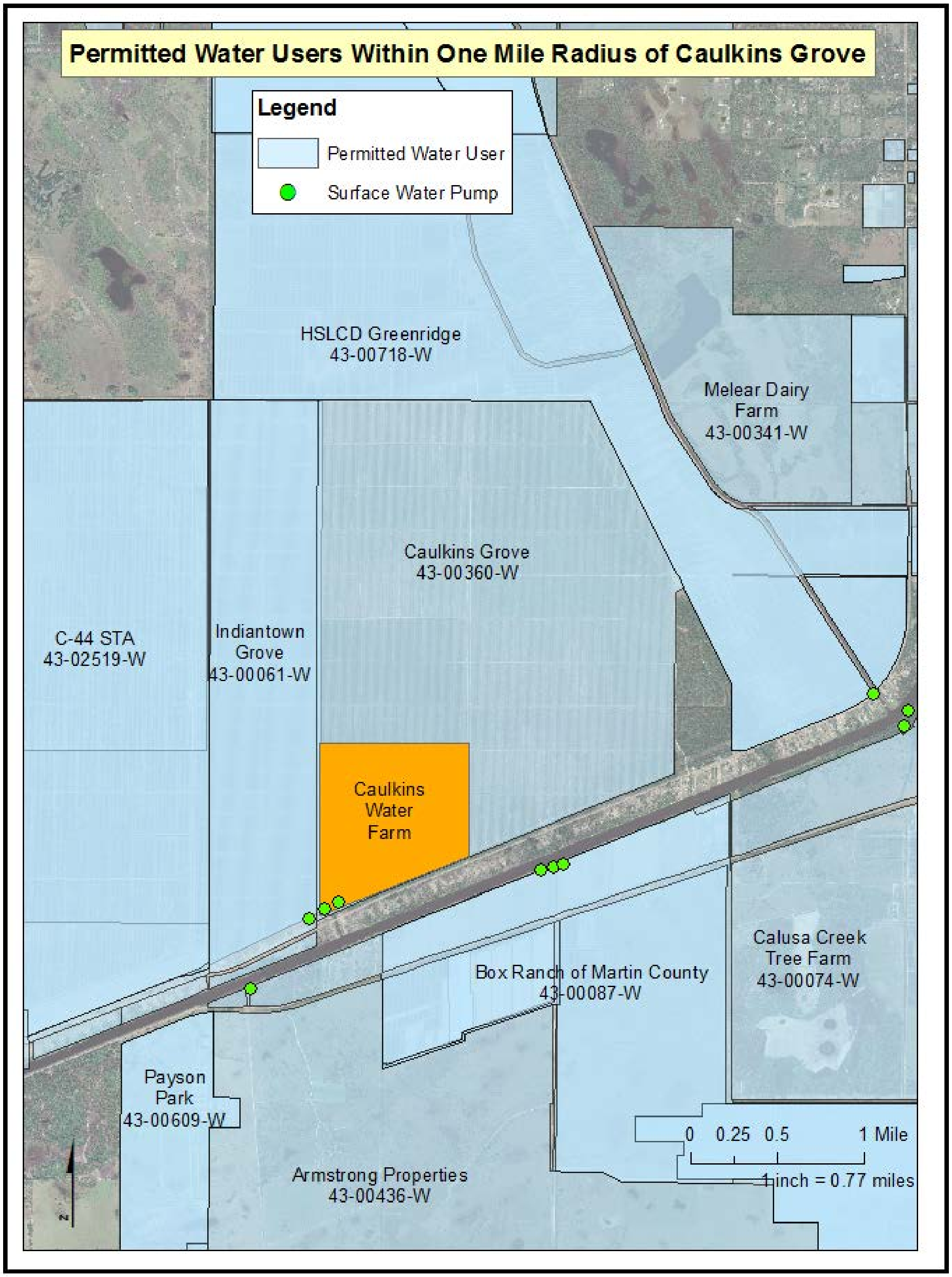

Figure 3. Permitted water users within a one-mile radius of Caulkins Citrus Grove.

Table 1. Location of surface water pumps within a one-mile radius of Caulkins Citrus Grove.

Permit	Permittee	Facility	Easting (feet)	Northing (feet)
43-00360-W	Caulkins Citrus Grove	Pump 1	860286	986463
		Pump 2	860286	986463
43-00061-W	Indiantown Grove	Pump 1	859666	986142
43-00718-W	HSLCD Greenridge	Pump 1	877050	992667
		Pump2	877058	992671
43-00074-W	Calusa Creek Tree Farm	Pump1	878766	993181
43-00436-W	Armstrong Properties	Pump 1	857656	984055
		Pump 2	857656	984055
43-00087-W	Box Ranch of Martin County	Pump 1	867042	987821
		Pump 2	867045	987819
		Pump 3	867075	987817

Source: SFWMD ePermitting Portal (http://my.sfwmd.gov/ePermitting/)

Table 2. Reported water use for 2014 (MG).

Month	Permittee and Permit Number			
	Caulkins Grove 43-00360-W	Indiantown Grove 43-00061-W	HSLCD Greenridge 43-00718-W	Calusa Creek Tree Farm 43-00074-W
January	22	139	159	0
February	531	61	219	0
March	638	158	251	0
April	556	175	338	0
May	256	106	383	0
June	24	58	0	0
July	664	0	216	5
August	683	0	56	6
September	478	43	102	5
October	711	69	273	5
November	719	82	266	6
December	358	122	380	5
Total	**5,641**	**1,014**	**2,643**	**33**

Source: SFWMD Regulation Database

Table 3. Groundwater wells within one-mile radius of Caulkins Citrus Grove.

Permit Number	Permittee	Aquifer	Facility	Purpose	Easting (feet)	Northing (feet)
43-00360-W	Caulkins Citrus Grove	Floridan Aquifer	W1	Standby - Freeze Protection	864237	990662
			W2	Standby - Freeze Protection	864237	992963
			W3	Standby - Freeze Protection	864237	996863
			W4	Standby - Freeze Protection	864237	1000963
43-00061-W	Indiantown Grove	Surficial Aquifer System	Well 1	Standby	858090	986007
			Well 2	Standby	858090	988896
			Well 3	Standby	858090	992132
			Well 5	Primary	858163	985593
			Well 6	Standby	858090	995368
			Well 7	Standby	858090	998102
			Well 8	Standby	858090	1001377
43-00074-W	Calusa Creek Tree Farm	Surficial Aquifer System	W-1	Secondary	877510	987708
			W-2	Secondary	877546	987381
43-00609-W	Payson Park Thoroughbred Training Center	Surficial Aquifer System	A - Dormitory	Public Water Supply	856056	982409
			B - Cafeteria	Public Water Supply	855856	980225
			C - Barns	Public Water Supply	856902	980040
			D1 - Track	Public Water Supply	855933	979117
			D2 - Track	Public Water Supply	856125	979271
			E - Track	Public Water Supply	855006	978561
			F - Irrigation	Standby	845095	980304

Source: SFWMD ePermitting Portal (http://my.sfwmd.gov/ePermitting/)

The nearest legal existing user of the C-44 Canal is the grove located adjacent to the western property boundary—Indiantown Grove (Permit Number 43-00061-W). This permittee utilizes a microsprinkler irrigation system to water 981 acres of citrus. The system is fed water, if required, from the C-44 Canal via a single pump located approximately 200 feet from the Caulkins Citrus Grove pump station. There are seven surficial aquifer system (SAS) wells on-site. None were pumped in 2014. The total annual allocation is 976.16 MG (approximately 3,000 ac-ft) and the total maximum monthly allocation is 164.68 MG (approximately 500 ac-ft). The volume of C-44 Canal water pumped into this grove in 2014 was 1,014 MG.

To the north and east of the Caulkins Citrus Grove is HSLCD Greenridge Grove (Permit Number 43-00718-W). Permit Number 43-00718-W is for a diversion and reservoir system. The grove irrigates 2,284 acres of citrus and 600 acres of small vegetables. Water is pumped from the C-44 Canal into an on-site canal. The stage here is maintained at between +23 to +24 feet NGVD29 during times when supplemental irrigation water is required. Secondary pumps distribute the water as needed throughout the grove. No wells exist on this property. The total annual allocation is 2,728.51 MG (approximately 8,400 ac-ft) with a monthly maximum if 447.98 MG (approximately 1,400 ac-ft). In 2014, the reported annual volume was 2,643 MG (approximately 8,100 ac-ft).

Calusa Creek Tree Farm (Permit Number 43-00074-W) lies to the east of Caulkins Citrus Grove, on the south side of the C-44 Canal. The farm irrigates 2,800 acres using a crown flood system and 200 acres using a drip irrigation system. There are two SAS wells on-site as secondary water sources, which were not used in 2014. C-44 Canal water is the primary source of water. The annual permitted volume for surface water is 2,975 MG (approximately 9,100 acre-feet) and total monthly maximum is 524.3 MG (approximately 1,600 acre-feet). The annual and monthly limits for SAS withdrawals are 27 MG and 9 MG, respectively. The volume of surface water from the C-44 Canal pumped into this grove in 2014 was 33 MG (approximately 100 ac-ft).

Box Ranch of Martin County (Permit Number 43-00087-W) is a diversion and reservoir system and has three pumps to withdraw from the C-44 Canal. There are no groundwater facilities. Irrigation water is used for citrus, turf and improved pasture. The total permitted annual allocation is 2,644 MG (approximately 8,100 ac-ft) with a monthly maximum of 347.7 MG (approximately 1,100 ac-ft). No C-44 Canal water usage was reported for 2014 on this ranch.

Armstrong Properties (Permit Number 43-00436-W) is located to the south of Caulkins Citrus Grove. There are two surface water pumps on-site that withdraw from the C-44 Canal. The permit is for supplemental water that may be required for the seepage/furrow irrigation system for improved pasture. There are no groundwater facilities. The maximum annual allocation for this permittee is 3,607.5 MG (approximately 11,000 ac-ft) and the total monthly maximum allocation is 578.93 MG (approximately 1,800 ac-ft). In 2014, no withdrawals from the C-44 Canal were reported.

Payson Park Thoroughbred Training Center, Inc. (Permit Number 43-00609-W) is permitted water use for public water supply, livestock and landscaping. There are seven SAS wells on-site and no pumps to withdraw water from the C-44 Canal. The annual and monthly groundwater allocations are 26.3 MG (approximately 80 ac-ft) and 2.5 MG (approximately 7.5 ac-ft), respectively. No groundwater usage was reported for 2014.

The Comprehensive Everglades Restoration Plan C-44 Reservoir and Stormwater Treatment Area is under construction to the west of the project area. It is one grove removed from Caulkins Citrus Grove. The permit for this project (Permit Number 43-02519-W) is for diversion and reservoir necessary for construction of culverts, a boat ramp, bridge and spillway. The maximum extent of groundwater drawdown is stated to be +4.4 feet NGVD29. The average land surface elevation at this site is +26.4 feet NGVD29. There is no off-site discharge. The reader is referred to the ePermitting portal for further information. The locations of the withdrawal facilities are not listed in the permit or associated staff report. In 2014, no surface or groundwater withdrawals were reported.

Permit 43-00341-W for Melear Brothers Dairy, Inc. expired in 1992.

3

Site Hydrogeology

3.1 Geologic Framework

The SAS in Martin County is a sequence of mainly unconsolidated sand, silt and shell and is underlain by the Hawthorn Group, which has very low permeability and serves as an underlying confining unit (Lukasiewicz and Adams-Smith, 1996). Regionally, the SAS is unconfined to semi-confined and composed of three hydrogeologic units: the shallow unconsolidated sand/soil unit, the more permeable sandy shell bed and sandstone beds, which together comprise a production unit, and the less permeable granular limestone unit, which inter-fingers with and underlies the production unit (Lukasiewicz and Adams-Smith, 1996). The geologic units comprising the SAS are (in descending order) the Pamlico sand (Pleistocene), the Anastasia formation (Pleistocene), the Fort Thompson formation (Pleistocene) and possibly part of the Tamiami formation of Pliocene age. The Anastasia formation constitutes the bulk of the SAS in the project area.

The lithology of the SAS in the vicinity of the Caulkins WFPP is described as consisting of three informal layers: Layer 1 consisting of approximately 20 feet of olive-green sandy clay; Layer 2 consisting of approximately 90 feet of shell and sand; and Layer 3 consisting of approximately 30 feet of limestone with sand and calcareous clay (Lukasiewicz and Adams-Smith, 1996, Cross Section D-D'; Adams, 1992). The base the SAS is shown at approximately 145 feet below land surface (bls).

Hydrogeologic characterization of the planned C-44 Reservoir and Stormwater Treatment Area Project, approximately one-half to seven miles west and northwest of the WFPP, divides the SAS into three informal units (USACE, 2014). Units A and B extend from surface to approximately 8 to 18 feet bls and consist of mostly sand with varying percentages of silt, clay and shell, and also cemented sand, limestone and clay. Unit C is mostly a mixture of grey, fine sand and/or silty sand with variable shell content, with some intervals mostly shell, and with cemented fragments and limestone, and is present to at least a depth of approximately 50 feet bls, the maximum depth drilled over most of the site. The investigation identified the base of the SAS at approximately 115 to 125 feet bls based on three deep soil borings.

SFWMD installed 14 groundwater monitoring wells including four well clusters as part of the current investigation, shown in **Figure 4**. Well construction details are provided in **Table 4**.

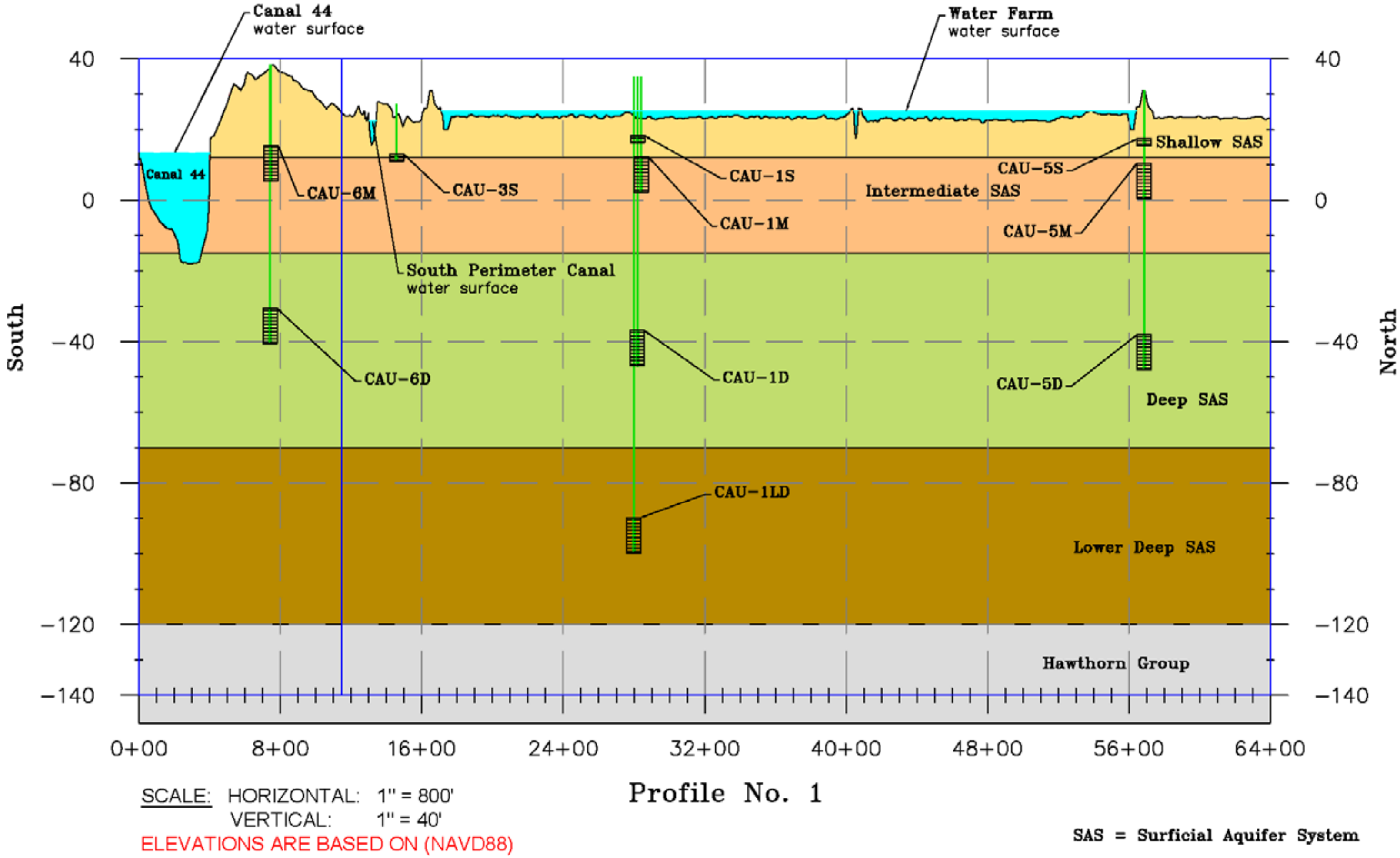

Figure 4. Generalized north–south Hydrogeologic cross-section through the WFPP and C-44 Canal. (Note: NAVD88 – North American Vertical Datum of 1988; NAVD88 = NGVD29 - 1.40 feet.)

Table 4. SFWMD Caulkins Citrus Grove well construction table.

Monitor Well	Diameter (inches)	Total Depth (feet bls)	Cased Depth (feet)	Casing	Screen Slot (inches)	Screen Length (feet)	Filter Pack	Ground Level Elevation (feet NGVD29)	Top of Casing Elevation (feet NGVD29)	Bottom Screen Elevation (feet NGDV29)	Location
CAU-1S	2	9.5	7.5	PVC[a]	0.02	2	6/20 Silica Sand	27.1	36.20	17.63	Center of WFPP
CAU-1M	2	23.2	13.2	PVC	0.02	10	6/20 Silica Sand	26.9	36.27	3.73	Center of WFPP
CAU-1D	2	72.2	62.2	PVC	0.02	10	6/20 Silica Sand	27.0	36.18	-44.87	Center of WFPP
CAU-1LD	2	130.4	120.4	PVC	0.02	10	6/20 Silica Sand	26.3	36.13	-103.37	Center of WFPP
CAU-2S	2	15.9	13.9	PVC	0.02	2	6/20 Silica Sand	32.6	32.18	16.33	East of WFPP
CAU-3S	2	15.9	13.9	PVC	0.02	2	6/20 Silica Sand	28.6	28.38	12.50	South of WFPP
CAU-4S	2	16.1	14.1	PVC	0.02	2	6/20 Silica Sand	32.3	31.92	15.84	West of WFPP
CAU-5S	2	15.8	13.8	PVC	0.02	2	6/20 Silica Sand	32.8	32.34	16.54	North of WFPP
CAU-5M	2	30.5	20.5	PVC	0.02	10	6/20 Silica Sand	32.8	32.42	1.92	North of WFPP
CAU-5D	2	79.1	69.1	PVC	0.02	10	6/20 Silica Sand	32.8	32.50	-46.60	North of WFPP
CAU-6M	2	32.8	22.8	PVC	0.02	10	6/20 Silica Sand	40.1	39.73	6.93	North of C-44 (east)
CAU-6D	2	78.8	68.8	PVC	0.02	10	6/20 Silica Sand	40.1	39.63	-39.17	North of C-44 (east)
CAU-7M	2	31.9	21.9	PVC	0.02	10	6/20 Silica Sand	35.6	35.25	3.35	North of C-44 (west)
CAU-7D	2	79.5	69.5	PVC	0.02	10	6/20 Silica Sand	35.6	35.32	-44.18	North of C-44 (west)

a. PVC – polyvinyl casing

During well installation, samples were collected for lithologic description using the Standard Penetration Test method with plastic lined cores and drill cuttings. A hydrogeologic cross-section is provided in **Figure 4** and lithologic descriptions are provided in **Appendix C**. Lithology beneath the WFPP is generally consistent with the investigations discussed above and consists of silty sand with interbeds of sandy clay grading to clayey sand and sandy, calcareous clay from approximately four to 13 feet bls; and predominately silty sand and shell and poorly graded sand with shell to a depth of approximately 130 feet bls, the deepest boring drilled. In general, very fine to fine quartz sand predominates the sand and shell layers above approximately 70 feet bls, and fine to medium shell sand predominates from 70 to 130 feet bls. Up to six feet of sandy silt was encountered from 60 to 72 feet bls at CAU-1 in the center of the WFPP. A few intervals less than two feet in thickness of sandy and shelly limestone were encountered from 17 to 86 feet bls. For purposes of this investigation, the SAS is divided into the shallow SAS from surface to approximately 13 feet bls (+13.4 feet NGVD29), the intermediate SAS from approximately 13 ft bls to 40 ft bls, the deep SAS from 40 ft bls to 95 feet bls, and the lower deep SAS from 95 feet bls to 145 ft bls. The shallow SAS corresponds to Layer 1 described by Lukasiewicz and Adams-Smith (1996) and Units A and B described in the *Geotechnical Data Report C-44 Reservoir/STA* (USACE, 2014). The intermediate, deep and deepest SAS appear to correspond to Layer 2 described by Lukasiewicz and Adams-Smith (1996) and Unit C described in the *Geotechnical Data Report C-44 Reservoir/STA* (USACE, 2014). Layer 3 described by Lukasiewicz and Adams-Smith (1996) did not appear to be encountered at the site.

3.2 Regional Groundwater Flow

Water levels in Martin County were used to calibrate models that simulated groundwater flow in Layers 1, 2 and 3 within the project area (Adams, 1992). Modeled and observed groundwater elevations indicate that groundwater flow within each layer in the vicinity of the WFPP is consistently south towards the C-44 Canal. Vertical flow was downward in the vicinity of the WFPP between Layers 1 and 2, and Layers 2 and 3, with the exception of areas inclusive of the C-44 Canal and its immediate vicinity where there was an upward gradient, indicating upward flow into the C-44 Canal from the underlying SAS.

Physiographic features in the project vicinity that may influence groundwater flow include a topographic ridge and likely drainage divide located along the northeastern side of the Caulkins Citrus Grove, approximately 1.5 miles east of the WFPP, and a large drainage canal approximately one-half mile to the west, which will be used as a major seepage collection canal for the C-44 Reservoir and Stormwater Treatment Area Project, currently under construction (Brown, 2015). Additionally, the combined surface water pumping from the C-444 Canal by the Caulkins Citrus Grove (grove intake pump) and Indiantown Grove, both located near the southwestern corner of Caulkins Citrus Grove, was 6,655 MG (approximately 20,400 ac-ft) in 2014.

Together, these factors are thought to add a western component to the predominately southern regional groundwater flow.

3.3 Hydraulic Conductivity

SFWMD staff conducted slug tests and short-term aquifer performance tests (APTs) in the newly installed wells at the WFPP. Published hydraulic conductivity (K) data for similar lithology and aquifer test data in the vicinity of the WFPP was reviewed and is described in detail in **Appendix B**. Hydraulic conductivity values have previously been derived in the area from slug tests, APTs and laboratory permeability tests in the footprint of the planned C-44 Reservoir and Stormwater Treatment Area Project, approximately one-half to 5 miles west of the site (USACE, 2014), and an APT conducted by SFWMD approximately one mile north of the WFPP (Lukasiewicz and Adams-Smith, 1996), which is shown in **Figure 5**. Results for horizontal hydraulic conductivity (Kh) and vertical hydraulic conductivity (Kv) are summarized in **Tables 5** and **6**.

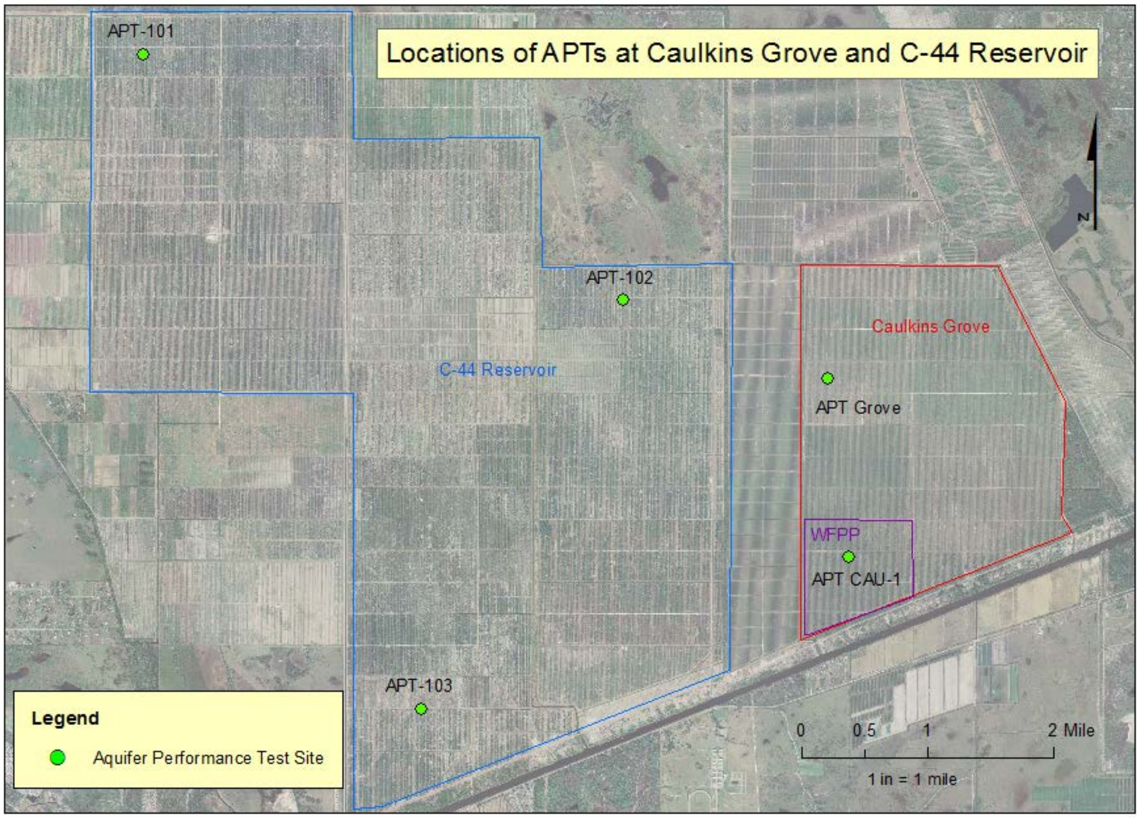

Figure 5. Location of previous and current APTs at Caulkins Citrus Grove and C-44 Reservoir and Stormwater Treatment Area Project.

Table 5. Comparison of horizontal hydraulic conductivity (Kh) values (feet per day).

Zone	On-site Aquifer Tests	On-site Slug Tests	Caulkins Citrus Historical APT	C-44 APT Average
Shallow	10	77	No Data	No Data
Intermediate	11	26	51	24
Deep	27	10		
Lower Deep	5	49		

Table 6. Comparison of vertical hydraulic conductivity (Kv) values (feet per day)

Zone	On-site APTs	C-44 Lab Hydraulic Conductivities	Caulkins Citrus Historical APT	C-44 APT Average
Shallow	No Data	0.10	No Data	No Data
Intermediate	No Data	No Data	No Data	0.7
Deep	No Data	No Data		
Lower Deep	No Data	No Data		

On-site slug tests were performed on each well except CAU-1S, and short-term aquifer tests were performed on CAU-1S, CAU-1M, CAU-1D and CAU-1LD. The average K from the slug tests were 77 feet per day (ft/d) for shallow wells, 26 ft/d for intermediate wells, 10 ft/d for deep wells, and 49 ft/d for the lower deep well. It is helpful to bear in mind that slug tests are generally considered good for providing reasonable estimates of order of magnitude for K values (Thompson, 1987).

The average K from the aquifer tests at site CAU-1 were 10 ft/d for the shallow zone, 11 ft/d for intermediate zone, 27 ft/d for the deep zone and 5 ft/d for the lower deep zone. **Tables 5** and **6** provide a comparison of results for K values for the slug tests and APTs at the WFPP, C-44 Canal and the historical APT at Caulkins Citrus Grove.

The result for the slug test in the lower deep zone is consistent with the published test data; however, the aquifer test result appears low. No slug tests were conducted at CAU-1S and the well pumped dry during the APT, leaving only the recovery data usable for analysis. These factors add uncertainty to the results for this zone.

The APTs at the C-44 Reservoir and Stormwater Treatment Area Project and Caulkins Citrus Grove included observation wells and were much longer tests (24 hours minimum), and are thought to provide better validity than the on-site aquifer and slug tests. However, the screened intervals of the pumping and observation wells were long and included the intermediate, deep and lower deep zones, in contrast to the zone-specific on-site tests. Together, the on-site aquifer tests and off-site APTs are thought to provide reasonable ranges for K to be used in seepage analysis, which is described in **Section 6**.

4

Hydrologic Data Collection and Processing

4.1 Automated Monitoring

Seven surface water stage stations, one rain station and 14 groundwater monitoring wells were used to collect automated water level and rain data during the first year of operation of the Caulkins WFPP. Automated monitoring stations are described below and shown in **Figure 2** in **Section 2** and **Table 7** below**.**

4.1.1 Surface Water Stage and Rainfall Monitoring

SG-7, in the southeastern portion of the WFPP, includes a staff gauge and stage monitoring Rittmier water level sensor and a rain station (0.01-inch resolution tipping bucket) with a Campbell Scientific data logger. The station was installed and monitored by the MilCor Group, Inc., located in Stuart, Florida. The station records water levels and rainfall at 15-minute intervals starting at the top of the hour. Data collection was initiated on February 10, 2014.

SG-1 through SG-6 are stage monitoring staff gauges installed by the Wantman Group Inc., contracted by SFWMD in September 2014. Each gauge consists of an open ended, 2-inch polyvinyl casing (PVC) pipe and staff gauge installed at a depth of approximately one-foot above substrate, and accessible via a wooden walkway. In-situ Level-Troll 500 (15 pounds per square inch) and associated vented poly cable and desiccant cartridges were deployed by SFWMD from November 13 through November 17, 2014. SG-2, SG-3 and SG-4 are located in the east, south and west perimeter canals, respectively; SG-5 and SG-6 are located in the north and southwestern portions of the WFPP interior, respectively; and SG-1 is located in the C-444 Canal approximately 30 feet north of the C-44 Canal. The devices record water levels at 15-minute intervals starting at the top of the hour.

Table 7. Automated monitoring stations.

Station Name[a]	Station Type	Latitude	Longitude	Monitoring Initiated	Station Location
SG-1	Surface Water	27˚ 02' 39.0"	80˚ 22' 19.8"	11/17/2015	C-44 Canal
SG-2	Surface Water	27˚ 03' 20.0"	80˚ 21' 36.8"	11/13/2015	East perimeter canal stage
SG-3	Surface Water	27˚ 02' 55.1"	80˚ 21' 58.0"	11/13/2015	South perimeter canal stage
SG-4	Surface Water	27˚ 03' 09.4"	80˚ 22' 27.7"	11/13/2015	West perimeter canal stage
SG-5	Surface Water	27˚ 03' 36.8"	80˚ 22' 01.4"	11/13/2015	North interior stage
SG-6	Surface Water	27˚ 02' 56.1"	80˚ 22' 26.7"	11/13/2015	Southwest interior stage
SG-7	Surface Water	27˚ 03' 05.9"	80˚ 21' 38.5"	2/10/2014	Southeast interior rain and stage, installed by Milcor Group, Inc.
CAU-1S	Groundwater	27˚ 03' 08.9"	80˚ 22' 00.9"	2/20/2015	Center of WFPP
CAU-1M	Groundwater	27˚ 03' 08.9"	80˚ 22' 00.9"	2/20/2015	Center of WFPP
CAU-1D	Groundwater	27˚ 03' 08.9"	80˚ 22' 00.9"	2/20/2015	Center of WFPP
CAU-1LD	Groundwater	27˚ 03' 08.9"	80˚ 22' 00.9"	2/20/2015	Center of WFPP
CAU-2S	Groundwater	27˚ 03' 19.9"	80˚ 21' 37.7"	10/24/2014	East of WFPP
CAU-3S	Groundwater	27˚ 02' 55.4"	80˚ 21' 58.1"	10/24/2014	South of WFPP
CAU-4S	Groundwater	27˚ 03' 09.3"	80˚ 22' 27"	10/24/2014	West of WFPP
CAU-5S	Groundwater	27˚ 03' 37.3"	80˚ 22' 01.6"	10/24/2014	North of WFPP
CAU-5M	Groundwater	27˚ 03' 37.3"	80˚ 22' 01.6"	10/24/2014	North of WFPP
CAU-5D	Groundwater	27˚ 03' 37.3"	80˚ 22' 01.5"	10/24/2014	North of WFPP
CAU-6M	Groundwater	27˚ 02' 55.3"	80˚ 21' 39.7"	10/23/2014	North of C-44 Canal (east)
CAU-6D	Groundwater	27˚ 02' 55.4"	80˚ 21' 39.7"	10/23/2014	North of C-44 Canal (east)
CAU-7M	Groundwater	27˚ 02' 40.2"	80˚ 22' 18"	10/23/2014	North of C-44 Canal (west)
CAU-7D	Groundwater	27˚ 02' 40.2"	80˚ 22' 18.1"	10/23/2014	North of C-44 Canal (west)

a. Letters at the end of well names indicate the following: S – shallow, M – intermediate, D – deep and LD – lower deep.

4.1.2 Groundwater Monitoring Wells

Monitoring wells were installed in the center of the WFPP, along the perimeters and near the C-44 Canal for monitoring water levels and water quality sampling. Each well is constructed of 2-inch PVC casing with 2-foot, 20-slot screens for shallow wells and 10-foot, 20-slot screens for wells installed in the intermediate, deep and lower deep zones in the SAS. In-situ Level-Troll 500 (15 PSIG) and associated vented poly cable and desiccant cartridges were deployed by SFWMD on October 23 and 24, 2014 and February 20, 2015 (CAU-1). Well construction tables are presented in **Appendix B** and lithology logs are presented in **Appendix C**. Following is a description of each well cluster:

- Well Cluster CAU-1 was constructed in the center of the WFPP by GFA International in February 2015. The well cluster includes one shallow (12 feet bls), one intermediate (25 feet bls), one deep (75 feet bls) and one lower deep (130 feet bls) well. The wells have 9-foot risers and are installed adjacent to a wooden platform 6-feet above grade for access.

- Well Cluster CAU-5 was constructed on the north levee with flush-mount well pads, and was installed by Drillpro, Inc. in October 2014. The well cluster includes one shallow well (approximately 30 feet bls), one intermediate well (approximately 30 feet bls) and one deep well (approximately 80 feet bls).
- Well Clusters CAU-6M, CAU-6D, CAU-7M and CAU-7D, were constructed near the north bank of the C-44 Canal, approximately 900 feet south of the east and west edges of the water farm, respectively. The well clusters were installed by Drillpro Inc. in October 2014 and each includes an intermediate well (approximately 30 feet bls) and a deep well (approximately 80 feet bls).
- Shallow wells CAU-2S, CAU-3S and CAU-4S were installed to a depth of approximately 16 feet bls on the east levee, north of the south perimeter canal, and on the west levee of the WFPP, respectively. The wells were installed by Drillpro, Inc. in October 2014.

4.2 Surface Water Pump Volumes

Surface water pump volumes from the C-44 Canal to the feeder canal, and from the feeder canal to the WFPP, are calculated by Caulkins Citrus Company Ltd. based on pump ratings and operating times, and reported to SFWMD monthly.

4.3 Water Quality Sample Collection

Surface water samples are collected from the feeder canal adjacent to the farm intake pump by MacArthur Environmental Research Center and then transported to the SFWMD laboratory in West Palm Beach, Florida for analysis. Water quality samples are collected (when the WFPP is operational) from an autosampler providing a weekly composite and a weekly grab sample is collected when the autosampler is serviced. Water quality parameters analyzed include total phosphorus, total nitrogen, nitrate plus nitrite and total suspended solids. Once the samples have been analyzed, all water quality data is then stored in DBHYDRO, SFWMD's corporate environmental database. A summary of water quality sample results is included in **Appendix A**.

4.4 Downloading and Processing of Automated Data

4.4.1 SFWMD Stations

SFWMD data loggers are downloaded monthly by SFWMD personnel. A manual measurement of water level is also taken and used to verify groundwater levels. The raw data is processed by the SFWMD groundwater data steward and is uploaded into DBHYDRO.

All groundwater data are categorized as time-series data—a single data variable that changes trough time. The raw time-series data are processed using the Data Collection/Validation Preprocessing System and any adjustments are made in the Graphical Verification Analysis Program. Standard operating procedures with respect to groundwater data are documented in *Q205, QA/QC of Groundwater Level Data Procedures* (SFWMD, 2006). This standard operating procedure ensures the integrity of the data during collection, data entry processing analysis, validation and uploading to the DBHYDRO database.

During post processing, issues may arise with regard to the quality of the data. Missing data may be estimated using spatial and temporal techniques, erroneous data may be deleted or replaced with better quality data, or qualified and tagged. The groundwater data steward will tag all raw data that has been changed. For example, the “E” tag is for estimated values and “M” for missing values. The reader is referred to Appendix B of *Q205, QA/QC of Groundwater Level Data Procedures* (SFWMD, 2006) for a full listing of DBHYDRO data qualifiers and their respective meanings.

4.4.2 SG-7 (MilCor Group Inc. Station)

SG-7 is a surface water stage and rain station in the southeastern portion of the WFPP. Data from this station is downloaded monthly by MilCor Group Inc, contracted by Caulkins Citrus Company Ltd., and then transmitted to SFWMD. Data from the SG-7 site is then loaded as daily rainfall and stage in an Excel spreadsheet and stored in the SFWMD’s Dispersed Water Management database. During the data download, Milcor Inc. verifies that the stage reading and surveyed staff gauge are within 0.05 feet of each other. If the reading is outside this tolerance level, the stage reading is then calibrated.

4.5 SFWMD Survey and Elevation Drawings

SFWMD conducted a topographic survey of the WFPP and adjacent properties from November 2014 through February 2015. The survey included establishment of North American Vertical Datum of 1988 (NAVD88) benchmarks, well reference elevation and ground elevations at each groundwater monitoring well, and a bathymetry survey of the C-44 Canal south of the WFPP. The Wantman Group surveyed the top of each staff gauge after construction using benchmarks installed by SFWMD.

SFWMD developed detailed drawings of the WFPP and adjacent land using a computer-aided drafting program showing site features and land surface contours at 2-foot intervals using the following resources: *Surveyors Report, Specific Purpose Survey, Caulkins Water Farm Pilot Project, Martin County, Florida* (SFWMD, 2015; February 20, 2015); light detection and radar (LIDAR) data collected by the United

States Army Corps of Engineers in 1999[1]; a previous survey showing elevations and vertical profiles of levees and adjacent land surfaces (MilCor Group, Inc., 2013), and a previous survey of perimeter canals and adjacent land surface elevations (Engineering and Water Resources, Inc., 2005). Fill volume (water) and water surface area calculations were made using a range of water surface elevations, at 0.5-foot intervals, from +23.4 through +28.9 feet NGVD29. Fill volumes were subsequently used to develop a stage-storage relationship for the water budget (**Appendix A**). Water surface area calculations were used to develop vertical seepage estimates presented in **Section 6** of this report.

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[1] 25-foot pixel resolution, Indian River Lagoon, 1999. Data retained at SFWMD at \ad.sfwmd.gov\DFSRoot\data\elevation\lidar\Deliverables\USACE_LiDAR\Usace_Other\IndianRiverLagoon_1999\99-215\grids\irl_orig88.

5

Hydrographic Analysis

5.1 Hydrographic Period

Hydrographs were prepared for all stage and monitoring stations for the period from data logger installation in October and November 2014 through March 17, 2015. This period includes the final one-third of the first monitoring year (February 2014 through January 2015). The hydrograph review was extended into March 2015 to include the data from the CAU-1 monitor well cluster installed in the center of the Caulkins WFPP during February 2015 so that surrogate data from CAU-1 could be used for the first reporting year (discussed in more detail in **Section 5.2** below). Water was not pumped into the WFPP from December 2, 2014, through February 12, 2015, which resulted in a significant lowering of water levels within the WFPP that is evident on the hydrographs presented.

5.2 Development and Use of Surrogate Values for CAU-1

Estimation of vertical seepage and groundwater flow during the POR is limited because the center well cluster, CAU-1, was not constructed and operational until February 2015. Therefore, surrogate water levels representative of the shallow, intermediate, deep and lower deep wells at CAU-1 are used based on correlation of stage within the interior of the CV, as shown by water levels in SG-5, SG-6 and/or SG-7, and measured water levels at well cluster CAU-1 during February and March 2015. Using this correlation, surrogate water levels for CAU-1 were used for seepage calculations during the first monitoring year. Calculated water levels are plotted against actual water levels for each well shown in **Figure 6**. A good correlation of calculated values versus observed values, with an R^2 value 0.984 or greater is evident above a surface stage elevation of +26.28 feet NGVD29, and less correlation is evident below this elevation. Therefore, a POR was selected for evaluating seepage within the first year of operation (November 13, 2014), through which the average daily elevation in the WFPP was above +26.28 feet NGVD or above (December 27, 2014), a period of approximately six weeks.

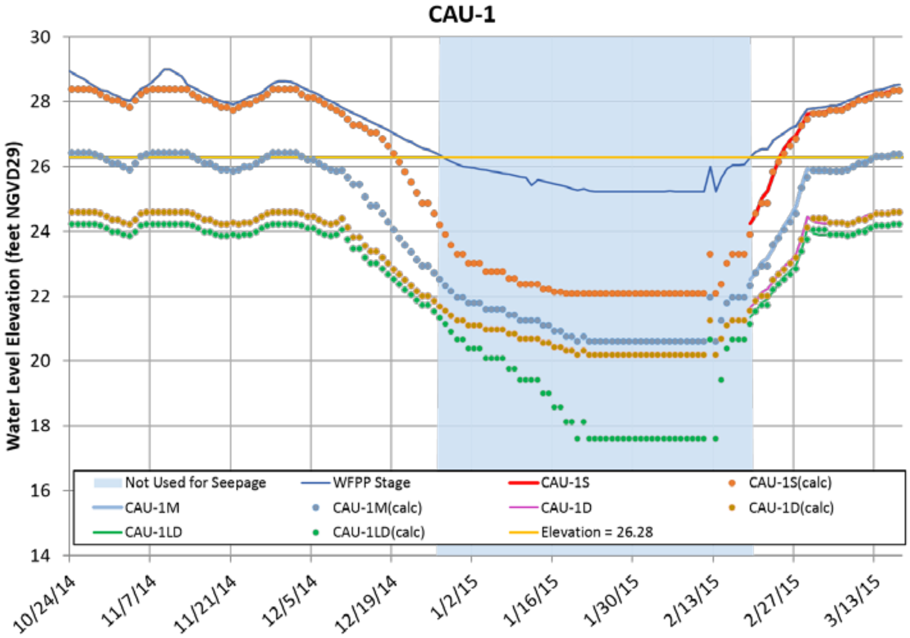


Figure 6. Surrogate and observed water levels in CAU-1.
The shaded area represents periods with lower correlation with surface water levels in the WFPP, and therefore was not used for seepage estimates.

The POR used for seepage analysis, i.e., when average water levels were equal to or above +26.28 feet NGDV29, represents a period in which the WFPP contains a minimum of approximately 340 ac-ft of water, approximately 25% of the maximum capacity of 1,280 ac-ft. This elevation is approximately half the vertical distance between the lowest measurable water level of +23.75 feet NGVD29 and the maximum capacity of +29.9 feet NGVD29.

5.3 Surface Water and Shallow SAS Hydrographs

Hydrographs representative of shallow wells adjacent to the WFPP—CAU-2 through CAU-5—stages in adjacent perimeter canals, and interior stage of the WFPP (shown in **Figures 7** through **10**) indicate downward seepage (i.e., surface water stage higher than groundwater level at the specific site) through the entire POR, and outward seepage through the shallow SAS towards perimeter canals (i.e., groundwater level higher than perimeter canal stage) to the east, south and west, and towards the shallow SAS to the north except for the periods when the WFPP was nearly dry. Relative gradients are shown in **Table 8**. The highest gradients are towards the north (CAU-5S), and to the west towards the west perimeter canal. The west perimeter canal was nearly dry and water levels were not recorded in the canal during the POR, so a default level of +18 feet NGDV29 was used. The higher gradient to the north may be biased upward because the down-gradient station, CAU-5S, was only 18 feet from the reservoir. The lower gradient to the south may be biased downward because the down-gradient station is 300 feet from the reservoir.

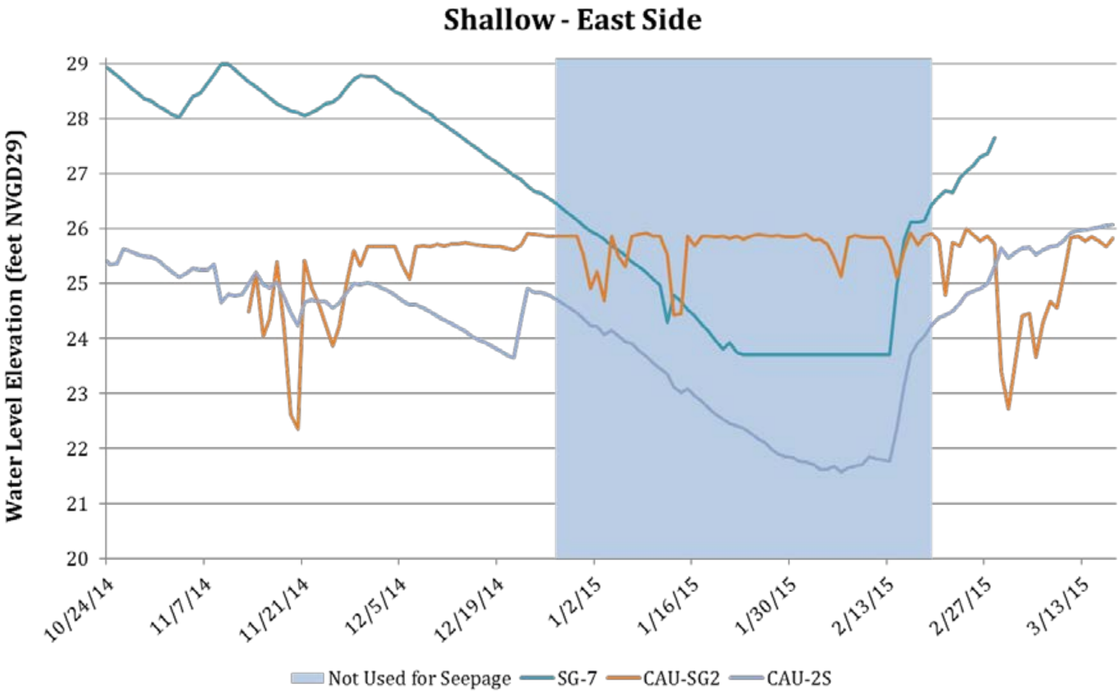


Figure 7. Hydrograph of SG-7 (WFPP), CAU-2S and SG-2 (east perimeter canal).

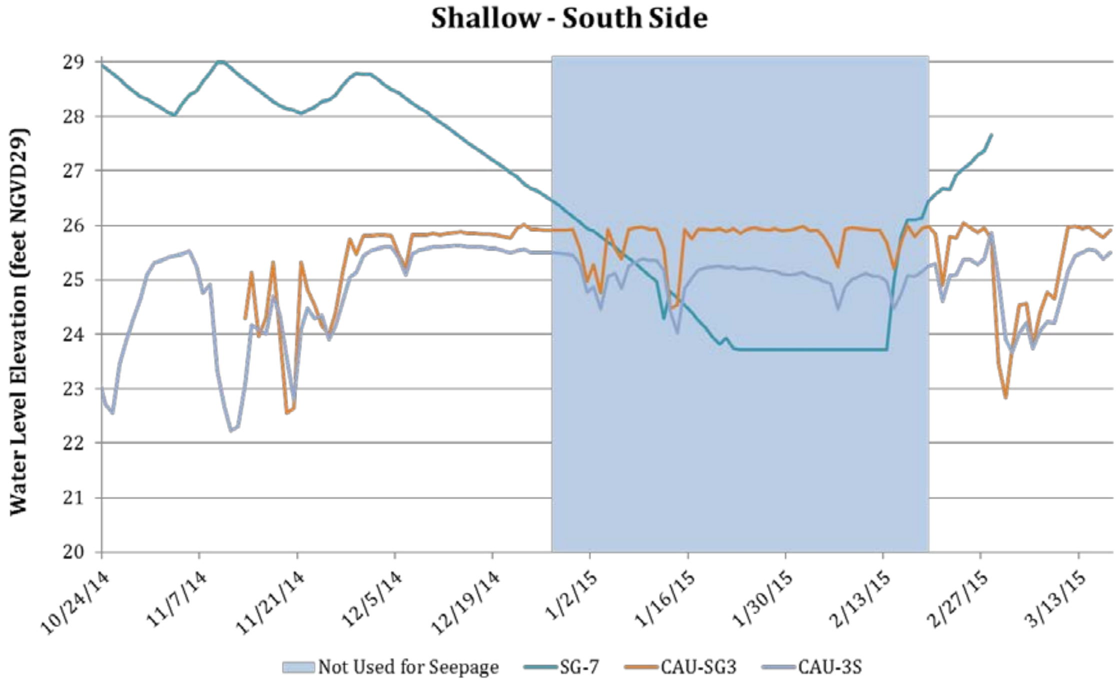
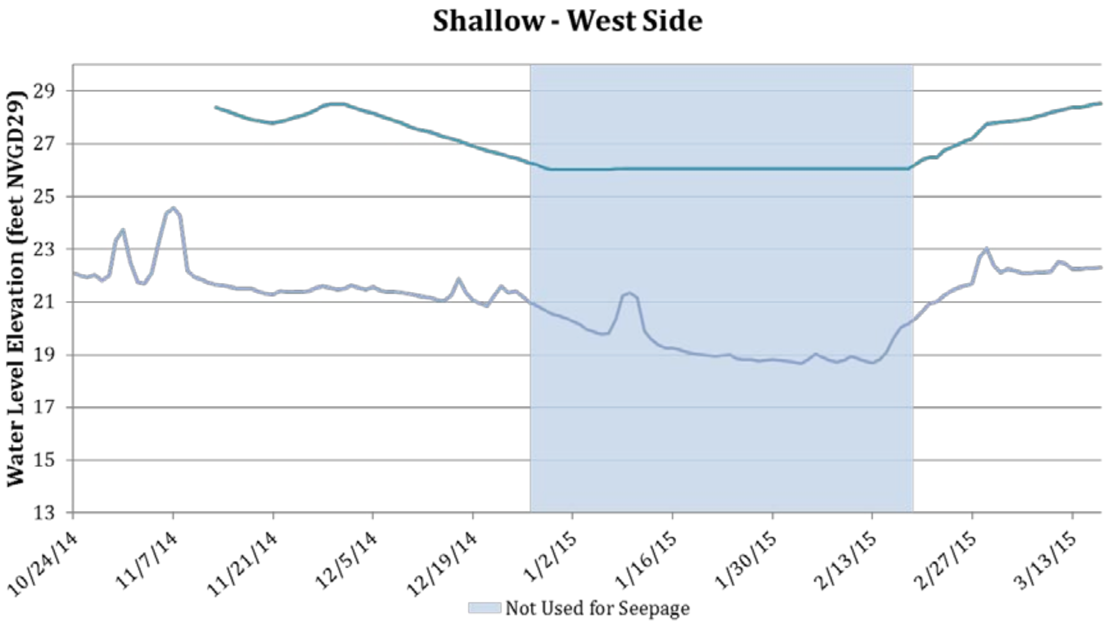


Figure 8. Hydrograph of SG-7 (WFPP), CAU-3S and SG-3 (south perimeter canal).



Note: CAU-SG4 stage was below monitoring station, default value of 18 feet was used for seepage calculations.

Figure 9. Hydrograph of SG-6 (WFPP) and CAU-4S (SG-4 stage was below the transducer elevation during the POR).

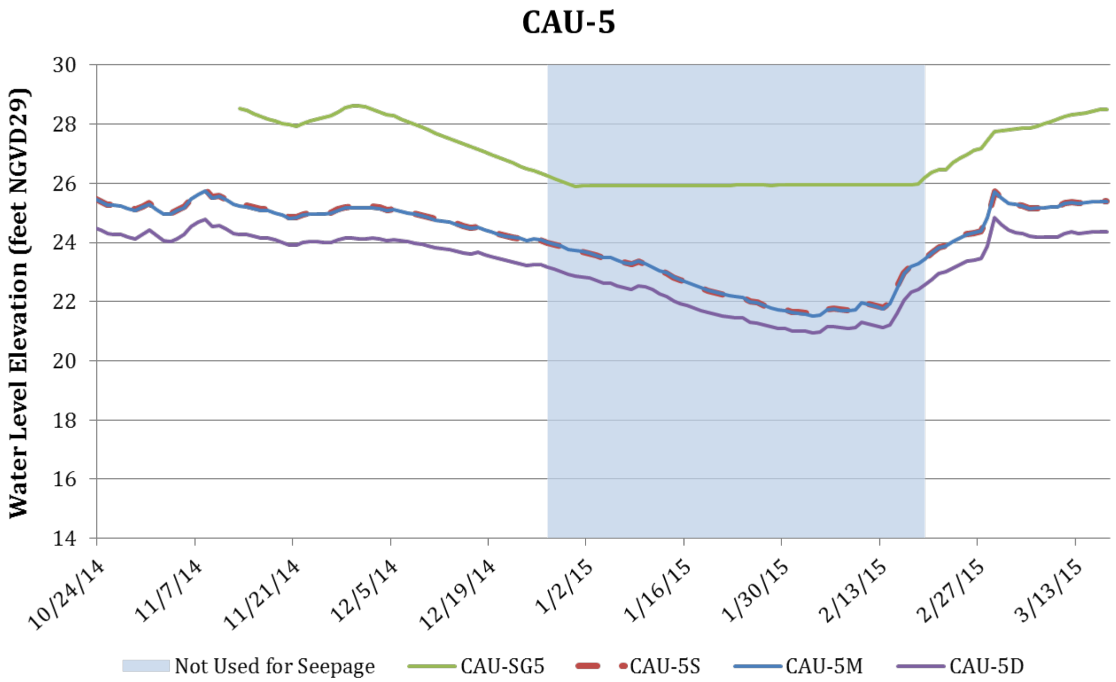


Figure 10. Hydrograph of Well Cluster CAU-5 including surface water at SG-5.

Table 8. Shallow lateral hydraulic gradients.

Description	Stations	Lateral Hydraulic Gradient (feet/feet)
Reservoir to east perimeter canal	SG-7, SG-5 and/or SG-6 to SG-2	0.039
Reservoir to south perimeter canal	SG-7, SG-5 and/or SG-6 to SG-3	0.008
Reservoir to west perimeter canal	SG-6 to SG-4[a]	0.136
Reservoir to north well	SG-5 to CAU-5S	0.164

a. West perimeter canal was below sensor, default value of +18 feet NGDV29 was used.

5.4 Vertical Hydraulic Gradient Analysis

Relative water levels were reviewed within well clusters CAU-1, CAU-5, CAU-6 and CAU-7 to characterize vertical hydraulic gradient relationships. During the POR (November 13, 2014–December 27, 2014), a downward hydraulic gradient was evident between all zones in the CAU-1 and CAU-5 well clusters in and adjacent to the WFPP (**Figures 6** and **10**). CAU-1 in the center of the WFPP is the only well cluster directly below surface water in the reservoir and provides direct evidence of downward hydraulic gradients. Mean downward hydraulic gradients over the POR are presented in **Table 9**.

Table 9. Mean vertical hydraulic gradients in CAU-1 Well Cluster.

Description	Stations	Vertical Gradient (feet/feet)
Surface water to shallow SAS	SG-7, SG-5 and/or SG-6 to CAU-1S	0.056
Shallow SAS to intermediate SAS	CAU-1S to CAU-1M	0.204
Intermediate SAS to deep SAS	CAU-1M to CAU-1D	0.032
Deep SAS to lower deep SAS	CAU-1D to CAU-1LD	0.006

Hydraulic gradients between the reservoir, shallow SAS, intermediate SAS and deep SAS are fairly consistent with each other and generally low. The highest hydraulic gradient, between the shallow and intermediate zones (0.204 feet per feet [ft/ft]), indicates lower connectivity and possibly semi-confinement, and may be reflective of clayey sand and sandy clay observed in the CAU-1 borehole in the interval adjacent to and just below the CAU-1S well screen. The hydraulic gradient between the deep and lower deep aquifer is lower by an order of magnitude, which may be a function of higher Kv due to a lithology change from predominately fine to very fine quartz sand to predominately medium to coarse grained shell sand in the lower deep SAS and/or and increased flow component to the south.

The water levels in the intermediate and deep zones in CAU-6 and CAU-7, 900 feet south of the WFPP and approximately 160 feet north of the C-44 Canal, track closely together (**Figures 11** and **12**) A slight upward hydraulic gradient is evident between CAU-7D and CAU-7M, and a stronger upward gradient is evident between the deep wells (CAU-6D and CAU-7D) and SG-1 (adjacent to the C-44 Canal). Since the screen intervals in the deep wells are well below the surface water levels in the C-44 Canal, an upward gradient towards the C-44 Canal from the deep wells is evident.

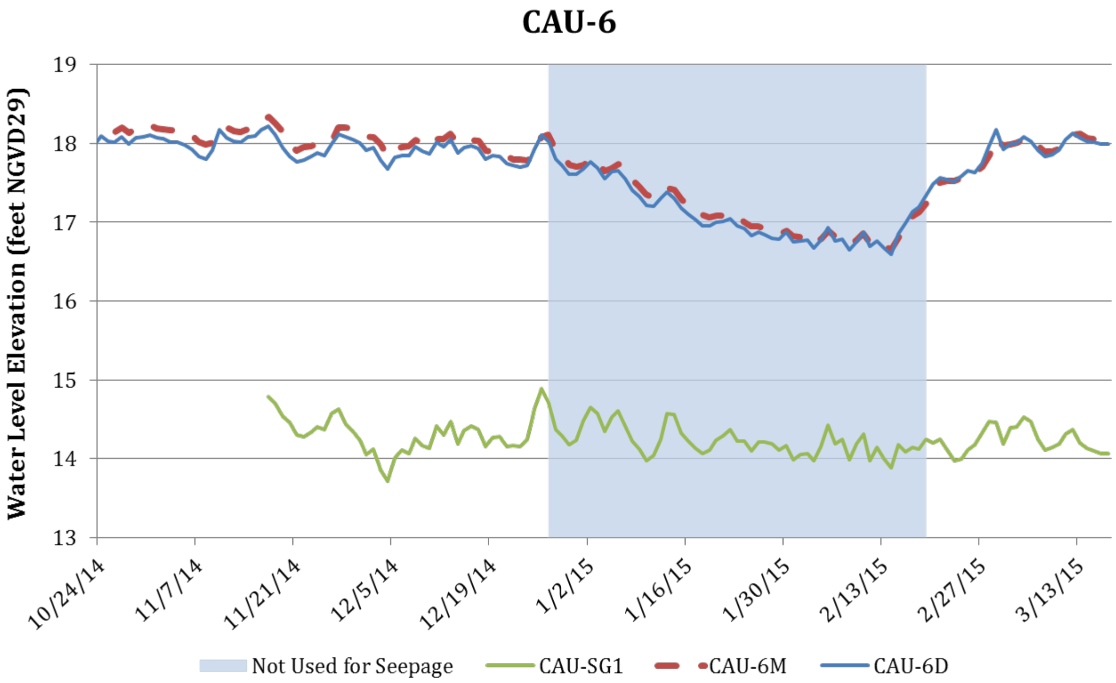


Figure 11. Hydrograph of Well Cluster CAU-6 including surface water at the C-44 Canal (SG-1).

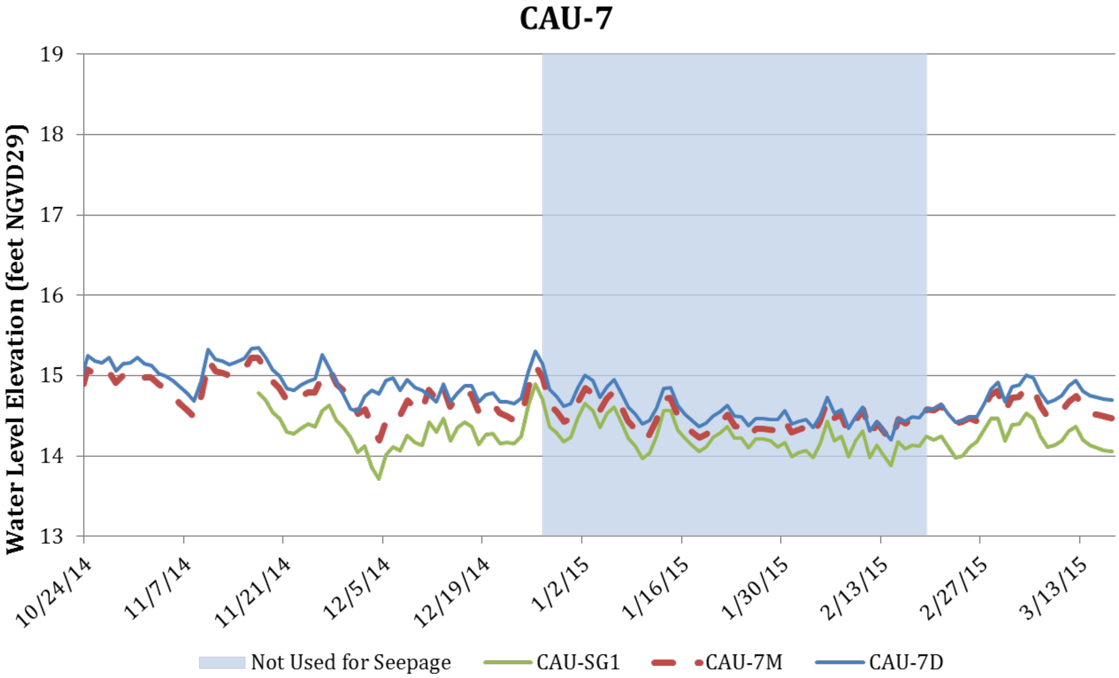


Figure 12. Hydrograph of Well Cluster CAU-7 including surface water at the C-44 Canal (SG-1).

5.5 Lateral Hydraulic Gradients in the Intermediate and Deep SAS

Lateral hydraulic gradients in the intermediate and deep zones were estimated by comparing wells at Well Clusters CAU-1, CAU-5, CAU-6 and CAU-7, shown in **Figures 13** and **14**, and **Table 10**. In each zone, a slight northerly hydraulic gradient is evident between CAU-1 and CAU-5 (to the north) over most of the POR, with the exception being a period of southerly hydraulic gradient from approximately mid-December through the end of the POR after pumping stopped and water levels began to fall in the WFPP. A higher southerly hydraulic gradient was observed between CAU-1 and CAU-6 and CAU-7M near the C-44 Canal. Water levels in CAU-6M and CAU-6D are several feet above those of CAU-7, indicative of a westerly component to the hydraulic gradient, which is consistent with a potential western component to groundwater flow based on a topographic high to the east and potential hydrologic sink due to the C-43 Canal to the west, discussed in **Section 3.2**.

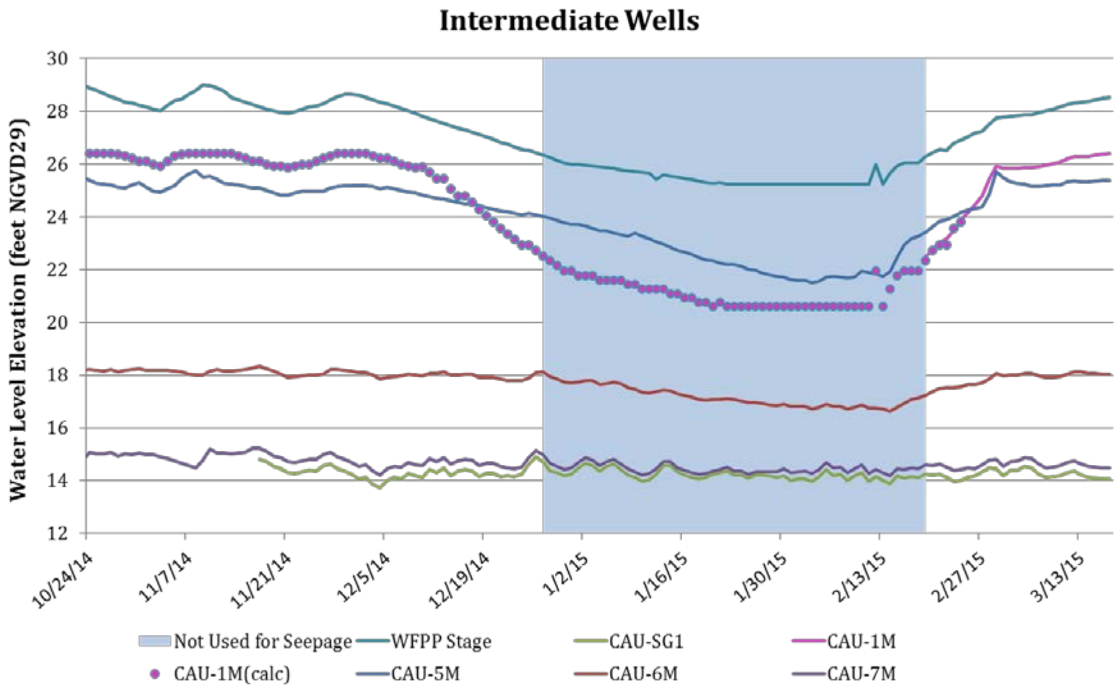


Figure 13. Hydrograph of intermediate well and stage in the WFPP and C-44 Canal.

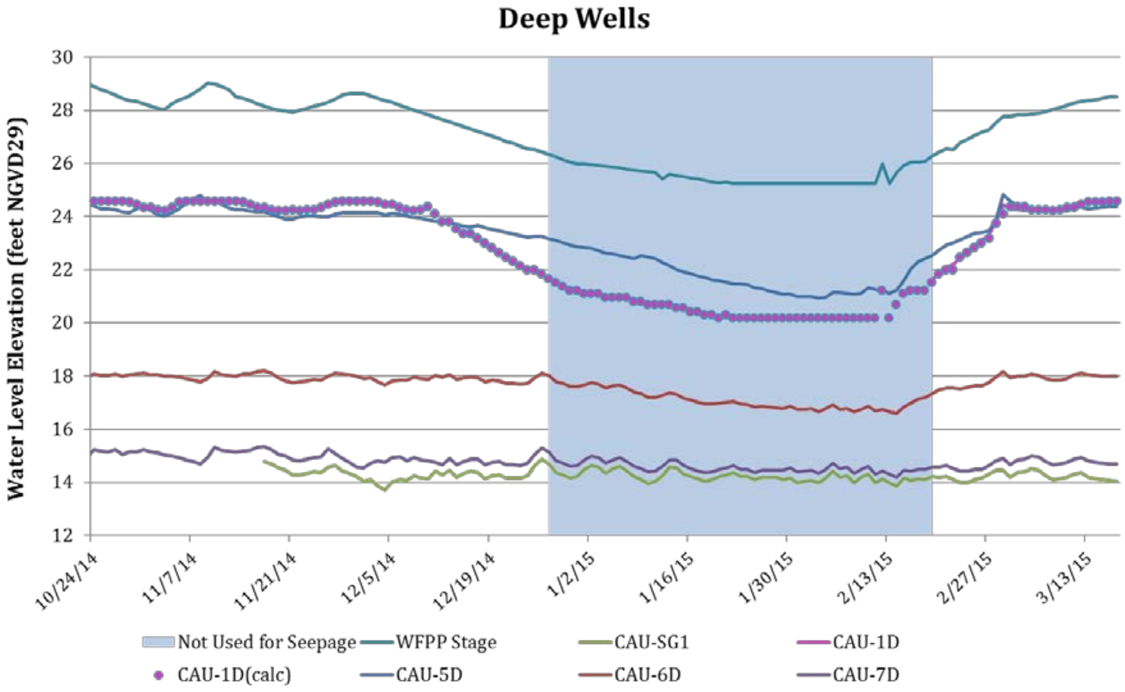


Figure 14. Hydrograph of deep wells and stage in the WFPP and C-44 Canal.

Table 10. Mean lateral hydraulic gradients in intermediate and deep wells during the POR.

Description	Stations	Lateral Gradient (ft/ft)
Intermediate SAS north	CAU-1M to CAU-5M	<.001
Intermediate SAS south	CAU-1M to CAU-6M/7M	0.005
Deep SAS north	CAU-1D to CAU-5D	<.001
Deep SAS south	CAU-1D to CAU-6D/7D	0.004

6

Seepage Model Development and Analysis

6.1 Conceptual Model

A conceptual model was developed for characterizing seepage from the Caulkins WFPP into adjacent land and surface water, and groundwater flow within the SAS, and relies on data from the hydrostratigraphic framework (discussed in **Section 3**) and hydrographic data collected during the POR (discussed in **Section 5**).

Assumptions regarding seepage and groundwater flow include the following:

- The CV is defined as the WFPP reservoir. Seepage from the CV consists of downward seepage into the shallow SAS, and lateral seepage through the levees and shallow SAS towards perimeter canals to the east, south and west, and towards the north into the shallow SAS.
- Since all lateral seepage through the shallow SAS is assumed to be from the CV, groundwater flow from the shallow SAS consists solely of downward seepage into the intermediate SAS with no lateral component.
- Groundwater flow from the intermediate and deep SAS is predominately downward, with relatively little lateral flow components, which are predominately towards the south, towards the C-44 Canal.
- Groundwater flow from the lower deep SAS is predominately towards the south, towards the C-44 Canal, with no downward component.

The lower boundary of the CV is the top of the underlying substrate (shallow SAS), and the lateral boundaries consist of land surfaces from the base of the borrow pits along the sides to the interior slopes of the earthen levees. The shallow SAS includes the top of the substrate (at an elevation of approximately +25 feet NGVD29) to an elevation of +12 feet NGVD29, at a depth of approximately 13 feet bls. This elevation is approximately equivalent to the base of the east, south and west perimeter canals, and also to a lithology change from silty sand, sandy clay and calcareous clay to predominately silty and shelly sand.

The intermediate SAS includes the base of the shallow SAS to an elevation of -15 feet NGVD29, at depth of approximately 40 feet bls. Lithology consists of predominately silty, quartz and shell sand grading to poorly graded sand. The deep SAS includes the base of the intermediate SAS to an elevation of -68.6 feet NGVD29, a depth of approximately 95 feet bls. Lithology consists of mostly silty, quartz and shell sand with minor beds of sandy silt. The lower deep SAS includes the base of the deep SAS to the top of the Hawthorn Group (base of the SAS), at a depth of approximately 145 feet bls. Lithology consists of predominately silty sand comprised of mostly shell fragments.

6.2 Seepage Calculation Formulas

A spreadsheet model was developed using Microsoft© Excel for calculation of daily average values for the seepage/groundwater flow paths described in this section using Darcy's general equation for groundwater flow, below (Todd, 1980):

$$Q = -KA\,(dh/dl) \qquad (1)$$

where:

K = hydraulic conductivity (either vertical or horizontal) of the media through which water flows (ft/d)

A = cross-sectional area of the face through which the water flows

dh = change in head between the up-gradient and down-gradient measurement stations based on daily average water levels

dl = distance, either vertical or horizontal, between the up-gradient and down-gradient measurement stations.

6.2.1 Downward Seepage from Control Volume (Qcvb)

Seepage through the bottom face of the CV is derived by subtracting the daily mean water levels in the CV, represented by SG-5, SG-6 and SG-7, and daily calculated levels at CAU-1S to represent the change in head (dh). When data for one or two of the surface water stations are unavailable, the average of available data is used. The distance (dl) between the bottom of surface water reservoir and the shallow screen interval is used.

Parameters for calculation of downward seepage from the CV include the following:

- Vertical distance between the CV water surface and water levels in CAU-1S (dh)
- Distance between the base of the CV and the mid-screen interval of CAU-1S (dl; 8.37 feet)
- Bottom surface area covered by water as estimated by the stage-bottom area correlation relationship described below (A)

Due to the uneven surface of the bottom of the CV (substrate) at relatively shallow water depths, the bottom area of the CV (area covered by water) increases rapidly with increased water depth, until water covers the entire bottom, then increases at a slower rate until the CV reaches capacity. Since the downward gradient from the CV is calculated using the bottom surface area (A), only the bottom area covered by water, not subareal area, can be used. The computer-aiding drafting survey generated for the stage-storage relationship described in **Section 4.5** was used to calculate a CV bottom area for each 0.5 foot rise in water elevation from +23.4 to +28.9 feet NGVD29. A ninth order polynomial regression was used to fit the calculated bottom area curve, which was used to interpolate between each 0.5 foot to calculate bottom areas for each 0.1 foot in water level elevation rise, shown in **Figure 15**. The shaded area represents the stage in the WFPP above +26.28 NGVD29, which was used as the minimum stage for seepage calculations based on data limitations during the first monitoring year (discussed in **Section 5-2**).

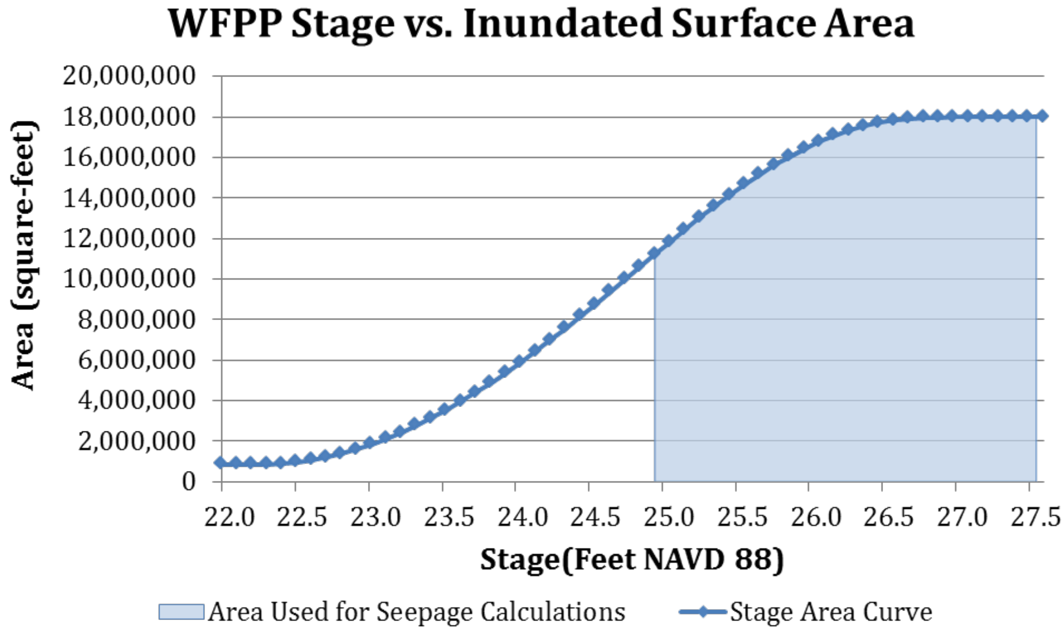


Figure 15. WFPP Stage versus inundated surface area.
(Note: NAVD 88 – North American Vertical Datum of 1988; NGVD29 = NAVD 88 + 1.40.)

6.2.2 Shallow East Face Seepage (Qcve)

Seepage through the east face of the CV is derived using water levels in the eastern side of the CV, represented by SG-7, and water levels in the east perimeter canal, represented by SG-2. This calculation assumes that all seepage through the eastern face travels through the shallow portion of the SAS and into the east perimeter canal. Other parameters for calculation of southern seepage include the following:

- Distance between the CV and east perimeter canal (dlse) = 70 feet
- Height of east seepage face (dH) = the water level in the CV (SG-7) – 12 feet NGVD29 (elevation of the base of the shallow SAS)
- Length of eastern seepage face (EFL) = 3,120 feet

6.2.3 Shallow South Face Seepage (Qcvs)

Seepage through the south face of the CV is derived using water levels in the southern side of the CV, represented by SG-7 and SG-6, and in the south perimeter canal (feeder canal), represented by SG-3. This calculation assumes that all seepage through the southern face travels through the shallow portion of the SAS. Other parameters for calculation of southern seepage include the following:

- Distance between the CV and south perimeter canal (dlss) = 300 feet
- Length of southern seepage face (SFL) = 4,320 feet
- Height of seepage face (dH) = the water level (WL) in the CV (average of SG-7 and SG-6) – 12 feet NGVD29 (elevation of the base of the shallow SAS)

6.2.4 Shallow West Face Seepage (Qcvw)

Seepage through the west face of the CV is derived using water levels in the western side of the CV, represented by SG-6, and in the west perimeter canal (drainage canal), represented by SG-4. This calculation assumes that all seepage through the western face travels within the shallow portion of the SAS.

The west perimeter canal typically contains very little water, and water levels were below the SG-4 stage recording device during the POR. The west perimeter canal consists of the southern portion of the return canal from the entire farm, and as such is controlled by irrigation ditch gates that minimize return flow. Based on visual observation, under these "almost dry" conditions, there is typically a small amount of water (one foot or less) in topographic lows at the bottom of the canal. Based on field observations, the bottom of the canal is approximately 18 feet NGVD29 elevation. Therefore, when the water level is below the recording device at SG-4, a default water level of +18 feet NGVD29 was used for gradient calculation. Other parameters for calculation of western seepage include the following:

- Distance between the CV and west perimeter canal (dlsw) = 71 feet
- Length of western seepage face (WFL) = 5,690 feet
- Height of seepage face (dH) = the WL in the CV (SG-6) –12 NGVD29 (elevation of the base of the shallow SAS)

6.2.5 Shallow North Face Seepage (Qcvn)

Seepage through the north face of the CV is derived using water levels in the northern side of the CV, represented by SG-5, and shallow groundwater to the north, represented by CAU-5S. This calculation assumes that all seepage through the northern face travels within the shallow portion of the SAS. Other parameters for calculation of northern seepage include the following:

- Distance between the CV and CAU-5S (dlsn) = 18 feet
- Length of northern seepage face (NFL) = 4,320 feet
- Height of seepage face (dH) = the water level in the CV (SG-5) – 12 feet NGVD29 (elevation of the base of the shallow SAS).

6.2.6 Downward Flow from Shallow SAS (Qsb)

Downward flow through the bottom face of the shallow SAS is derived from water levels in the shallow SAS represented by using surrogate values for the monitoring well CAU-1S, screened at a depth of approximately 7 to 9 feet bls, and water levels in CAU-1M, screened at a depth of approximately 15 to 25 feet bls. Parameters for calculation of intermediate vertical seepage include the following:

- Distance between water levels at CAU-1S and CAU-1M (dh)
- Distance between the mid-screen intervals of CAU-1S and CAU-1M (dliv) = 9.9 feet
- Bottom area beneath the outer edges of the CV = 414 acres

6.2.7 Downward Flow from Intermediate SAS (Qid)

Groundwater flow through the bottom face of the intermediate SAS is derived from using surrogate water levels for the monitoring well CAU-1M, screened at a depth of approximately 15 to 25 feet bls, and CAU-1D, screened at a depth of approximately 62 to 72 feet bls. Parameters for calculation of intermediate vertical flow include the following:

- Distance between water levels at CAU-1M and CAU-1D
- Distance between the mid-screen intervals of CAU-1M and CAU-1D (dldv) = 48.5 feet
- Bottom area beneath the outer edges of the WFPP = 414 acres

6.2.8 Lateral Flow from Intermediate SAS (Qis and Qin)

Calculation of lateral flow from the intermediate SAS beneath the CV is limited in this investigation to northerly flow and southerly flow based on placement of intermediate monitoring wells, and hydrographic data that shows a prevailing southerly gradient beneath the CV. Lateral flow through the south face of the intermediate SAS is derived using water levels represented by using surrogate values for the monitoring well CAU-1M, screened at a depth of approximately 15 to 25 ft bls and down-gradient water levels represented by the average of CAU-6M and CAU-7M, near the C-44 Canal. Parameters for calculation of southerly flow include the following:

- Distance between the CAU-1M and CAU-6M/CAU-7M (dlis) = 2,000 feet
- Length of southern seepage face (SFL) = 4,320 feet
- Height of seepage face (dH) = 27 feet

Lateral flow through the north face of the intermediate SAS is derived using water levels represented by surrogate values for the monitoring well CAU-1D and water levels represented by the water level at CAU-5M, on the north levee. Parameters for calculation of intermediate northerly lateral flow seepage include the following:

- Distance between the CAU-1M and CAU-5M (dlin) = 2,900 feet
- Length of southern seepage face (SFL) = 4,320 feet
- Height of seepage face (dH) = 27 feet

6.2.9 Downward Flow from Deep SAS (Qdb)

Flow through the bottom face of the deep SAS is derived using water levels represented by surrogate values for the monitoring well CAU-1D, screened at a depth of approximately 62 to 72 feet bls, and CAU-1LD. screened at a depth of approximately 120 to 130 feet bls. Parameters for calculation include the following:

- Distance between water levels at CAU-1D and CAU-1LD
- Distance between the mid-screen intervals of CAU-1D and CAU-1LD (dlldv) = 58.5 feet
- Bottom area beneath the outer edges of the WFPP = 414 acres.

6.2.10 Lateral Flow from Deep SAS (Qds and Qdn)

Calculation of lateral flow from the deep SAS beneath the CV is limited in this investigation to northerly flow and southerly flow based on placement of deep monitoring wells, and hydrographic data that shows a prevailing southerly gradient beneath the CV. Lateral flow to the south face of the deep SAS is calculated using water levels represented by surrogate values for the monitoring well CAU-1D, screened at a depth of approximately 62 to 72 feet bls, and down-gradient water levels represented by CAU-6D and CAU-7D near the C-44 Canal, screened at depths of approximately 69 to 79 feet bls. Parameters for calculation of southerly flow include the following:

- Distance between CAU-1D and CAU-6D/CAU-7D (dlds) = 2,000 feet
- Length of southern seepage face (SFL) = 4,930 feet
- Height of seepage face (dH) = 50 feet

Lateral flow through the north face of the deep SAS primarily driven by water levels represented by using surrogate values for the monitoring well CAU-1D, and water levels down-gradient end is represented by CAU-5D on the north levee, screened from 69 to 79 feet bls. Parameters for calculation of intermediate northerly lateral flow include the following:

- Distance between CAU-1D and CAU-5D (dlin) = 2,900 feet
- Length of northern face (SFL) = 4,930 feet
- Height of seepage face (dH) = 50 feet

6.3 Development of Seepage Estimates

Lateral and vertical (downward) seepage estimates were developed for the CV, shallow SAS, intermediate SAS and deep SAS using seepage formulas described above. Estimates for horizontal conductivity (Kh) and vertical hydraulic conductivity (Kv) are critical variables. Seepage estimates were calibrated the Excel spreadsheet model by varying Kh parameters and Kv parameters while satisfying the following flow conditions based on the conceptual model:

- The daily average for residual seepage during the POR estimated in the water budget of approximately 34 ac-ft/d (**Appendix A**) is equivalent to the total seepage from the CV (Qcvt), which is equivalent to the seepage from each of the four side faces (lateral seepage) plus seepage from the bottom face (Qcvb + Qcve + Qcvs +Qcvw +Qcvn).
- Since all lateral seepage from the CV is through the shallow aquifer, then downward seepage through the CV (Qcvb) is equivalent to downward flow through the shallow SAS (Qsb).
- As supported by hydrographs, horizontal seepage in the shallow, intermediate and deep portions of the SAS is predominantly outward and horizontal flow direction from the intermediate and deep zones are less than 1 to 2% of the total flow from each zone. Therefore, downward flow from the shallow SAS (Qsb) is equivalent to all flow from the intermediate SAS (Qib + Qin + Qis). Since lateral flow from the intermediate and deep SAS is minimal (less than 2% of total flow), downward flow from the shallow SAS (Qsb) is substantially equivalent to flow from both the intermediate SAS (Qib + Qin + Qis) and deep SAS (Qdb + Qdn + Qds).

The various combinations used for Kh and Kv for the shallow, intermediate, deep and lower deep SAS are shown in **Table 11**, and a graphical solution representing these flow conditions using a mid-level estimate for Kh in the shallow SAS of 30 ft/d in **Figure 16**. Initially, Kh was varied between 10 and 50 ft/d for the shallow, intermediate and deep zones and between 5 and 50 ft/d for the lower deep zone. Kv values were limited to those that would be within an anisotropy ratio (Kv to Kh) of between 0.01 and 0.1 in the shallow, intermediate and deep zones, and between 0.01 and 0.5 in the lower deep zone. The limiting factors in this analysis proved to be Kh and Kv values in the shallow SAS, whereas criteria in the lower layers were met as long as criteria in the SAS were met. The low- and high-end K values of 10 and 50 ft/d in the shallow SAS were not able to satisfy flow conditions while staying within criteria for anisotropy; therefore, they were not used for subsequent analysis. Subsequently, all criteria were able to be met using Kh values for the shallow SAS between 15 and 48 ft/d. Downward seepage estimates from the CV varied from 32 to 79% of total seepage using Kh values of 48 and 15 ft/d, respectively, or 11 to 27 ac-ft/d. Based on a surface area of 414 acres, downward seepage was a rate of 0.027 ft/d to 0.065 ft/d is estimated.

Table 11. Seepage estimates using Kh ranges between 15 and 48 ft/d.

Shallow SAS			Intermediate SAS			Deep SAS			Lower Deep SAS			Downward Flow (ac- ft/d)
Kh	Kv	AR	Kh	Kv	AR	Kh	Kv	AR	Kh	Kv	AR	
15	1.5	0.1	20	0.33	0.016	30	2.1	0.068	50	10.9	0.218	27
30	1.1	0.04	20	0.24	0.012	30	1.47	0.049	50	7.7	0.149	20
48	0.6	0.012	13	0.13	0.01	30	0.84	0.028	50	4.4	0.088	11

Note: AR = Kv to Kh anisotropic ratio; Kh= horizontal hydraulic conductivity in ft/ d; Kv = vertical hydraulic conductivity in ft/d.

The relative percentages of lateral and downward seepage from the CV using Kh values from 15 and 48 ft/d are presented in **Table 12**. Since total seepage from the CV is constant (34 ac-ft/d), an increase in Kh, which increases lateral seepage, requires decreasing Kv (downward seepage) and visa-versa. The greatest lateral seepage was to the west, which ranged from 10 to 32% of total seepage, which would be expected because the perimeter canal to the west (drainage canal), was substantially empty during the POR and therefore the greatest hydraulic gradient was to the west. Lateral seepage to the north ranged from 9 to 30% of total seepage. This seepage is expected to flow downward into lower portions of the SAS. The eastern and southern seepages were minimal, which would be expected since the southern and eastern perimeter canals maintained relatively higher water levels during the POR.

Table 12. Seepage estimates from CV as a percentage of total seepage using shallow Kh between 15 and 48 ft/d.

Shallow SAS K_h (ft/d)	Downward Seepage (ac-ft/d)	Downward Seepage Percent	Lateral Seepage (ac-ft/d)	Lateral Seepage Percent	North Seepage Percent	West Seepage Percent	East Seepage Percent	South Seepage Percent
15	27	79%	7	21%	9%	10%	1.6%	<1%
30	20	57%	14	42%	18%	20%	3%	<1%
48	11	32%	23	68%	30%	32%	5%	1%

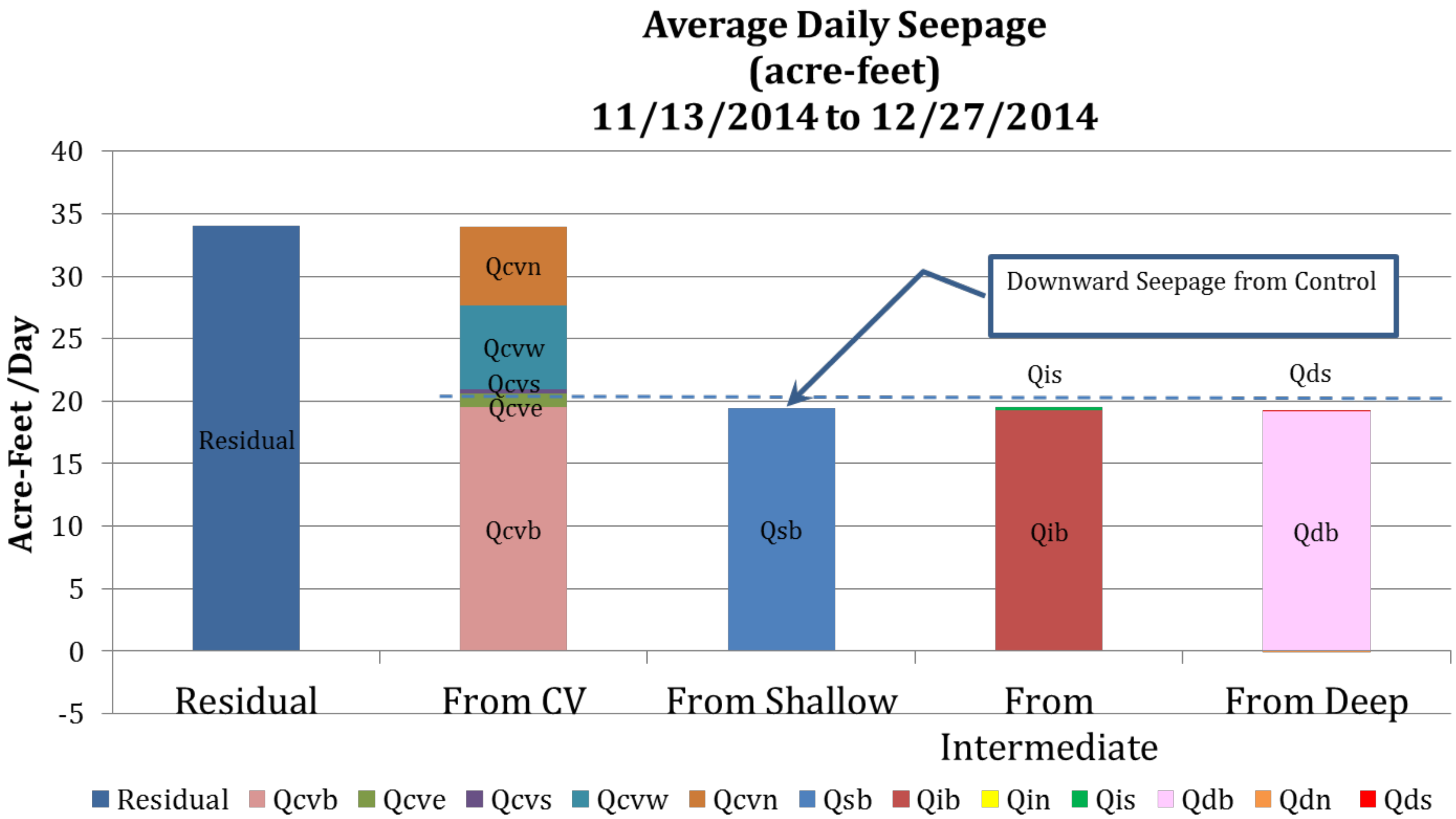


Figure 16. Graphical representation of seepage and groundwater flow using the mid-range estimate for Kh of 30 ft/d for the shallow SAS.

Based on relative K gradients within the intermediate and deep SAS, the predominant flow direction is downward. **Table 13** shows relative percentage of downward verses lateral seepage in each zone using the mid-range Kh solution of 30 ft/d in the shallow SAS. Lateral flow is less than 2% of the total flow in each zone, and the bulk of lateral flow is to the south towards the C-44 Canal. Based on this relationship, varying Kh values within reasonably anticipated ranges will not significantly change the observation that approximately 98% of flow from the intermediate and deep SAS is downward.

Table 13. Seepage estimates from the intermediate and deep SAS using a mid-level seepage range (shallow zone K = 30 ft/d).

Zone	Vertical Seepage	Southern Seepage	Northern Seepage
Intermediate SAS	98.7%	1.2%	<1%
Deep SAS	98.2%	<1%	<1%

6.4 Seepage from Lower Deep SAS and Estimated Travel Time from WFPP to C-44 Canal

Average flow velocities from the surface reservoir to the C-44 Canal were calculated under the assumption that most of the flow occurred through the lower deep portion of the SAS and towards the C-44 Canal based on the prevailing Kv gradients evident in the intermediate and deep zones, the underlying Hawthorn Group, which represents a hydraulic barrier, and regional hydraulic gradients towards the south. It is assumed that the bulk of downward seepage from the CV will flow below the screen interval of the deep well, CAU-1D (approximately 72 feet bls), southerly towards the C-44 Canal, representing a section approximately 73 feet thick assuming the base of the SAS is at 145 feet bls. Down-gradient wells were not installed in the lower deep zone so gradient data does not exist; however, the gradient for the deep zone is substituted using CAU-1D (simulated), CAU-7D and CAU-6D over the POR of November 13, 2104 through December 27, 2014.

The rate at which water moves through porous medium is equal to the Darcy velocity divided by effective porosity, as shown in the equation below (Fetter, 1980):

$$v = K(dh/dl)/n \quad (2)$$

where:

K = hydraulic conductivity of the media through which water flows (ft/d)

dh = change in head between the up-gradient and down-gradient measurement locations

dl = distance, either vertical or horizontal, between the up-gradient and down-gradient measurement locations

n = effective porosity

An estimate of 50 ft/d was used for K based on the results of on-site aquifer tests and APTs in the vicinity, and the lithology of the lower zone, described as mostly fine to medium shell sand and silty sand. A value of 0.22 was used for effective porosity of sand (Fetter, 1980). The average gradient in the deep zone between CAU-1D and the midpoint between CAU-5D and CAU-6D adjacent to the C-44 Canal over the POR was 0.00378 ft/ft. The resultant velocity and travel time estimate, based on a distance of 900 feet from the southern border of the WFPP to the C-44 Canal, is 0.9 ft/d and 2.7 years, respectively.

7

Summary and Conclusions

A seepage estimate of 34 ac-ft/d, based on the residuals value presented in the surface water budget (**Appendix A**), was used to calibrate an Excel spreadsheet model for development of average daily seepage estimates over the POR (November 13, 2014 through December 27, 2014). This POR represents approximately 6 weeks, a relatively small period for the first year of operation. Lateral and vertical seepage estimates were developed by matching the average daily seepage estimated from the water budget with the total seepage estimate using the Darcy general equation for groundwater flow, relative groundwater and surface water levels, and a range of K estimates obtained from on-site testing and published values from nearby tests. The calibrated Excel spreadsheet model provides a qualitative confirmation of the seepage estimate developed using the surface water budget.

A range of hydraulic conductivities from 15 to 48 ft/d in the shallow SAS and anisotropy ratios (Kv/Kh) between 0.01 and 0.5 yielded seepage results that satisfied the constraints of the water budget seepage estimate. The estimated downward seepage ranged from 11 to 27 ac-ft per day, or 32 to 79% of total seepage, and 7 to 23 ac-ft/d (21 to 68%) seeped to perimeter canals on the east, south and west sides and the adjacent shallow aquifer to the north. Based on a surface area of 414 acres, the downward seepage rate ranged from 0.027 ft/d to 0.065 ft/d. Based on lithology, published data, and the aquifer test conducted on-site that yielded a Kh result of 10 ft/d in the shallow aquifer, the lowest Kh value that satisfies model criteria, 15 ft/d, is the best estimate for downward seepage. A Kh value of 15 ft/d yields a downward seepage on the upper end of the range of 27 ac-ft per day (0.065 ft/d), or 79 % of total seepage, and 7 ac-ft (21 %) of seepage laterally. Additional short-term APTs of the shallow SAS within and adjacent to the WFPP reservoir may narrow the range of estimated Kh and Kv values and therefore the ranges of estimated downward and lateral seepage.

Groundwater flow from the WFPP was downward into deeper portions of the aquifer and outward into perimeter canals to the east, south, and west, and the shallow aquifer to the north. Groundwater from the shallow aquifer flowed downward to the base of the SAS and then southerly towards the C-44 Canal. In the vicinity of the C-44 Canal, upward groundwater flow from the deep SAS towards the C-44 Canal is indicated by an upward hydraulic gradient between the deep wells (CAU-6D and CAU 7D, approximately 160 feet north of the C-44 Canal) and the C-44 Canal. There also appears to be a westerly component to flow in the deep and intermediate SAS indicated by the CAU-6 and CAU-7 well hydrographs, consistent with physiographic features and surface water pumping from the C-444 Canal.

Approximately 90% of lateral seepage was to the west, towards the west perimeter canal, which was nearly dry during the POR, and to the north into the shallow SAS. Since the ultimate disposition of the water that flows to the west perimeter canal is assumed to seep into the shallow SAS, then approximately 90% of the lateral seepage eventually flowed into the SAS.

Lithology of the shallow sediments includes thin, sandy clay and clayey sand interbeds from approximately 4 to 13 feet bls, which appear to be discontinuous and at variable depths. The presence of these lower permeability clayey zones may attenuate downward seepage from the Caulkins WFPP, and increase seepage to perimeter canals.

Average groundwater flow velocities from the surface reservoir to the C-44 Canal were calculated based on the assumption that most of the flow toward the C-44 Canal occurred through the lower deep portion of the SAS. Based on Kh values of 50 ft/d (the upper end of the Kh range) and using a distance of 900 feet from the southern edge of the WFPP to the C-44 Canal, the resultant velocity and travel time estimate are 0.9 ft/d and 2.7 years, respectively. This travel time may help nutrient reduction by absorbing nutrient pulses within the C-44 Canal and normalizing discharge back to the C-44 Canal over a period of years, and by providing residence time within the SAS to facilitate nutrient adsorption.

Expansion of the WFPP to include the bulk of the citrus farm would also likely result in significant lateral seepage into adjacent canals, much of which would flow back to the C-44 Canal and discharge via either the citrus farm discharge at the southeastern corner or the discharge canal in the southwestern corner. Assuming perimeter canals would border an expanded WFPP, there would be a lower ratio of the total seepage face associated with perimeter canal length relative to the bottom surface area, resulting in a lessor relative seepage to perimeter canals than at the WFPP.

8

Recommendations

It is recommend that SFWMD continue monitoring water levels and develop seepage estimates through the second monitoring year. A water and salt budget, including nutrients, should be developed to better understand groundwater seepage, groundwater directional flow, residence time and nutrient load reduction from the Caulkins WFPP. A semi-annual program using acoustic Doppler profiling of up-gradient and down-gradient portions of the C-44 Canal should be considered for independent seepage measurement validation from the portion of the aquifer that is intersected by the C-44 canal.

Additional short-term APTs within the shallow SAS at five wells within and adjacent to the WFPP reservoir are recommended to narrow the range of estimated downward and lateral seepages prior to the second annual report.

A semi-annual groundwater sampling program should be implemented to compliment the on-going surface water quality sampling and analysis of intake water to the WFPP. The objectives of the sampling program will be to 1) evaluate nutrient removal in groundwater eventually returned to the C-44 Canal, 2) further characterize source and direction of groundwater flow through the SAS, and 3) to use the salt concentrations to validate the water budget. Sampling should include all monitoring wells and surface water in the WFPP and C-44 Canal, and be conducted semi-annually and include ionic and nutrient parameters.

If additional data is needed to evaluate expansion, further hydrogeologic characterization of the citrus farm would include installation of monitoring wells for delineation of the extent of the clayey portions in the shallow SAS and additional wells for aquifer tests to estimate K in the shallow and middle SAS and monitoring of regional groundwater flow. A groundwater monitoring program, including permanent monitoring stations for water level and water quality sampling is recommended. All surface water drainages to the C-44 Canal or other water bodies from perimeter canals should be included, as well as integration with monitoring associated with planned the C-44 Reservoir and Stormwater Treatment Area Project approximately one-half mile to the west.

9

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Appendix A

Summary of Caulkins Water Farm Pilot Project Surface Water Budget and Water Quality Evaluation

Authors: Wossenu Abtew and Lucia Baldwin

This is a preliminary evaluation of a surface water budget and inflow water quality using a short period of data for the Caulkins Water Farm Pilot Project (WFPP). Data was collected from February 10, 2014, through January 31, 2015. Subsurface and perimeter canals monitoring and data analysis by groundwater experts are required to fully characterize the water flow pattern at the site. This summary is limited to observed/recorded surface water parameters and estimates for storage change.

Hydrological Observations and Estimations

Sources of Data

Daily water level data for the WFPP that represents water storage level at site SG-7, daily pumping volume into the WFPP, and daily rainfall data for the site were provided by the project manager. Evapotranspiration (ET) estimates are used from the closest weather station, JDWX (dbkey OH512 in DBHYDRO). For the period when ET data was not available in the database, ET was computed from solar radiation data at the same weather station (dbkey G0853 in DBHYDRO) using the same ET equation as the database. Summary of the hydrologic data for the whole period are provided in **Table A-1**. Monthly values are provided in **Table A-2**.

Table A-1. Summary of hydrologic observations (February 10, 2014–January 31, 2015)

Source	Amount	Amount (feet)
Pumping	11,656 acre-feet	28.15
Rainfall	46.36 inch	3.86
ET	48.43 inch	4.04
Change in Storage	-3.17 inch	-0.26
Area = 414 acres		

Table A-2. Monthly summary of hydrologic observations.

Month	Pump inflow (acre-feet)	Rainfall (inches)	ET (inches)
February 2014	850	2.53	2.87
March 2014	748	1.55	5.00
April 2014	679	1.01	5.56
May 2014	436	4.09	5.36
June 2014	0	11.76	4.82
July 2014	2,076	5.57	4.23
August 2014	1,804	3.64	4.89
September 2014	1,398	8.52	3.59
October 2014	1,980	2.95	3.86
November 2014	1,674	2.71	2.71
December 2014	9	1.34	2.60
January 2015	0	0.69	2.96

Surface Water Budget Analysis

Water budget analysis for a farm is subject to result in residuals due to ungauged inflows and outflows, errors in measurements of flows, rainfall, ET, water levels and change in storage. The general equation for mass balance of water for this type of system is expressed by **Equation A-1**. The unit for each parameter can be volume of water or depth of water on the surface area of the site (414 acres).

$$\Delta S = \text{Surface Water Inflow} + \text{Rainfall} - \text{Surface Water Outflow} - \text{ET} \pm \text{Seepage} \pm \epsilon \quad \text{(A-1)}$$

Where ΔS is change in storage as a difference between ending and beginning storage for the analysis period, and ϵ is errors associated with measurements and ungauged surface and subsurface flows. Since at the WFPP, surface outflow is not recorded and surface water discharge is not part of the operation, the water balance equation is modified as follows where residuals are measurement errors and ungauged surface and subsurface flows:

ΔS = Surface Water Inflow + Rainfall – ET ± Residuals (A-2)

Since the rest of the parameters are recorded or calculated values in **Equation A-2**, the unknown residuals can be calculated by **Equation A-3**.

Residuals = Surface Water Inflow + Rainfall – ET - ΔS (A-3)

where positive residuals are inflows without unknown destination (inflows exceed outflows) or negative residuals are outflows without unknown source (outflows exceed inflows).

Residuals for the analysis period are shown in **Table A-3** with the water budget components. Change in storage is the difference in stage between the beginning and the end of the analysis period. Positive change in storage is increase in stage while negative is decline in stage or storage. When water levels fall below ground at the end of the period, subsurface storage is estimated for the soil at the site (fine sand and slightly clay fine sand). Change in storage from February 10, 2014, to January 6, 2015 is zero since the beginning and ending stages are the same (25.5 feet National Geodetic Vertical Datum of 1929 [NGVD29], from **Figure A-1**). The surface and subsurface change in storage from January 7 to January 31, 2015, is -0.264 feet. The positive residual shows that the destination of 28.23 feet of the inflows cannot be identified from the surface water budget analysis.

Table A-3. Period of record residuals and water budget parameters in feet of depth of water over the 414-acre site.

Period	Pump Inflow (feet)	Rainfall (feet)	ET (feet)	Change in Storage (feet)	Water Budget Residual (feet)
February 10, 2014–January 31, 2015	28.15	3.86	4.04	-0.264	28.23

Daily Water Level Fluctuation and Net Inflow

(Pumping + Rain - ET)

Daily water level fluctuation at the SG-7 site and daily net inflow are shown in **Figure A-1**. Net inflow is the balance of pumping and rainfall as inflows and ET as outflow (dashed purple line). A negative value in **Figure A-1** means outflow is higher than inflow for a day where ET is higher than inflow pumping and rainfall combined. From the figure, the rapid drop in measured water level is observed when inflows are reduced indicating that without continuous pumping water levels will fall.

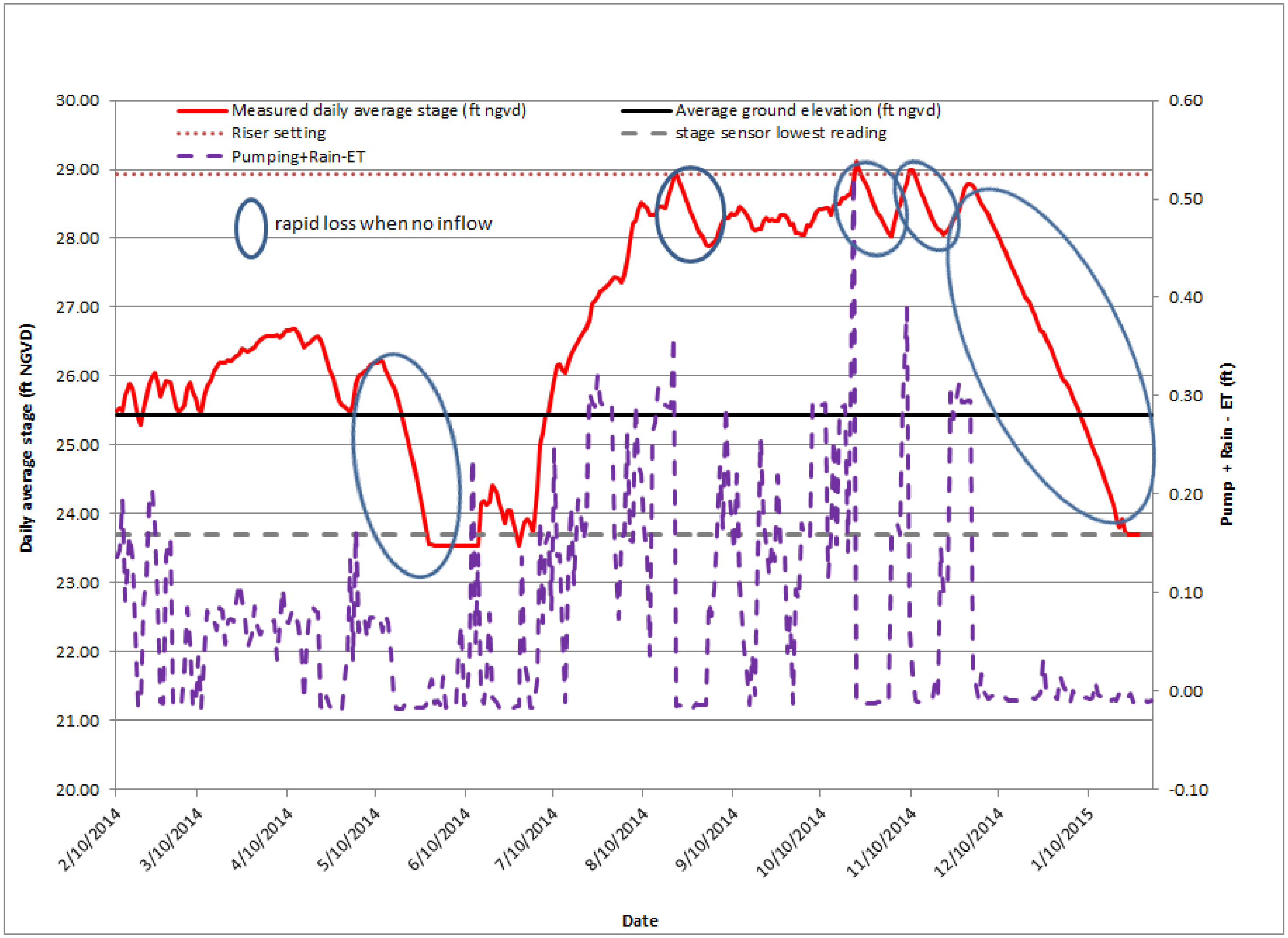

Figure A-1. Daily water level fluctuation and net inflows.
(Note: ft – feet and NGVD – NGVD29.)

Simulation of Water Level Fluctuation with Overflow over Riser (No Losses) and with Losses

The site can respond to inflows in two ways. First, with no losses from the site, with high inflows, the water level can reach the riser and overflow as shown in **Figure A-2** with the solid turquoise line. Second, if there are losses, pumping control, meteorology conditions and unmeasured losses, they will keep the water level below the riser overflow level. Water level can be simulated by estimating daily losses (**Figure A-2**). Different rates of daily loss for different time periods are shown in **Table A-4**, which was used to match the daily observed water levels through water balance simulation.

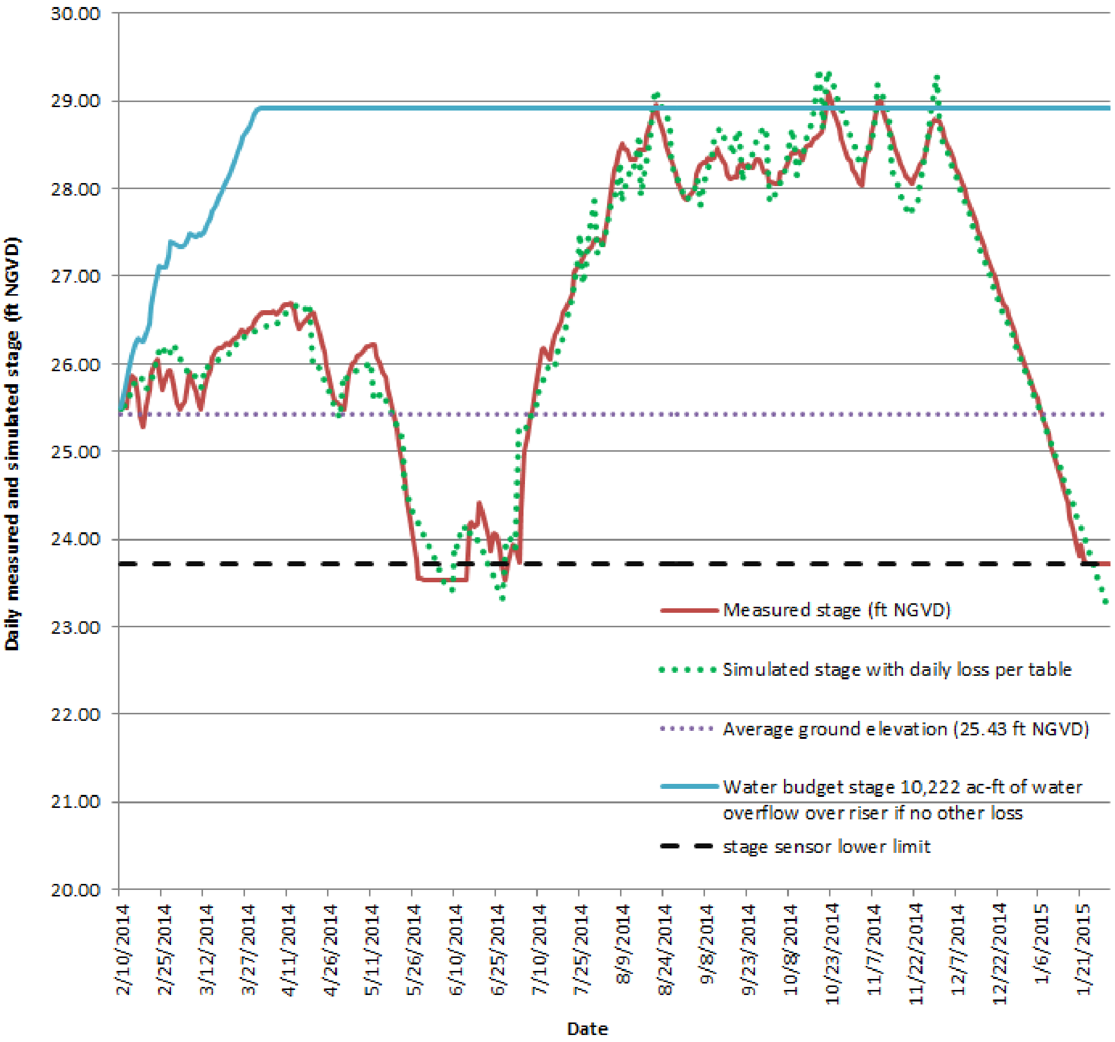

Figure A-2. Simulation of daily stage from water budget with estimated losses and no losses.
(Note: ac-ft – acre-feet, ft – feet and NGVD – NGVD29.)

Table A-4. Estimated periodic water budget losses (February 2014–January 2015).

Date Range (February 2014–January 2015)	Estimated Daily Loss (feet)	Estimated Daily Loss (inches)
February 10–March 11	0.060	0.72
March 12–April 19	0.050	0.60
April 20–April 30	0.060	0.72
May 1–May 11	0.065	0.78
May 12–May 22	0.060	0.72
May 23–June 9	0.065	0.78
June 10–June 27	0.060	0.72
June 28–July 2	0.055	0.66
July 3–July 25	0.045	0.54
July 26–July 30	0.050	0.60
August 1–August 8	0.055	0.66
August 9–August 15	0.058	0.70
August 16–August 26	0.063	0.76
August 27–September 5	0.065	0.78
September 6–September 20	0.067	0.80
September 21–September 30	0.070	0.84
October 1–October 10	0.073	0.88
October 11–October 19	0.077	0.92
October 20–November 13	0.080	0.96
November 14–November 30	0.082	0.98
December 1–January 31, 2015	0.085	1.02

Water Quality Observations and Load Estimations

Water quality samples were collected at CAULK-IN site using two collection methods, time composite autosampler (ACT) and grab sampling. Between February 2014 and January 2015, the frequency of sampling varies from month to month as shown in **Table A-5**. Samples were analyzed for total phosphorus (TPO4), total nitrogen (TOTN) and total suspended solids (TSS). Due to changes in laboratory procedures, two different analytical methods were used for analysis of TOTN. For the period February through May 2014, samples were analyzed for nitrate plus nitrite and total Kjeldahl nitrogen, and TOTN was calculated as the sum of the two. For the interval July through January 2015, TOTN was analyzed as a single distinct parameter. In June 2014 and January 2015, there was no pumping at the site and no sampling.

Table A-5. Number of samples collected each month between February 2014 and January 2015.

Month	Number of Site Visits, No Sample	Number of ACT Samples	Number of Grab Samples
February 2014		2	2
March 2014		5	5
April 2014		4	4
May 2014	2	2	2
June 2014	4		
July 2014		2	2
August 2014		4	4
September 2014		5	5
October 2014		4	4
November 2014		3	3
December 2014	3	1	2
January 2015	4		

Water quality analysis focuses on TPO4 and TOTN concentrations and loads that entered into the WFPP area as monitored at sampling station CAULK-IN. **Figures A-3** and **A-4** present TPO4 and TOTN concentrations measured at CAULK-IN between February 2014 and January 2015. The graphs also show daily inflows at CAULK-IN for the same interval in order to differentiate between nutrient concentrations registered during days with flow versus nutrient concentrations during days with no flow. One can notice that during days with no flow, the nutrient concentrations tend to be higher, especially for TPO4.

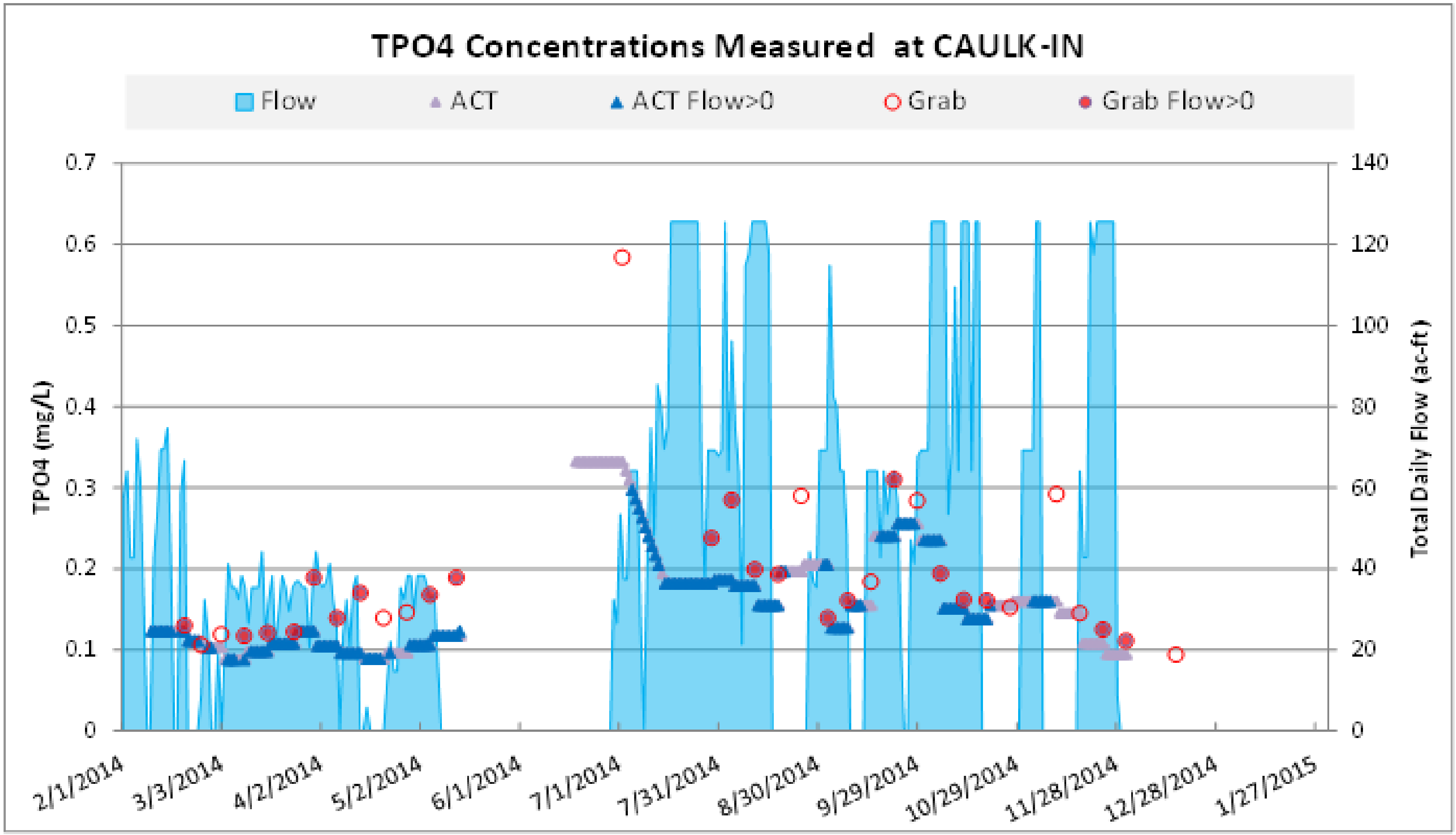

Figure A-3. Daily flow in acre-feet (ac-ft) and grab/ACT TPO4 concentrations in milligrams per liter (mg/L) at CAULK-IN sampling site between February 2014 and January 2015.

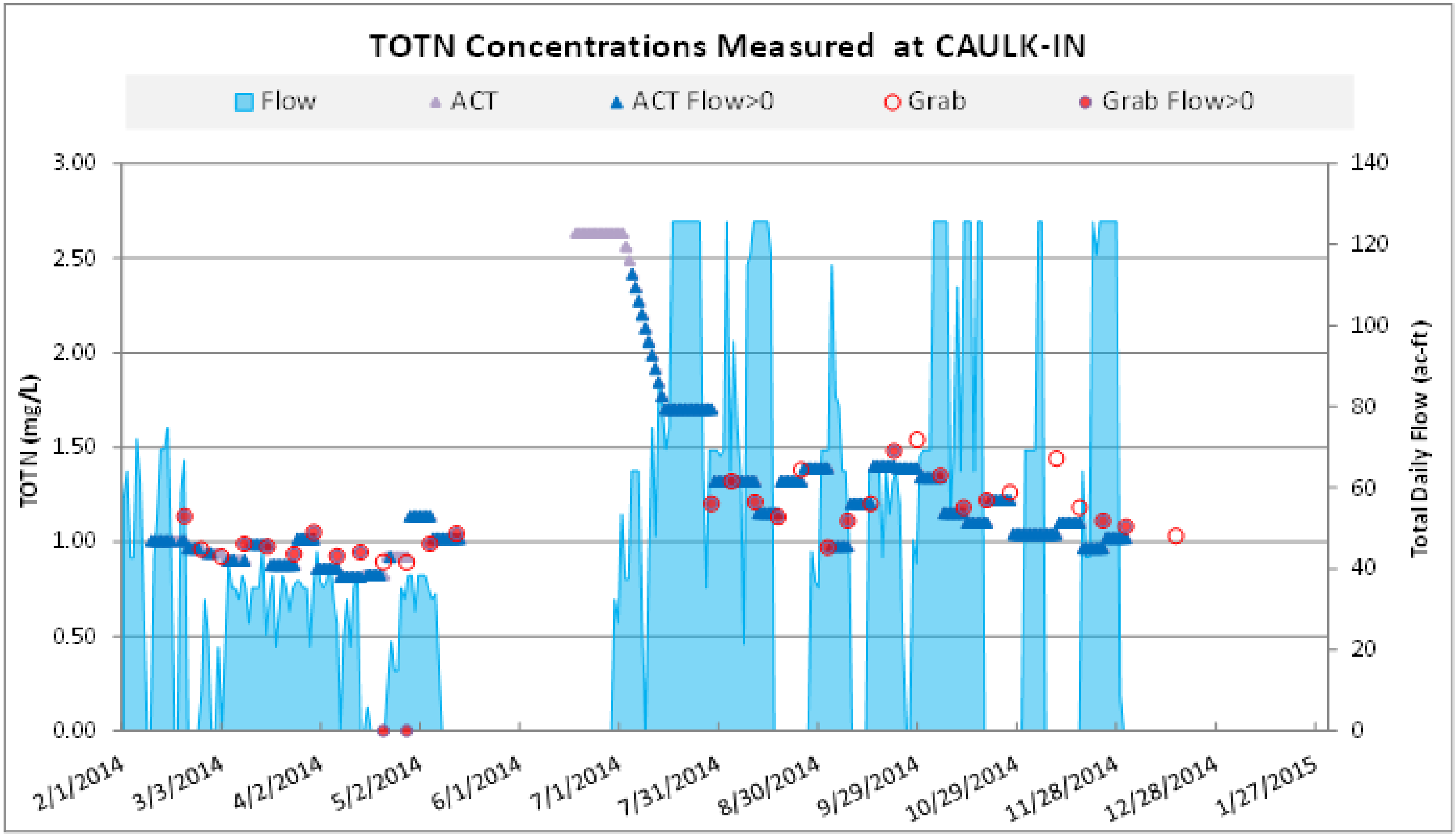

Figure A-4. Daily flow in acre-feet (ac-ft) and grab/ACT TOTN concentrations in milligrams per liter (mg/L) at CAULK-IN sampling site between February 2014 and January 2015.

Daily nutrient load is calculated as the product of daily flow and daily nutrient concentration. Daily flows pumped into the pilot project area are presented in the Hydrological Observations and Estimations section above. The nutrient concentrations are not measured daily and therefore they have been estimated using South Florida Water Management District protocols for load computation. In the current report, daily nutrient concentrations have been estimated separately based on grab samples and based on ACT samples. Grab samples on days without flow are ignored for load calculation. Daily nutrient concentrations estimated based on grab samples are calculated through linear interpolation between grab sample values occurring on days with flow. Daily nutrient concentrations estimated based on ACT samples are assumed to be equal to ACT sample value for up to fourteen days preceding the sample collection date. Daily nutrient concentrations estimated based on grab samples multiplied by daily flow generate grab nutrient loads and daily nutrient concentrations estimated based on ACT samples multiplied by daily flow generated ACT nutrient loads. The flow-weighted mean concentration (FWMC) of each parameter was calculated monthly as the ratio of monthly load and monthly flow. Total monthly flow, total monthly loads and FWMC for TPO4 and TOTN, using both sampling methods, are shown in **Tables A-6** and **A-7**, respectively.

Table A-6. Monthly inflow in acre-feet, TPO4 load in metric tons and TPO4 FWMC in milligrams per liter (mg/L) at sampling station CAULK-IN.

Month	Pump Inflow (acre-feet)	TPO4 Load ACT (metric tons)	TPO4 Load Grab (metric tons)	TPO4 FWMC ACT (mg/L)	TPO4 FWMC Grab (mg/L)
February 2014	850	0.122	0.136	0.116	0.130
March 2014	748	0.099	0.114	0.107	0.124
April 2014	679	0.082	0.137	0.098	0.164
May 2014	436	0.061	0.092	0.114	0.171
June 2014	0	0.000	0.000	NA	NA
July 2014	2,076	0.500	0.503	0.195	0.196
August 2014	1,804	0.383	0.509	0.172	0.229
September 2014	1,398	0.328	0.335	0.190	0.195
October 2014	1,980	0.395	0.479	0.162	0.196
November 2014	1,674	0.244	0.265	0.118	0.128
December 2014	9	0.001	0.001	0.094	0.111
January 2015	0	0.000	0.000	NA	NA
Total	**11,656**	**2.216**	**2.571**	**0.154**	**0.179**

Table A-7. Monthly inflow in acre-feet, TOTN load in metric tons and TOTN FWMC in milligrams per liter (mg/L) at sampling station CAULK-IN.

Month	Pump Inflow (acre-feet)	TOTN Load ACT (metric tons)	TOTN Load Grab (metric tons)	TOTN FWMC ACT (mg/L)	TOTN FWMC Grab (mg/L)
February 2014	850	1.03	1.17	0.98	1.12
March 2014	748	0.87	0.90	0.94	0.98
April 2014	679	0.71	0.80	0.85	0.96
May 2014	436	0.57	0.54	1.05	1.01
June 2014	0	0.00	0.00	NA	NA
July 2014	2,076	4.47	3.08	1.74	1.20
August 2014	1,804	2.78	2.68	1.25	1.20
September 2014	1,398	2.12	2.14	1.23	1.24
October 2014	1,980	2.86	3.07	1.17	1.26
November 2014	1,674	2.09	2.32	1.01	1.12
December 2014	9	0.01	0.01	1.02	1.08
January 2015	0	0.00	0.00	NA	NA
Total	**11,656**	**17.50**	**16.72**	**1.22**	**1.16**

In order to visualize the seasonal variability of the nutrients loads, **Figures A-5** and **A-6** represent the total monthly flow as well as the total TPO4 and TOTN monthly loads, respectively. As expected, increased flows produce increased nutrient loads, as seen for the interval between July and November 2014.

Figures A-7 and **A-8** represent the monthly input FWMC for TPO4 and TOTN at CAULK-IN from February 2014 to January 2015. Notice that for the analyzed interval, the increased flow registered from July through November is associated with increased nutrient FWMC. For comparison purposes, the plots in **Figures A-7** and **A-8** represent TPO4 and TOTN FWMC at the monitoring site C44S80. This monitoring site, located downstream of the WFPP area along the C-44 Canal, presents a similar pattern in which higher nutrient concentrations correspond to higher flows.

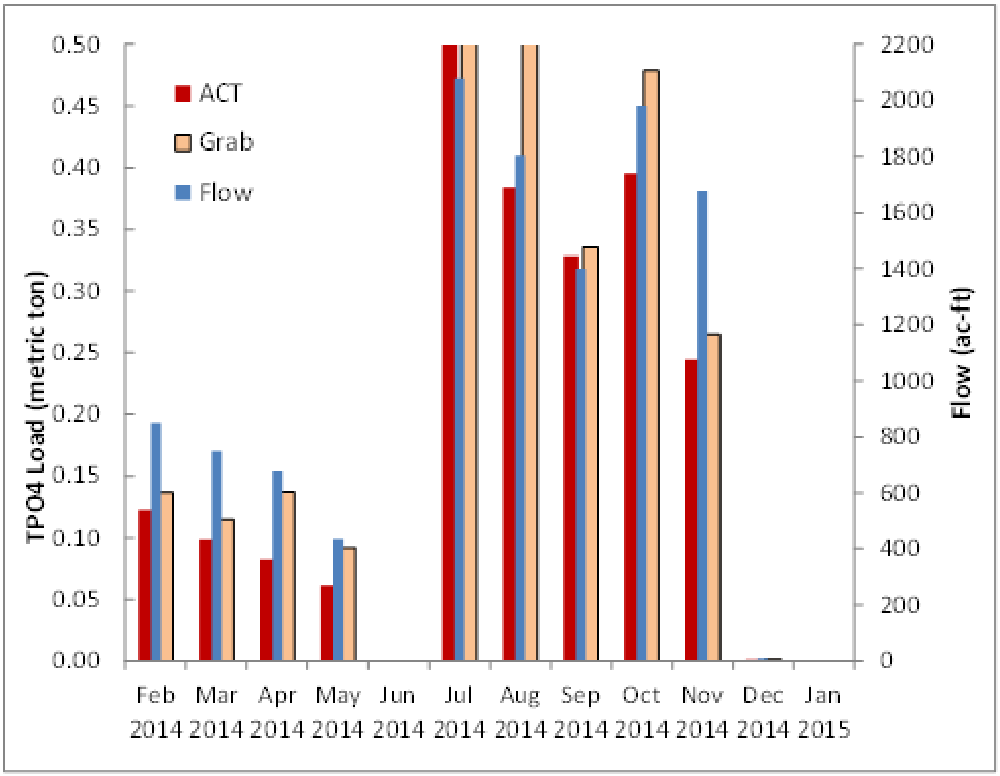

Figure A-5. Monthly inflow in acre-feet (ac-ft) and TPO4 loads in metric tons at CAULK-IN between February 2014 and January 2015.

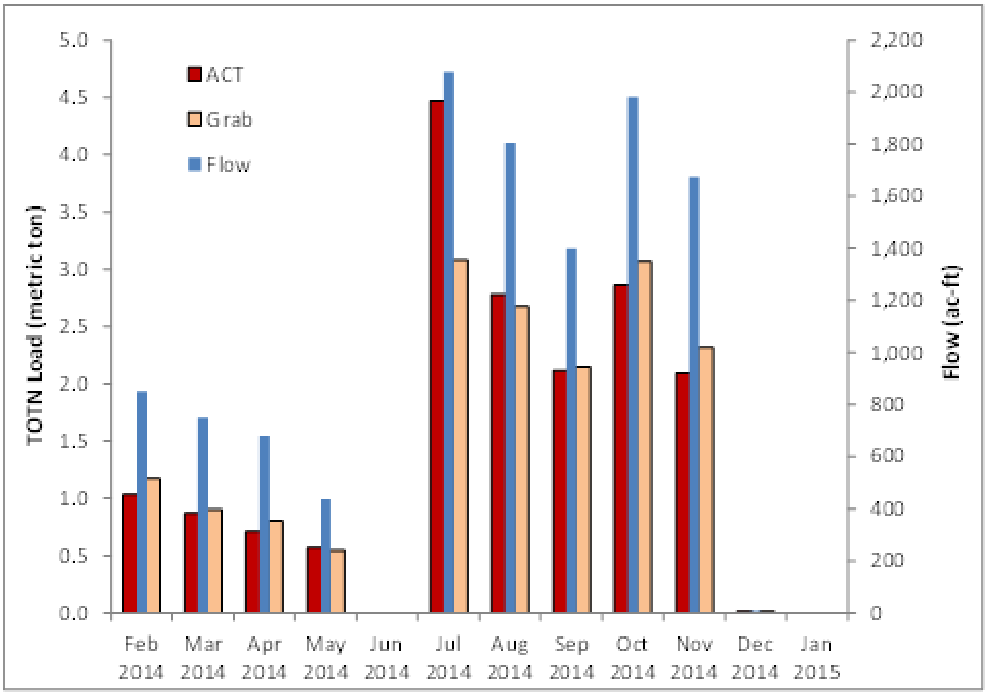

Figure A-6. Monthly inflow in acre-feet (ac-ft) and TOTN loads in metric tons at CAULK-IN between February 2014 and January 2015.

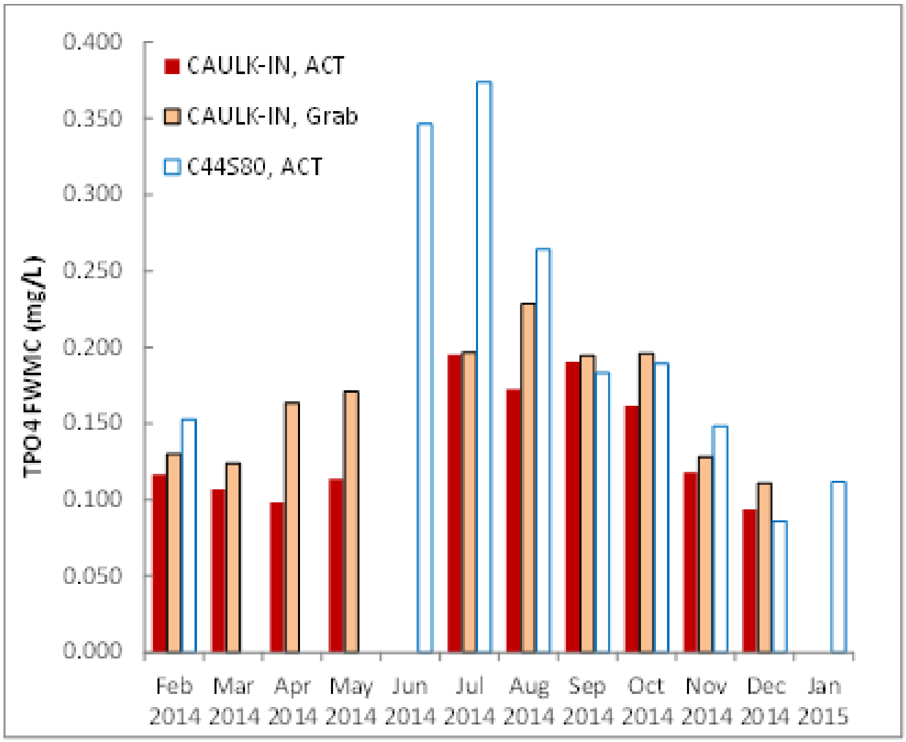

Figure A-7. Monthly TPO4 FWMC in milligrams per liter (mg/L) at CAULK-IN and C44S80 between February 2014 and January 2015.

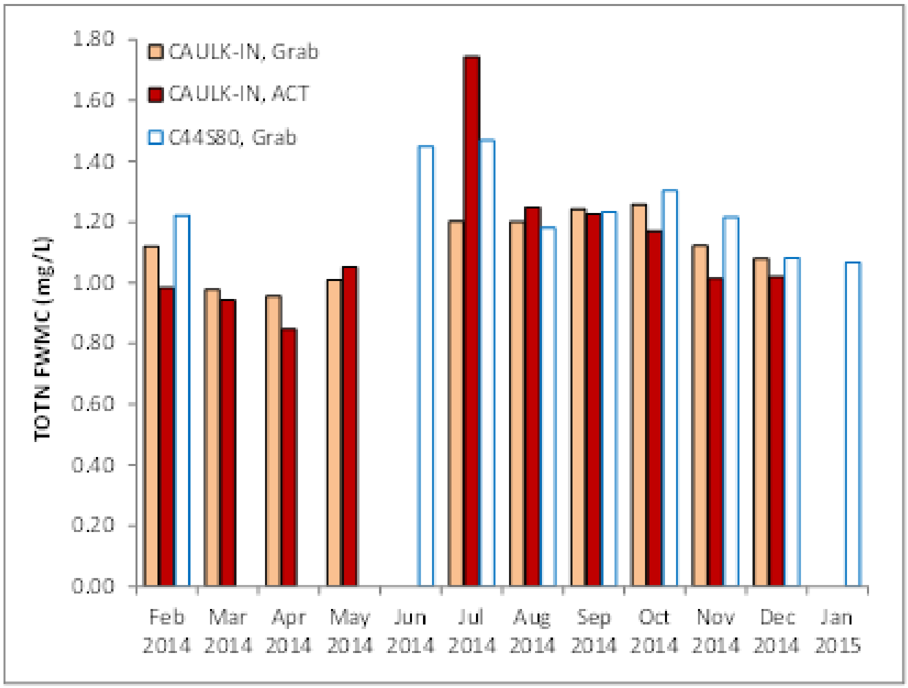

Figure A-8. Monthly TOTN FWMC in milligrams per liter (mg/L) at CAULK-IN and C44S80 between February 2014 and January 2015.

Table A-8 and **Figure A-9** present the monthly flow and average TSS concentrations at CAULK-IN from February 2014 to January 2015. While no correlation was observed between TSS concentrations and monthly flow, it is noteworthy to observe that TSS concentrations, similarly to TPO4 and TOTN concentrations, are the highest in July 2014, which is a month with high flow volume following a long dry period.

Table A-8. Monthly flow in acre-feet (ac-ft) and average TSS concentrations in milligrams per liter (mg/L) at CAULK-IN between February 2014 and January 2015.

Month	Pump inflow (acre-feet)	Number of TSS Records	Average TSS (mg/L)
February 2014	850	2	5.5
March 2014	748	5	7.6
April 2014	679	4	7.0
May 2014	436	2	9.0
June 2014	0	0	NA
July 2014	2,076	2	12.5
August 2014	1,804	4	4.8
September 2014	1,398	5	5.6
October 2014	1,980	4	3.8
November 2014	1,674	3	7.0
December 2014	9	2	3.0
January 2015	0	NA	NA
Total	**11,656**	**33**	**6.6**

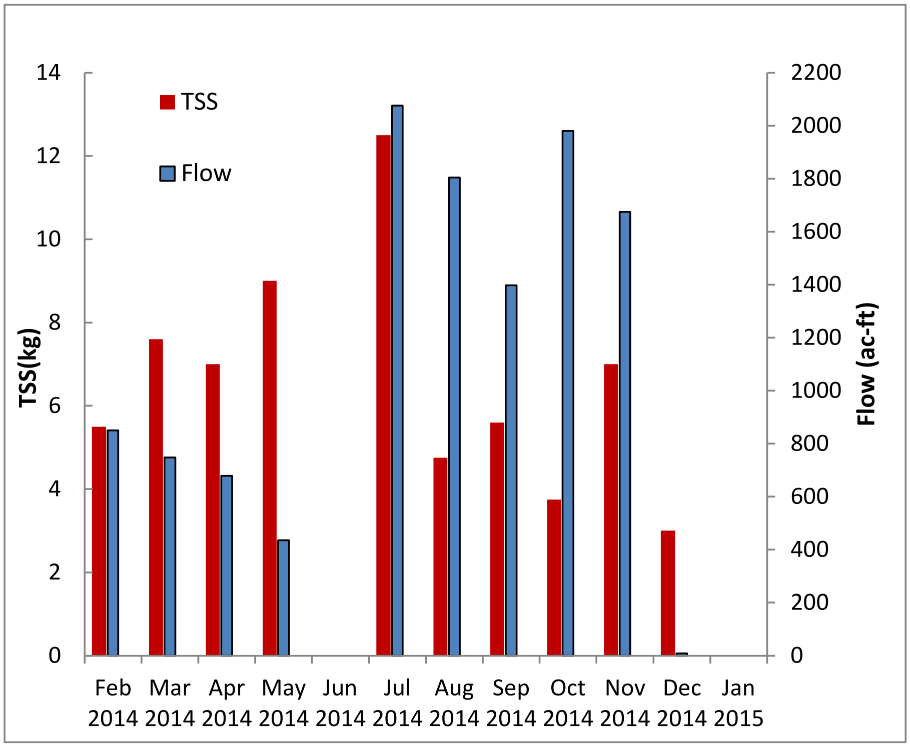

Figure A-9. Monthly flow in acre-feet (ac-ft) and average TSS in kilograms (kg) at CAULK-IN between February 2014 and January 2015.

Appendix B

Slug Tests and Aquifer Performance Tests

Slug Tests

Introduction

Ten slug tests were performed on wells on October 21 and 22, 2014, and a final slug test on February 19, 2015. The stages in the Caulkins Water Farm Pilot Project (WFPP) area on testing days were 28.83, 29.11 and 26.44 feet National Geodetic Vertical Datum of 1929 (NGVD29), respectively. 2.68 inches of rainfall fell on October 22 and 125.58 acre-feet of water was pumped into the WFPP on October 21, 2014, and February 19, 2015.

Methods

South Florida Water Management District (SFWMD) staff performed slug tests on all wells in the WFPP with the exception of the CAU-1 site on October 21 and 22, 2014. Wells CAU-1M, CAU-1D and CAU-1LD were tested on February 19, 2015, shortly after being constructed. An Insitu Troll™ 500 data logger was installed in each well to continuously collect water level data during each slug in and out test. Data were recorded until background conditions were reached. The Hvorslev (1951) analytical solution was applied to the data to determine hydraulic conductivity (K). It is based on the quasi-steady state (storage is negligible) slug test model that ignores elastic storage in the aquifer and is a straight line method used to analyze slug tests. This solution was used by previous researchers for analyses of C-44 Reservoir and Stormwater Treatment Area Project slug testing and is an industry standard. Aqtesolv Pro (Version 4.5) software (HydroSOLVE, Inc., 2007) was used to analyze the data.

Figure B-1. Locations of slug tests and aquifer performance tests (APTs) at the WFPP.

Three sets of analyses were done. In every analysis it is assumed that the saturated thickness of this aquifer is 131 feet below ground surface (bls). The differences in the approaches are as follows:

- For the first set, the K anisotropy ratio (vertical hydraulic conductivity [Kv]/horizontal hydraulic conductivity [Kh]) of the aquifer is assumed to be 1. These were compared with results using the Bouwer-Rice (1976) solution.
- Secondly, the slug tests were all reanalyzed including a clay layer of 2 to 10 feet in thickness depending on the lithology.
- The slug tests were run a third time assuming a K anisotropy ratio of 0.15 for shallow wells in the shallow interval. This is the average of field permeability tests for depths from 0 to 12 ft bls (USACE, 2014). For intermediate, deep and deep lower wells finished in deeper intervals, the assumed K anisotropy ratio is 0.03. This is the average from aquifer performance tests (APTs) for depths 40 to 80 feet bls (USACE, 2014). Both ratios are from field testing completed at the C-44 Reservoir and Stormwater Treatment Area.

Results

Table B-1 shows the results for K in feet per day (ft/d) for the slug testing at the WFPP for the first and third sets of analyses listed above. Comparison of results using the Bouwer-Rice (1976) solution revealed minimal differences. Solving with the clay layer did not make any appreciable difference to K values. These results are not included in the table.

Table B-1. Slug test results.

Well[a]	Slug In (ft/d)	Slug Out (ft/d)	Average K[b] (ft/d)	Slug In (ft/d)	Slug Out (ft/d)	Average K[c] (ft/d)	Difference in Average K
2S	26.20	28.69	27.45	42.74	44.11	43.43	15.98
3S	51.99	52.68	52.34	92.35	87.49	89.92	37.59
4S	108.90	61.97	85.44	150.20	84.25	117.23	31.79
5S	41.45	25.66	33.56	66.28	47.38	56.83	23.28
5M	5.22	4.50	4.86	8.78	7.91	8.35	3.49
6M	8.49	8.46	8.48	13.47	12.25	12.86	4.39
7M	12.76	66.05	39.41	21.10	94.10	57.60	18.20
5D	1.57	13.56	7.57	2.64	16.45	9.55	1.98
6D	2.30	2.35	2.33	3.92	3.75	3.84	1.51
7D	10.55	10.30	10.43	16.41	16.71	16.56	6.14
1LD	32.33	NA	32.33	49.24	NA	49.24	16.91

a. S indicates a shallow well, M an intermediate well, D a deep well and LD a lower deep well.

b. Amisotropy ratio of 1 (Kv/Kh) was used for analysis.

c. Anisotropy ratio of 0.15 (Kv/Kh) was used for analysis for shallow (S) wells – average of field permeability tests 0–12 ft bls (Ardaman & Associates, 2003) and 0.03 for intermdiate (M), deep (D) and lower deep (LD) wells – average from APTs 40–80 ft bls (CDM, 2004).

Analyses

For the first set of slug test analyses, the Hvorslev (1951) solution consistently gave slightly higher Ks when compared to Bouwer-Rice (1976) in each well. This is not significant given the fact that both solutions arrive at very similar values and are in the same order of magnitude. The inclusion of a thin aquitard in the second set of analyses contributed no appreciable change in results.

Adjusting the K anisotropy ratio in the third set of analyses to 0.03 for the shallow interval increased the calculated average K in this zone by approximately 59%. For the deeper zones, the change in ratio used in the solution increased the average K by 53% overall. While the percentage increases seem high, given the fact that the vast majority of K values remained in the same order of magnitude as the base case (ratio of 1), the difference in results is not significant. Slug testing is generally considered to provide reasonable estimates of the order of magnitude of K, but lack precision (Thompson, 1987).

Conclusions

The surficial aquifer system (SAS) below the WFPP is heterogeneous. A thin clay layer, silts and sands of varying particle size contribute to the spatial variation and make it difficult to compute Kv and Kh accurately. Slug testing adds to the uncertainty due to its imprecise results, but does provide reasonable "ballpark" estimates of K. The following ranges are suggested in **Table B-2** bearing in mind the aforementioned limitations. The values represent the minimum, maximum and average of the results from the third set of analyses for the shallow and deeper zones. The K anisotropy ratios (Kv/Kh) of 0.15 and 0.03 were derived from the *C-44 Reservoir/STA Geotechnical Data Report* (USACE, 2014; Table 6-2).

The overall average hydraulic conductivities from **Table B-2** are in the ballpark with the historical APT conducted in Caulkins Citrus Company Ltd. grove (Caulkins Citrus Grove) reported in Lukasiewicz and Adams-Smith (1996), which was 51 ft/d. The production interval for the historical Caulkins test was 120 feet thick. The shallow zone wells had a test interval of 2 feet. All other zones had tested intervals of 10 feet. It is likely that the three lower zones fell within the interval tested historically.

Table B-2. K ranges (ft/d) and ratios for Caulkins Citrus Grove.

Zone	Interval (ft bls)	K Minimum	K Maximum	K Average	Kv/Kh
Shallow	0 - 13	43	117	77	0.15
Intermediate	13 - 40	8	58	26	0.03
Deep	40 - 95	4	17	10	0.03
Lower Deep	95 - 145	N/A[a]	N/A	49	0.03

a. N/A – not available

Aquifer Performance Tests

Introduction

Four APTs were performed on the central cluster of wells (site CAU-1) in the WFPP on March 18, 2015. The reservoir stage was 28.83 feet NGVD29 and 106.87 acre-feet (ac-ft) of water were pumped into the water farm on the test day. An additional APT was performed on CAU-1D on May 27, 2015.

Methods

SFWMD staff performed APTs on the four wells at site CAU-1 located in the center of the WFPP. The tests were completed on March 18, 2015. In situ Troll™ data loggers were installed in each well and water level data were continuously collected for the duration of the four tests and their recovery periods. Manual water levels measurements were also taken before the start of each test. Data were recorded until each well recovered close to background conditions after pumping, then the pump was moved on to the next well, progressing from the deepest to most shallow. The first well pumped was 1LD at a rate of 8 gallons per minute (gpm). Next the pump was moved to 1D and this well was pumped at a rate of 1.5 gpm. Thirdly, well 1M was pumped at 3.5 gpm. The laptop battery failed during the latter part of the recovery component of this test, so some data is missing from all of the trolls during this time. The final well tested was 1S. After about one minute, it had been pumped dry, so the test was stepped into recovery at that point and data collected until the water level returned to background conditions.

Once the field component of the task was complete, the data were downloaded and graphed. Next, the displacement and drawdown data were formatted for input into Aqtesolv Pro (Version 4.5). This software was used to analyze the data. There was significant “noise” in the derivative data for each APT. The derivative curve is useful when taken together with the drawdown curve in selecting which solutions to apply. Therefore, the derivative curves were smoothed using the Bourdet method (Bourdet et al., 1989) to determine the general shape. A log cycle time of 0.5 was used for smoothing to minimize distortion of the derivative data (Horne, 1995). Once the smoothed derivative curves were plotted together with their associated drawdown, these diagnostic plots were used to select the appropriate solutions for analysis. The reader is referred to Renard et al. (2009) for the specifics of this methodology.

The APTs were analyzed assuming a K anisotropy ratio of 0.15 for shallow wells in the shallow interval. This is the average of field permeability tests for depths from 0 to 12 feet bls (Ardaman and Associates, 2003). For intermediate, deep and deep lower wells finished in deeper intervals, the assumed K anisotropy ratio is 0.03. This is the average from APTs for depths 40 to 80 feet bls (USACE, 2014). Both ratios are from field testing completed at the C-44 Reservoir and Stormwater Treatment Area.

Results

Figures B-2 through **B-5** show the drawdown of the pumped well and the three other observation wells for each APT. They are presented in the order they were executed in the field—the deepest well being pumped first. **Figure B-6** shows the plot drawdown and its derivative for Pump Test 1LD with and without derivative curve smoothing. The curve smoothing approach was applied to the derivative data for each APT.

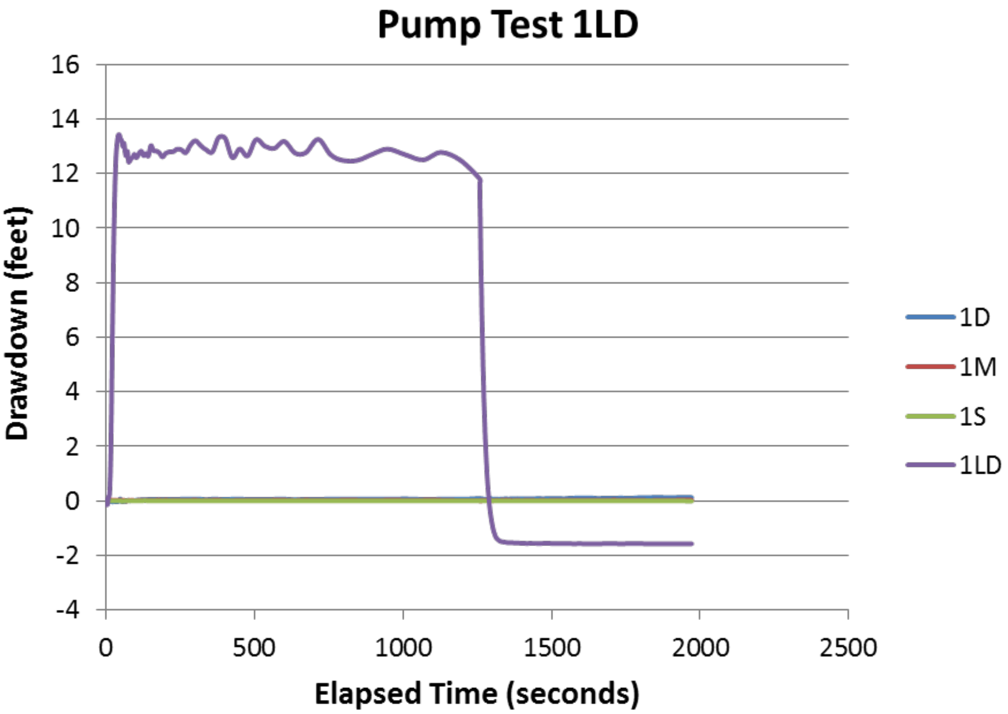

Figure B-2. Drawdown and observation of well responses to APT 1LD.

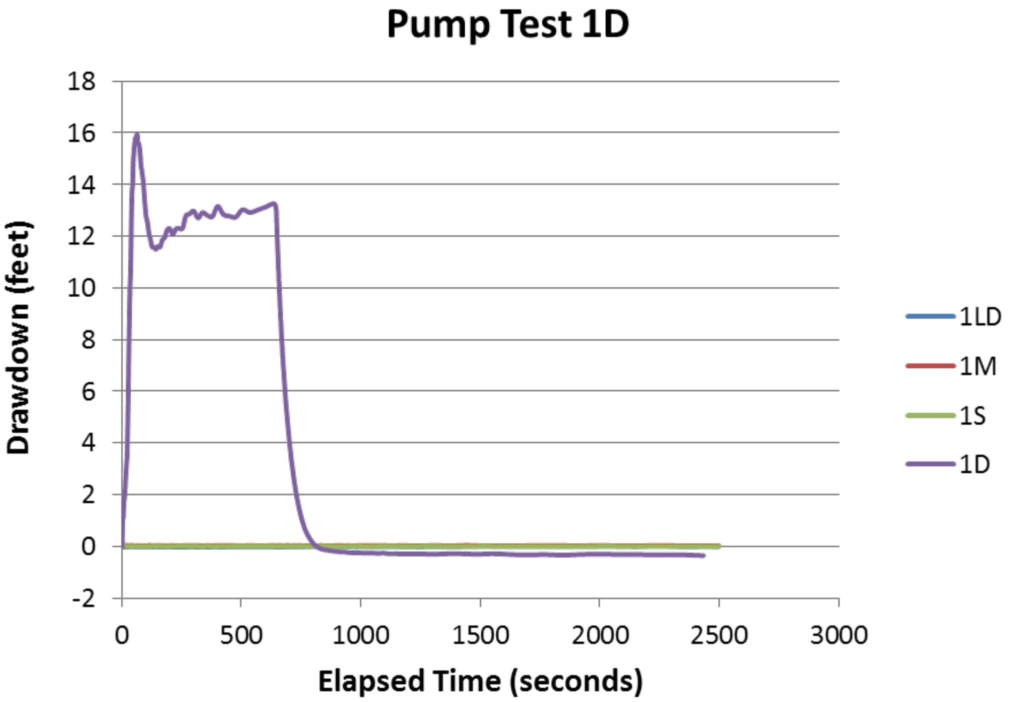

Figure B-3. Drawdown and observation well responses to APT 1D.

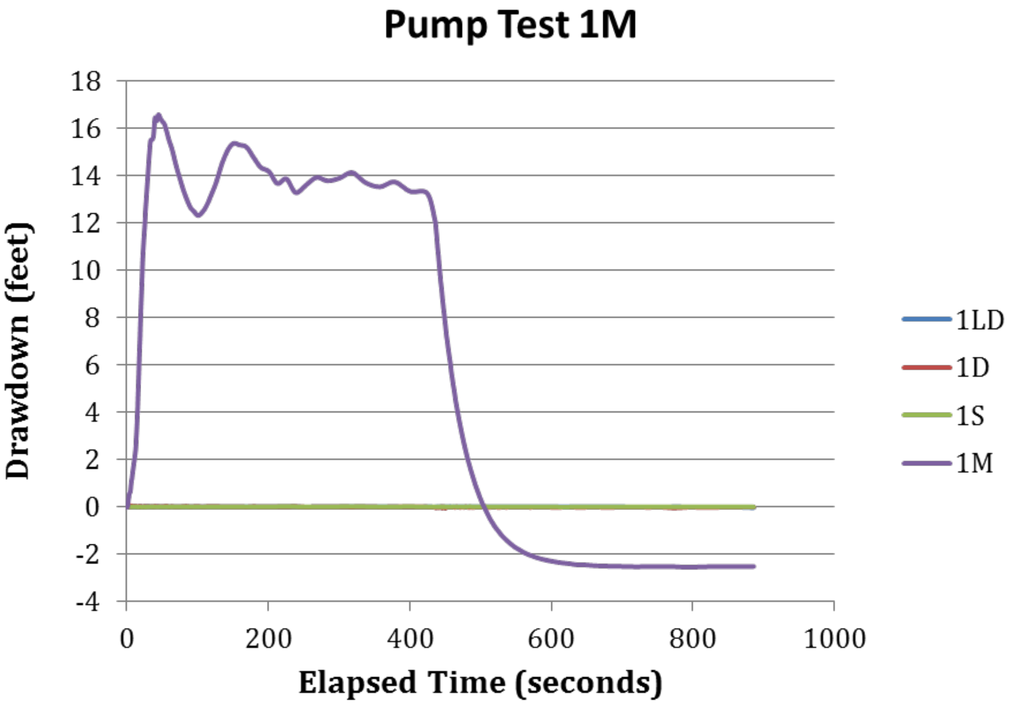

Figure B-4. Drawdown and observation well responses to APT 1M.

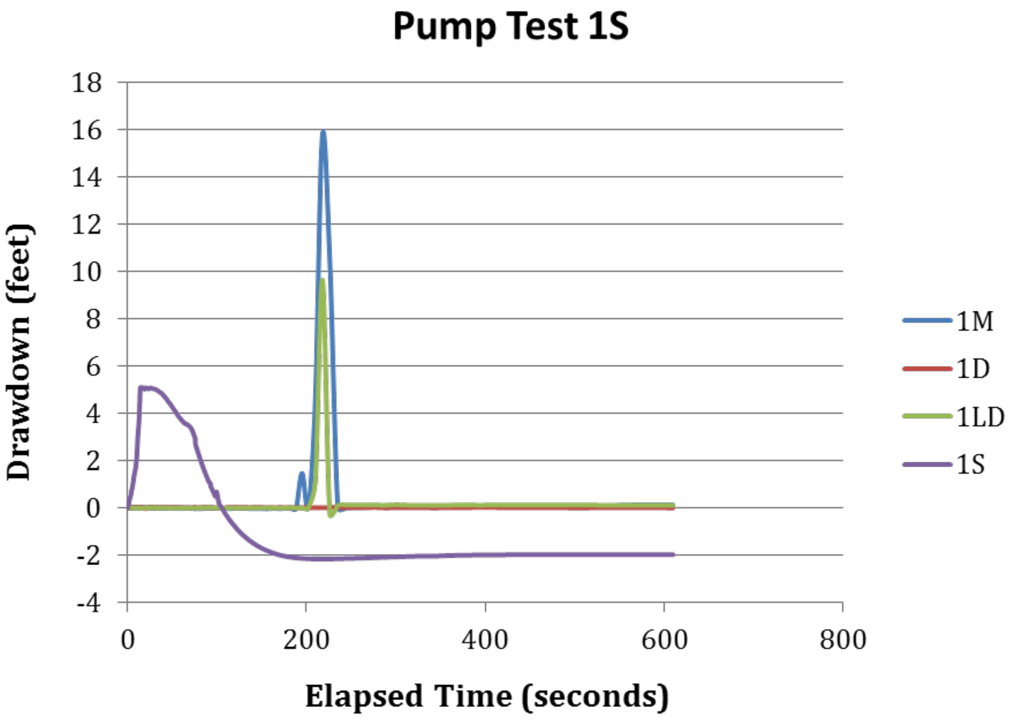

Figure B-5. Drawdown and observation well responses to APT 1S.

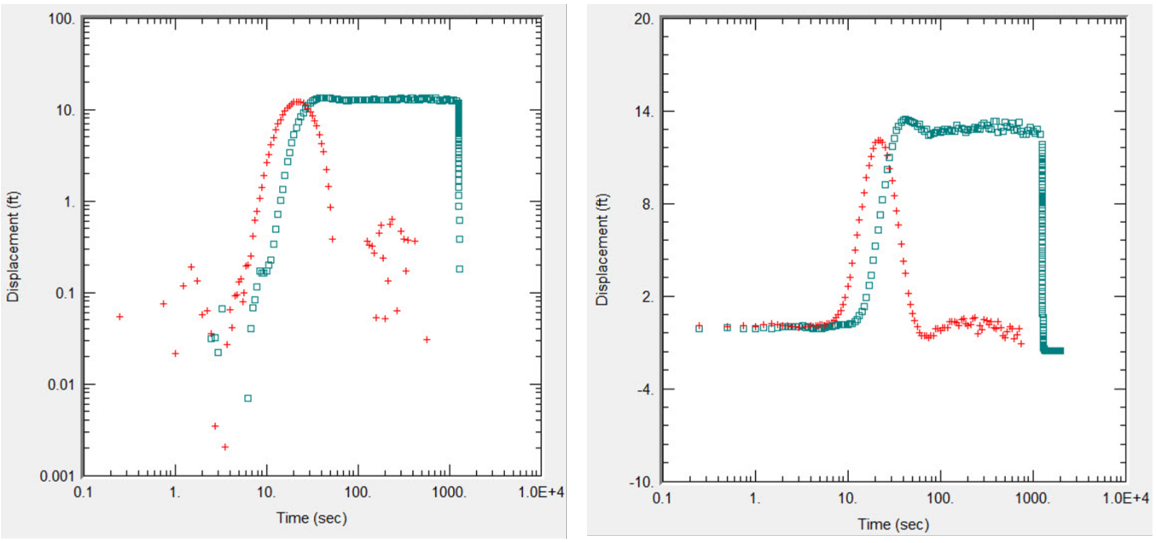

Figure B-6. Plot of APT 1LD displacement versus time without derivative smoothing (left) and with smoothing (right).

Well 1LD recovered to a water level approximately 1.6 feet higher than the beginning of the pump test. The duration of the pumping was approximately 21 minutes. There was no significant change in any of the observation well water levels during this 33-minute test. Single well pump test analysis is appropriate with these test results.

Well 1D recovered to a slightly higher water level than that at the beginning of the APT. The pumping phase lasted approximately 11 minutes and the test had a total duration of 41 minutes. No discernable displacement was noted in any of the observation wells. Again, single well pump test analysis is necessary.

APT 1M groundwater levels recovered to a shallower depth than initial conditions. The pumping phase lasted approximately 7 minutes and recovery data collection was briefer than planned due to equipment failure about 15 minutes into the test. Single well pump test analysis is also appropriate for 1M.

After approximately one minute of pumping, 1S was dry. The APT was stepped into recovery and data collect for a total of 10 minutes. This well recovered to a groundwater depth approximately 2 feet higher than the initial reading. There were major "spikes" in water level data in Test 1S observations wells 1M (16 feet) and 1LD (9 feet) during the recovery period. These were considered erroneous and removed from the data set. The anomalies during the recovery period in observation well data sets for 1M and 1LD are of concern and 1D showed no appreciable change in water level. Single well pump test analysis is also the preferred approach with this data set.

The Bourdet et al. (1989) derivative curve smoothing method was applied to the derivative data for each APT. This approach produces a better diagnostic plot for analysis. **Figure B-7** shows the log linear plot of displacement versus the elapsed time for APT 1LD without smoothing on the right and with smoothing (0.5 log time) on the left. The displacement is depicted in green squares and the corresponding derivatives are red crosses.

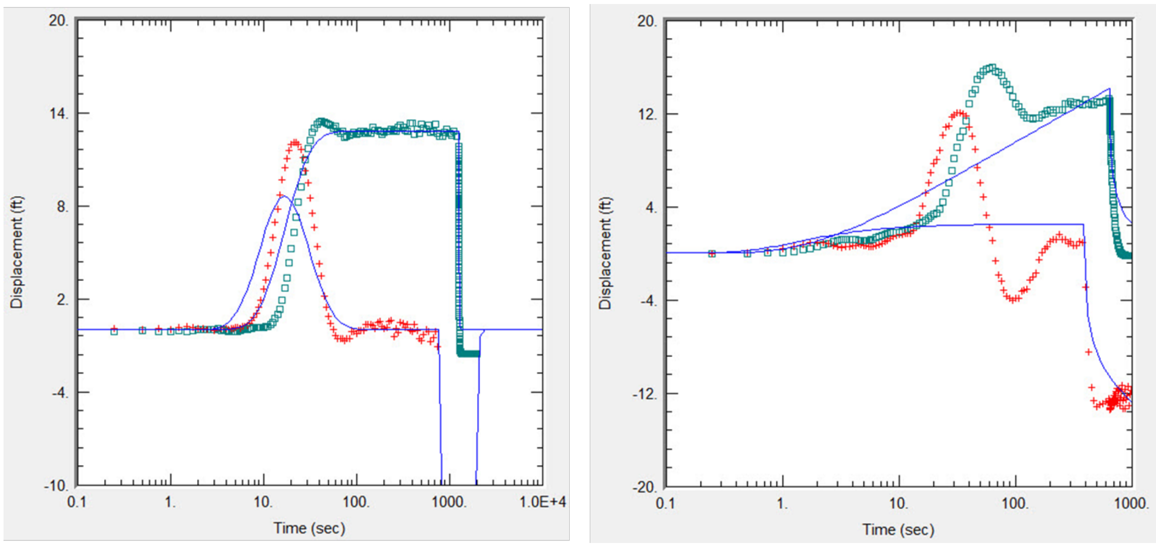

Figure B-7. Results for APT 1LD curve matching (left) and APT 1D (right) using the Hantush-Jacob (1955) solution.

The displacement versus time graphs for APTs 1LD, 1D and 1M all plot like a leaky aquifer. Potential solutions for leaky aquifers include Hantush-Jacob (1955), Hantush

(1960) Cooley-Case (1973), Neuman-Witherspoon (1969) and Moench (1985). **Table B-3** documents the results for the above three APTs using these solutions.

Table B-3. APT 1LD, 1D and 1M results.

Solution	K (ft/d) for APTs					
	1LD	Notes	1D	Notes	1M	Notes
Hantush-Jacob	13	fair match	40	very poor match	42	poor match
Hantush	1	poor match	24	very poor match	2	very poor match
Cooley-Case	1	poor match	25	very poor match	1	very poor match
Neuman-Witherspoon	2	poor match	24	very poor match	1	very poor match
Moench	8	very poor match	23	very poor match	7	very poor match
Average	**5**		**27**		**11**	

APT 1S is treated as an unconfined aquifer for analyses. The bottom of the casing (9.5 feet bls) is at the top of a clay layer, so this is assumed to be the base of the aquifer in these analyses. Cooper-Jacob (1946), Neuman (1974) and Moench (1997) solutions were used in analyses for this test. The results are presented in Error! Not a valid bookmark self-reference..

Table B-4. APT 1S results.

Solution	K (ft/d) APT 1S	Notes
Cooper-Jacob	3	very poor match
Neuman	5	very poor match
Moench	21	very poor match
Average	**10**	none

Figure B-7 shows the solution and data curve matching using the Hantush-Jacob (1955) for 1LD and 1D. **Figure B-8** shows the results for curve matching for APT 1M using the Hantush-Jacob (1955) and 1S using the Neuman (1974) solutions. The green squares represent the displacement data in the pumped well, the red crosses are the smoothed derivative data and the blue lines are the lines data are expected to fall along with the solution being applied.

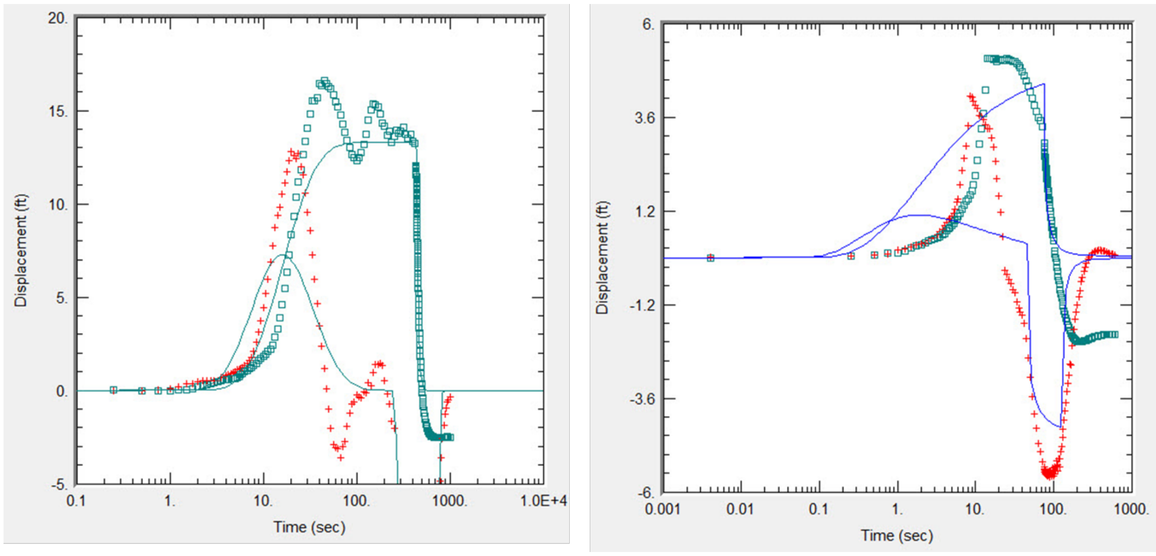

Figure B-8. Results for APT 1M curve matching (left) using Hantush-Jacob (1955) and APT 1S (right) using Neuman (1974) solutions.

Analysis

While none of the APTs fitted precisely along the curve of any solutions, for the most part, they followed the general shape. All analyses were done as single well tests as there were no useable observation well data. Other contributing factors impacting curve matching include the fact that in all tests, the initial and final water depths differed, particularly in the 1M and 1S APTs. The additional water being pumped into the WFPP during testing also introduces a margin of error.

When comparing the APT results with the slug tests also conducted on the WFPP, it is important to note that slug tests are generally considered to provide reasonable estimates of order of magnitude for K (Thompson, 1987). Both the intermediate and deep wells are in close agreement for the tests conducted on-site.

Off-Site Hydraulic Conductivity Data

According to Driscoll (1986), K in sediments consisting of fine sand, silty sand, sandy silt, and clayey sands, similar to those within the shallow SAS (upper 13 feet), range from approximately 0.003 to 30 ft/d, and for silty sands, fine sand and well sorted sands, similar to those within the remainder of the SAS, range from approximately 0.03 to 300 ft/d. Todd (1980), estimates the anisotropy ratio for Kv to Kh falls between 0.5 and 0.1 for alluvial deposits but may range upwards of 0.01 if clay is present. Estimates for K in the project area were developed during development and calibration of the Martin County Surficial Aquifer System Model (Adams, 1992). Hydraulic conductivities in the vicinity of the WFPP were approximately 20 ft/d, 50 ft/d and 20 ft/d for Layers 1, 2 and 3 respectively. The vertical anisotropy of all layers was assumed to be 0.1 ft/d.

Off-site K tests in the area included slug tests, APTs and laboratory permeability tests in the footprint of the planned C-44 Reservoir and Stormwater Treatment Area (USACE, 2014) approximately one-half to 5 miles west of the site (USACE, 2014), and one APT conducted by SFWMD approximately one mile north of the WFPP (Lukasiewicz and Adams-Smith, 1996). These tests are described below.

Laboratory K tests were conducted at samples from 26 soil borings at the planned C-44 Reservoir and Stormwater Treatment Area Project site. Soil samples were collected from depths of 0 to 12 feet bls, representative of the shallow SAS interval, and were described as predominately clayey sand, consistent with the shallow lithology underlying the WFPP. Laboratory K tests were conducted using a flexible wall permeameter in accordance with American Society for Testing and Materials D-5084 (2005), yielding a mean Kv of 0.10 ft/d with a range of 0.003 to 1.219 ft/d.

Two, 24-hour APTs were conducted approximately 3 and 4 miles northwest and southwest of the WFPP, respectively. The production well screen intervals were from 35 to 137.5 bls, representative of the intermediate, deep and lower deep SAS. Each test included one observation well. The mean average K was 24 ft/d with Kv of 0.7 ft/d.

SFWMD conducted an APT on the Caulkins Citrus Grove approximately one mile north of the WFPP. The test consisted of 19 hours of pumping of a production well screened from 30 to 110 feet bls and a deep observation well screened from 40 to 160 feet bls. A shallow observation was also used; however, the depth is not known. The test zone is representative of the intermediate, deep and lower deep sections of the SAS. Test results estimated a transmissivity of approximately 46,084 gallons per day per foot (51 ft/d) using the Neuman (1974) solution method.

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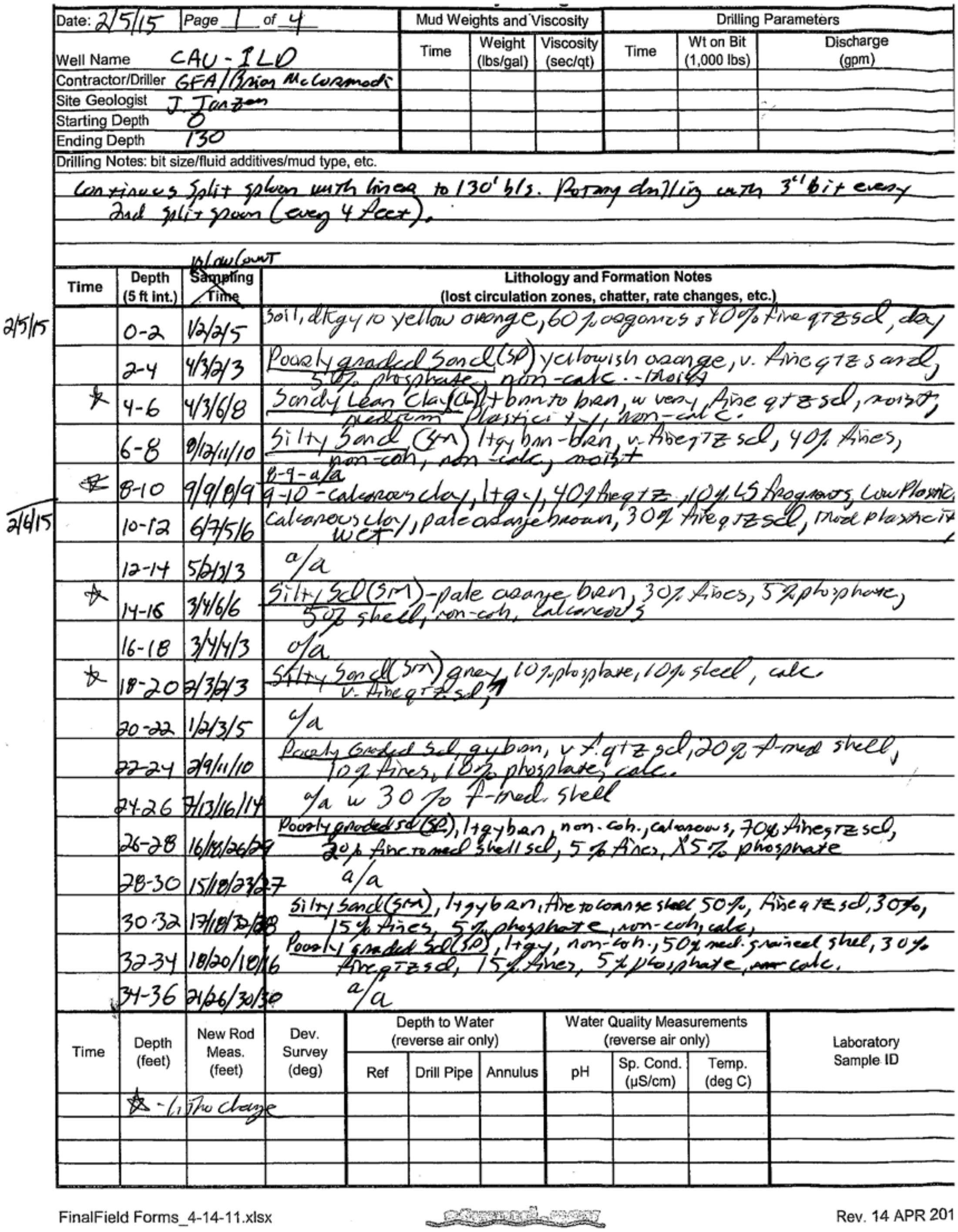
Appendix C

Lithographic Descriptions



		Mud Weights and Viscosity			Drilling Parameters		
Date: 2/5/15	Page 1 of 4	Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)
Well Name CAU-ILD							
Contractor/Driller GFA/Brian McCormack							
Site Geologist J. Janzen							
Starting Depth 0							
Ending Depth 130							

Drilling Notes: bit size/fluid additives/mud type, etc.

Continuous split spoon with liner to 130' bls. Rotary drilling with 3" bit every 2nd split spoon (every 4 feet).

Time	Depth (5 ft int.)	Blow Count ~~Sampling Time~~	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
2/5/15	0-2	1/2/2/5	Soil, dk gy to yellow orange, 60% organics, 40% fine qtz sd, dry
	2-4	4/3/2/3	Poorly graded Sand (SP) yellowish orange, v. fine qtz sand, 5% phosphate, non-calc. - moist
★	4-6	4/3/6/8	Sandy Lean Clay (CL) lt brn to brn, w very fine qtz sd, moist, medium plasticity, non-calc.
	6-8	9/12/11/10	Silty Sand (SM) lt gy brn-brn, v. fine qtz sd, 40% fines, non-coh, non-calc, moist
★	8-10	9/9/8/9	8-9 - a/a 9-10 - calcareous clay, lt gy, 40% fine qtz, 10% LS fragments, Low Plastic
2/6/15	10-12	6/7/5/6	Calcareous clay, pale orange brown, 30% fine qtz sd, mod plasticity wet
	12-14	5/2/3/3	a/a
★	14-16	3/4/6/6	Silty Sd (SM) - pale orange brn, 30% fines, 5% phosphate, 5% shell, non-coh, calcareous
	16-18	3/4/4/3	a/a
★	18-20	2/3/2/3	Silty Sand (SM) grey, v. fine qtz sd, 10% phosphate, 10% shell, calc.
	20-22	1/2/3/5	a/a
	22-24	2/9/11/10	Poorly Graded Sd, gy brn, v f. qtz sd, 20% f-med shell, 10% fines, 10% phosphate, calc.
	24-26	7/13/16/14	a/a w 30% f-med. shell
	26-28	16/18/26/29	Poorly graded sd (SP), lt gy brn, non-coh., calcareous, 70% fine qtz sd, 20% fine to med shell sd, 5% fines, <5% phosphate
	28-30	15/18/23/27	a/a
	30-32	17/18/20/28	Silty Sand (SM), lt gy brn, fine to coarse shell 50%, fine qtz sd, 30%, 15% fines, 5% phosphate, non-coh, calc,
	32-34	18/20/18/16	Poorly graded Sd (SP), lt gy, non-coh., 50% med. grained shell, 30% fine qtz sd, 15% fines, 5% phosphate, ~~non~~ calc.
	34-36	21/26/30/30	a/a

				Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			
Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	Laboratory Sample ID
	★ - Litho change									

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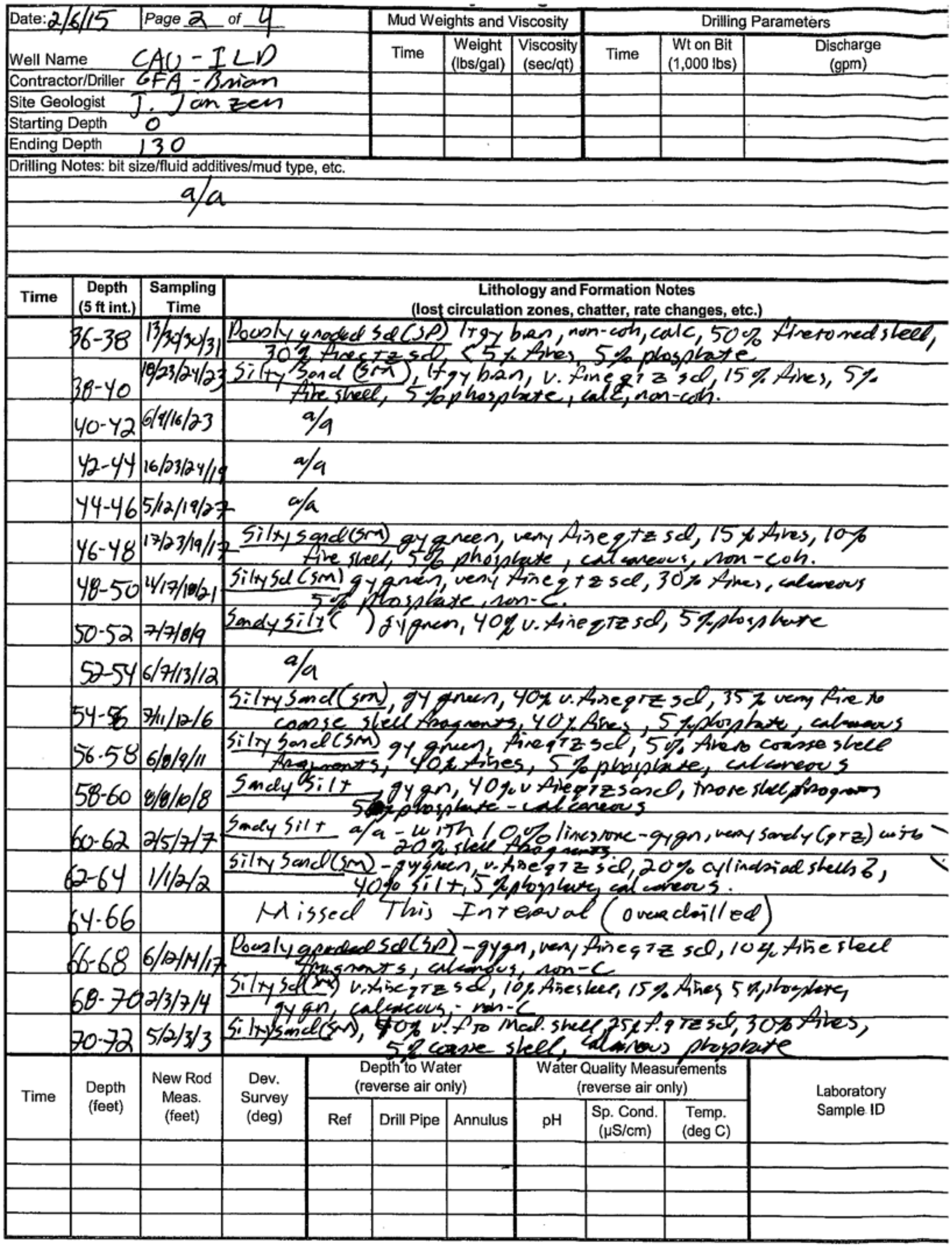


		Mud Weights and Viscosity			Drilling Parameters		
Date: 2/6/15	Page 2 of 4						
		Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)
Well Name	CAU-ILD						
Contractor/Driller	GFA - Brian						
Site Geologist	J. Janzen						
Starting Depth	0						
Ending Depth	130						

Drilling Notes: bit size/fluid additives/mud type, etc.

a/a

Time	Depth (5 ft int.)	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	36-38	13/30/30/31	Poorly graded sd (SP) lt gy brn, non-coh, calc, 50% fine to med shell, 30% fine qtz sd, <5% fines, 5% phosphate.
	38-40	18/23/24/23	Silty Sand (SM), lt gy brn, v. fine qtz sd, 15% fines, 5% fine shell, 5% phosphate, calc, non-coh.
	40-42	6/9/16/23	a/a
	42-44	16/23/24/19	a/a
	44-46	5/12/19/27	a/a
	46-48	17/23/19/17	Silty sand (SM) gy green, very fine qtz sd, 15% fines, 10% fine shell, 5% phosphate, calcareous, non-coh.
	48-50	4/17/10/21	Silty Sd (SM) gy green, very fine qtz sd, 30% fines, calcareous 5% phosphate, non-C.
	50-52	7/7/8/9	Sandy Silt ( ) gy green, 40% v. fine qtz sd, 5% phosphate
	52-54	6/7/13/12	a/a
	54-56	7/11/12/6	Silty Sand (SM), gy green, 40% v. fine qtz sd, 35% very fine to coarse shell fragments, 40% fines, 5% phosphate, calcareous
	56-58	6/8/9/11	Silty Sand (SM) gy green, fine qtz sd, 5% fine to coarse shell fragments, 40% fines, 5% phosphate, calcareous
	58-60	8/8/10/8	Sandy Silt gy grn, 40% v fine qtz sand, trace shell fragments 5% phosphate - calcareous
	60-62	2/5/7/7	Sandy Silt a/a - with 10% limestone - gy grn, very sandy (qtz) with 20% shell fragments
	62-64	1/1/2/2	Silty Sand (SM) - gy green, v. fine qtz sd, 20% cylindrical shells ?, 40% silt, 5% phosphate, calcareous.
	64-66		Missed This Interval (overdrilled)
	66-68	6/12/14/17	Poorly graded Sd (SP) - gy gn, very fine qtz sd, 10% fine shell fragments, calcareous, non-c
	68-70	2/3/7/4	Silty Sd (SM) v. fine qtz sd, 10% fine shell, 15% fines 5% phosphate, gy gn, calcareous - non-c
	70-72	5/2/3/3	Silty sand (SM), 40% v. f to med. shell 25% f. qtz sd, 30% fines, 5% coarse shell, calcareous phosphate

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

FinalField Forms_4-14-11.xlsx

Rev. 14 APR 2011

Date: 2/6/15 | Page 3 of 4

Well Name CAU-ILD

Contractor/Driller GEA - Brian

Site Geologist I. Janzen

Starting Depth 0

Ending Depth 130

Mud Weights and Viscosity			Drilling Parameters		
Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc.

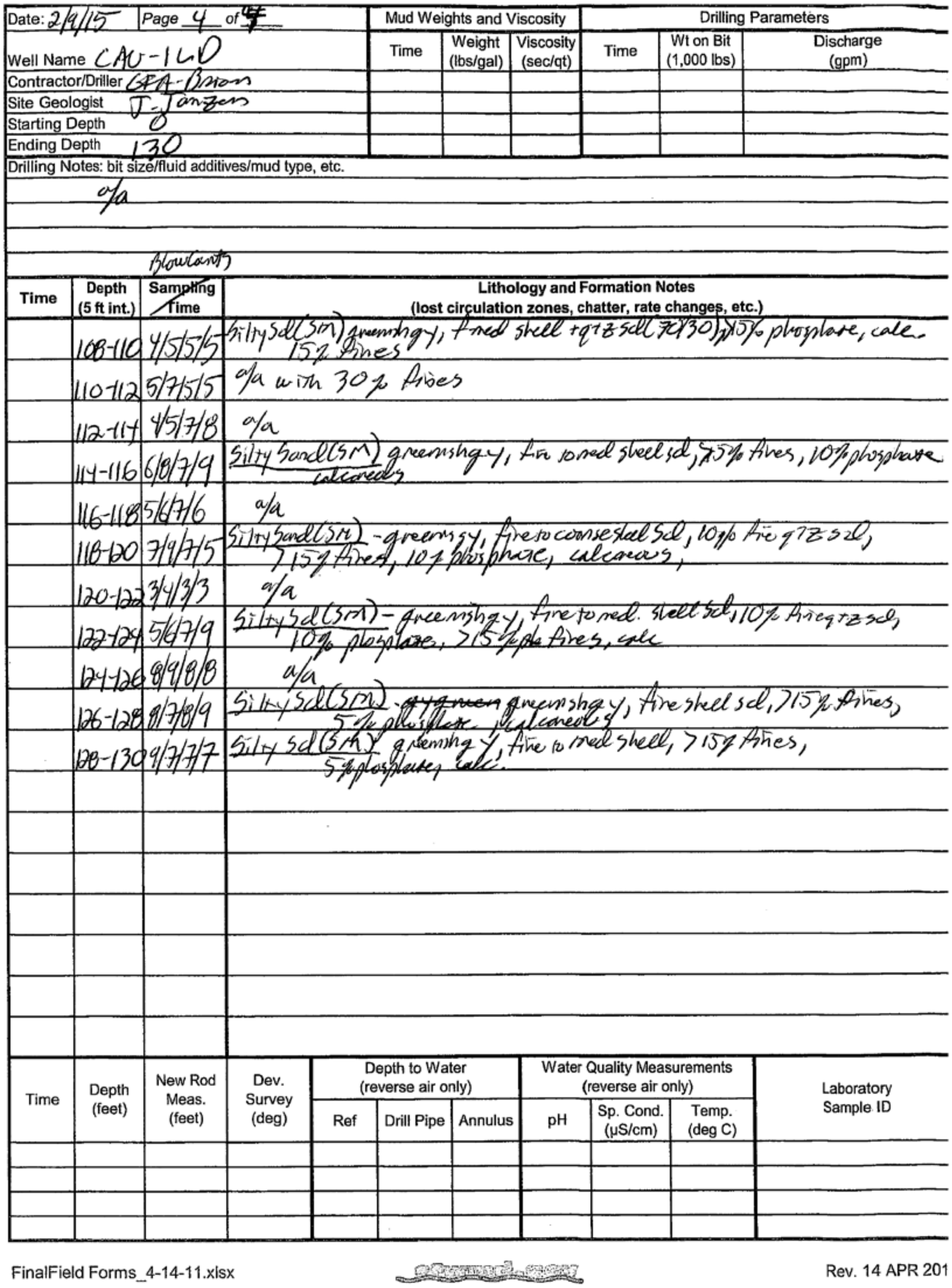
o/a

Time	Depth (5 ft int.)	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	72-74	12/10/9/12	Silty sd(SM), 80% fine-med shell, 20% fine qtz sd, 15% fines, 5% phosp gygn, calc.
	74-76	9/11/10/11	o/a
	76-78	0/4/9/10	Silty Sd(SM) - gy gn to pale brn, 70% f to med shell, 20% fine qtz sd, 5% gravel sized shell, 5% phosphate, calcareous
	78-80	10/11/15/14	o/a with 50% fine qtz sd.
	80-82	11/12/11/14	o/a
	82-84	11/10/8/10	Silty sd & Gravel(SM), gy green, fine sand & gravel sized shell, 10% fine qtz sd, 15% fines, 5% phosphate, calc.
☆	84-86	11/12/15/18	o/a with 20% coquina - shell + qtz sd o/a
	86-88	26/26/23/24	Silty Sand - fine to med shell + fine qtz sd (50/50), >15% fines, gy green 10% phosphate, calc,
	88-90	14/15/15/11	o/a
	90-92	8/8/10/11	Poorly Graded Sd(SP) - gygn, fine shell + qtz sand (70/30); <5% fines, calc.
	92-94	8/8/7/6	o/a w. fine to med. shell sd, 10% phosphate
	94-96	7/9/9/7	o/a w 5% phosphate
	96-98	2/5/5/5	Silty Sd(SM) gygn, fine-med shell sd, 20% fine qtz, 5% phospha calc,
	98-100	5/6/4/5	Poorly graded sd(SP) - pale brn to gygn, vf to f shell sd, 5% med to coarse shell, 5% phosphate, <5% fines, calc.
	100-102	8/8/8/8	Silty Sd(SM) - pale brn to gygn, f to Coarse shell sd, 20% fine qtz sd, >15% fines, 5% phosphate, calc
	102-104	8/16/21/15	o/a with fine shell + qtz sd (50/50)
	104-106	7/9/9/7	o/a
	106-108	9/9/10/8	Silty sd(SM) - greenish gy, fine to medium shell sd and qtz sd (70/30) 15% phosphate, calc, 15% fines

2/6/15

2/9/15

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	



Date: 2/9/15	Page 4 of 4
Well Name	CAU-14D
Contractor/Driller	GFA-Brown
Site Geologist	J. Janzen
Starting Depth	0
Ending Depth	130

Mud Weights and Viscosity

Time	Weight (lbs/gal)	Viscosity (sec/qt)

Drilling Parameters

Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc.

a/a

Time	Depth (5 ft int.)	Blowcounts Sampling ~~Time~~	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	108-110	4/5/5/5	Silty Sd (SM) greenish gy, f-med shell + qtz sd (70/30), 15% phosphate, calc. 15% fines
	110-112	5/7/5/5	a/a with 30% fines
	112-114	4/5/7/8	a/a
	114-116	6/8/7/9	Silty Sand (SM) greenish gy, fn to med shell sd, >15% fines, 10% phosphate calcareous
	116-118	5/6/7/6	a/a
	118-120	7/9/7/5	Silty Sand (SM) - greenish gy, fine to coarse shell sd, 10% fine qtz sd, >15% fines, 10% phosphate, calcareous,
	120-122	3/4/3/3	a/a
	122-124	5/6/7/9	Silty Sd (SM) - greenish gy, fine to med. shell sd, 10% fine qtz sd, 10% phosphate, >15% ~~ph~~ fines, calc
	124-126	8/9/8/8	a/a
	126-128	8/7/8/9	Silty Sd (SM) - ~~gy green~~ greenish gy, fine shell sd, >15% fines, 5% phosphate, calcareous
	128-130	9/7/7/7	Silty Sd (SM) greenish gy, fine to med shell, >15% fines, 5% phosphate, calc.

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

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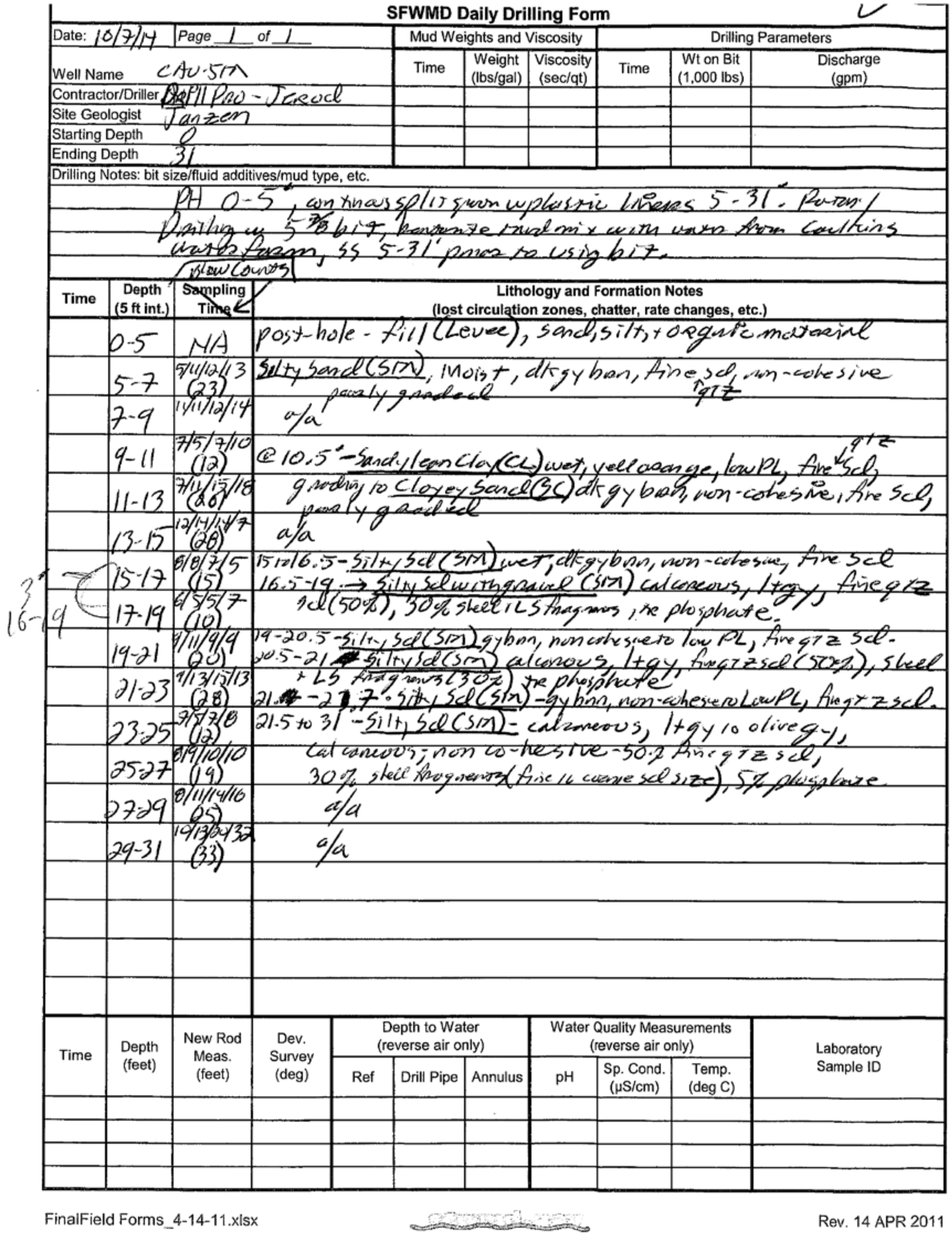

SFWMD Daily Drilling Form

✓

Date: 10/7/14 Page 1 of 1
Well Name CAU-SM
Contractor/Driller Drill Pro - Jarod
Site Geologist Janzen
Starting Depth 0
Ending Depth 31

Mud Weights and Viscosity			Drilling Parameters		
Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc.

PH 0-5', continuous split spoon w/plastic liners 5-31'. Rotary Drilling w/ 5 7/8 bit, bentonite mud mix with water from Caulkins water farm, SS 5-31' prior to using bit.

Time	Depth (5 ft int.)	Sampling ~~Time~~ Blow Counts	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	0-5	NA	post-hole - fill (Levee), sand, silt, + organic material
	5-7	9/11/12/13 (23)	Silty Sand (SM), Moist, dk gy brn, fine qtz sd, non-cohesive poorly graded
	7-9	11/11/12/14	a/a
	9-11	7/5/7/10 (12)	@ 10.5' – Sandy lean Clay (CL) wet, yell orange, low PL, fine qtz Sd,
	11-13	7/11/15/18 (26)	grading to Clayey Sand (SC) dk gy brn, non-cohesive, fine Sd, poorly graded
	13-15	12/14/14/7 (28)	a/a
3'	15-17	8/8/7/5 (15)	15 to 16.5 - Silty Sd (SM) wet, dk gy brn, non-cohesive, fine Sd 16.5-19 → Silty Sd with gravel (SM) calcareous, lt gy, fine qtz
16-19	17-19	6/5/5/7 (10)	Sd (50%), 30% shell + LS fragments, tr phosphate.
	19-21	9/11/9/9 (20)	19-20.5 - Silty Sd (SM) gy brn, non cohesive to low PL, fine qtz Sd. 20.5-21 Silty Sd (SM) calcareous, lt gy, fine qtz Sd (50%), shell
	21-23	9/13/15/13 (28)	+ LS fragments (30%) tr phosphate 21 - 21.7 - Silty Sd (SM) - gy brn, non-cohesive to Low PL, fine qtz Sd.
	23-25	3/5/7/8 (12)	21.5 to 31 - Silty Sd (SM) - calcareous, lt gy to olive gy,
	25-27	8/9/10/10 (19)	calcareous, non co-hesive - 50% fine qtz sd, 30% shell fragments (fine to coarse sd size), 5% phosphate.
	27-29	8/11/14/16 (25)	a/a
	29-31	10/13/20/32 (33)	a/a

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

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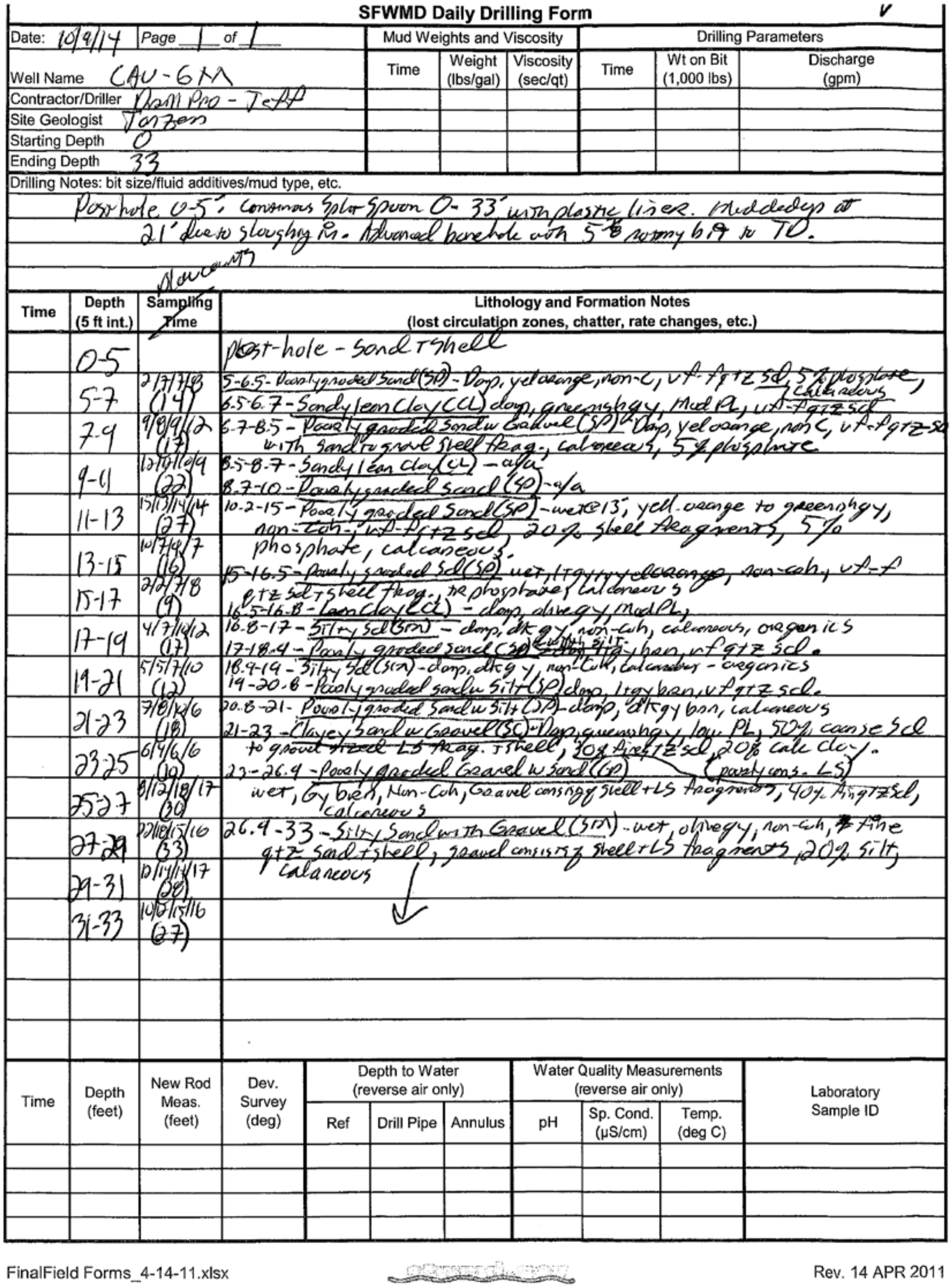

SFWMD Daily Drilling Form

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Date: 10/9/14	Page 1 of 1	Mud Weights and Viscosity			Drilling Parameters		
Well Name CAU-6M		Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)
Contractor/Driller Dam Pro - Jeff							
Site Geologist Janzen							
Starting Depth 0							
Ending Depth 33							

Drilling Notes: bit size/fluid additives/mud type, etc.

Post hole 0-5'. Continuous Split Spoon 0-33' with plastic liner. Mud added at 21' due to sloughing in. Advanced borehole with 5 7/8 rotary bit to TD.

Time	Depth (5 ft int.)	Sampling ~~Time~~ Blow counts	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	0-5		post-hole - Sand + shell
	5-7	2/7/7/8 (14)	5-6.5 - Poorly graded Sand (SP) - Damp, yel orange, non-C, vf-f qtz sd, 5% phosphate, calcareous 6.5-6.7 - Sandy lean Clay (CL) damp, greenish gy, Med PL, vf-f qtz sd
	7-9	9/8/9/12 (17)	6.7-8.5 - Poorly graded Sand w Gravel (SP) - Damp, yel orange, non C, vf-f qtz sd with sand to gravel shell frag., calcareous, 5% phosphate
	9-11	12/10/10/9 (22)	8.5-8.7 - Sandy lean Clay (CL) - a/a 8.7-10 - Poorly graded sand (SP) - a/a
	11-13	15/13/14/14 (27)	10.2-15 - Poorly graded Sand (SP) - wet @ 13', yell. orange to greenish gy, non-coh., vf-f qtz sd, 20% shell fragments, 5%
	13-15	10/7/9/7 (16)	phosphate, calcareous. 15-16.5 - Poorly graded Sd (SP) wet, lt gy/yel orange, non-coh, vf-f
	15-17	2/2/7/8 (9)	qtz sd + shell frag., tr phosphate, calcareous 16.5-16.8 - Lean Clay (CL) - damp, olive gy, Med PL,
	17-19	4/7/10/12 (17)	16.8-17 - Silty Sd (SM) - damp, dk gy, non-coh, calcareous, organics 17-18.4 - Poorly graded Sand (SP) with silt ~~Silty~~ lt gy, brn, vf qtz sd.
	19-21	5/5/7/10 (12)	18.4-19 - Silty Sd (SM) - damp, dk gy, non-coh, calcareous - organics 19-20.8 - Poorly graded sand w Silt (SP) damp, lt gy brn, vf qtz sd.
	21-23	7/8/10/6 (18)	20.8-21 - Poorly graded Sand w Silt (SP) - damp, dk gy brn, calcareous 21-23 - Clayey Sand w Gravel (SC) - Damp, greenish gy, low PL, 50% coarse sd
	23-25	6/4/6/6 (10)	to gravel ~~sized~~ LS frag. + shell, 30% fine qtz sd, 20% calc clay. (partly cons. LS) 23-26.4 - Poorly graded Gravel w Sand (GP)
	25-27	8/12/18/17 (30)	wet, Gy brn, Non-Coh, Gravel consisting of shell + LS fragments, 40% fine qtz sd, calcareous
	27-29	22/18/15/16 (33)	26.4-33 - Silty Sand with Gravel (SM) - wet, olive gy, non-coh, fine qtz sand + shell, gravel consisting of shell + LS fragments, 20% silt,
	29-31	12/14/14/17 (28)	calcareous
	31-33	10/12/15/16 (27)	↓

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

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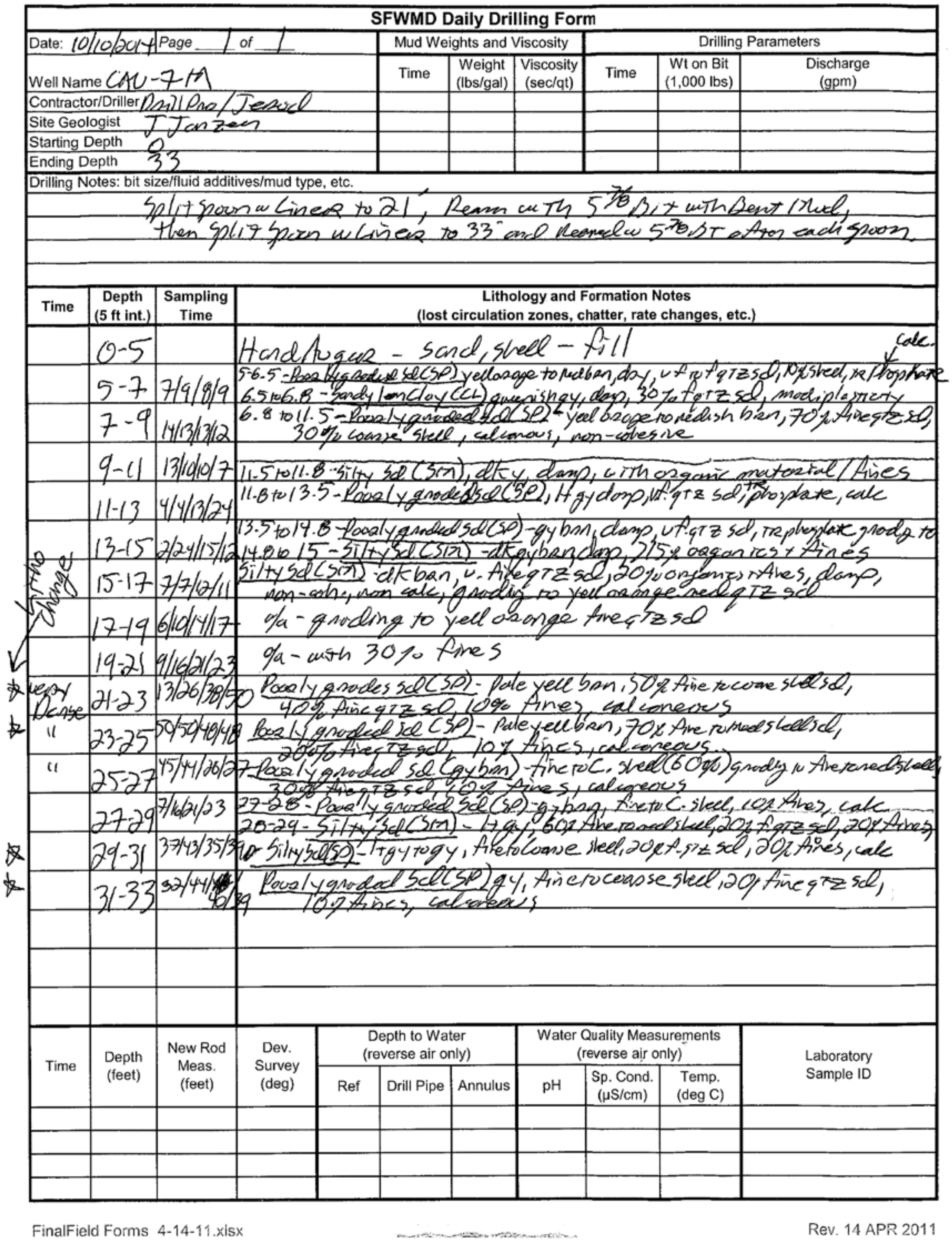

SFWMD Daily Drilling Form

Date: 10/10/2014 Page 1 of 1
Well Name CAU-7M
Contractor/Driller Drill Pro / Jerrod
Site Geologist T Janzen
Starting Depth 0
Ending Depth 33

Mud Weights and Viscosity			Drilling Parameters		
Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc.
Split spoon w Liner to 21', Ream with 5 7/8 Bit with Bent Mud,
then Split Spoon w Liner to 33' and Reamed w 5 7/8 BT after each spoon

Time	Depth (5 ft int.)	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	0-5		Hand Auger - sand, shell - fill calc.
	5-7	7/9/8/9	5-6.5 - Poorly graded sd (SP) yell orange to red brn, dry, vf to f qtz sd, 10% shell, tr phosphate 6.5 to 6.8 - Sandy lean Clay (CL) greenish gy, damp, 30% f qtz sd, mod. plasticity
	7-9	14/13/13/12	6.8 to 11.5 - Poorly graded sd (SP) - yell orange to redish brn, 70% fine qtz sd, 30% coarse shell, calcareous, non-cohesive
	9-11	13/10/10/7	11.5 to 11.8 - Silty sd (SM), dk gy, damp, with organic material / fines
	11-13	4/4/13/24	11.8 to 13.5 - Poorly graded sd (SP), lt gy damp, vf qtz sd, tr phosphate, calc
Litho change	13-15	2/24/15/12	13.5 to 14.8 - Poorly graded sd (SP) - gy brn, damp, vf qtz sd, tr phosphate, grading to 14.8 to 15 - Silty sd (SM) - dk gy brn damp, >15% organics + fines
	15-17	7/7/12/11	Silty sd (SM) - dk brn, v. fine qtz sd, 20% organics + fines, damp, non-coh., non calc, grading to yell orange red qtz sd
	17-19	6/10/14/17	o/a - grading to yell orange fine qtz sd
	19-21	9/16/21/23	o/a - with 30% fines
☆ very Dense	21-23	13/26/38/50	Poorly graded sd (SP) - pale yell brn, 50% fine to coarse shell sd, 40% fine qtz sd, 10% fines, calcareous
☆ "	23-25	50/50/40/48	Poorly graded sd (SP) - pale yell brn, 70% fine to med shell sd, 20% fine qtz sd, 10% fines, calcareous.
"	25-27	45/44/26/27	Poorly graded sd (gy brn) - fine to c. shell (60%) grading to fine to med shell, 30% fine qtz sd, 10% fines, calcareous
	27-29	7/16/21/23	27-28 - Poorly graded sd (SP) - gy brn, fine to c. shell, 10% fines, calc 28-29 - Silty sd (SM) - lt gy, 60% fine to med shell, 20% f qtz sd, 20% fines
☆	29-31	37/43/35/39	Silty sd (SP) - lt gy to gy, fine to coarse shell, 20% f. qtz sd, 20% fines, calc
☆	31-33	32/44/40/39	Poorly graded sd (SP) gy, fine to coarse shell, 20% fine qtz sd, 10% fines, calcareous

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

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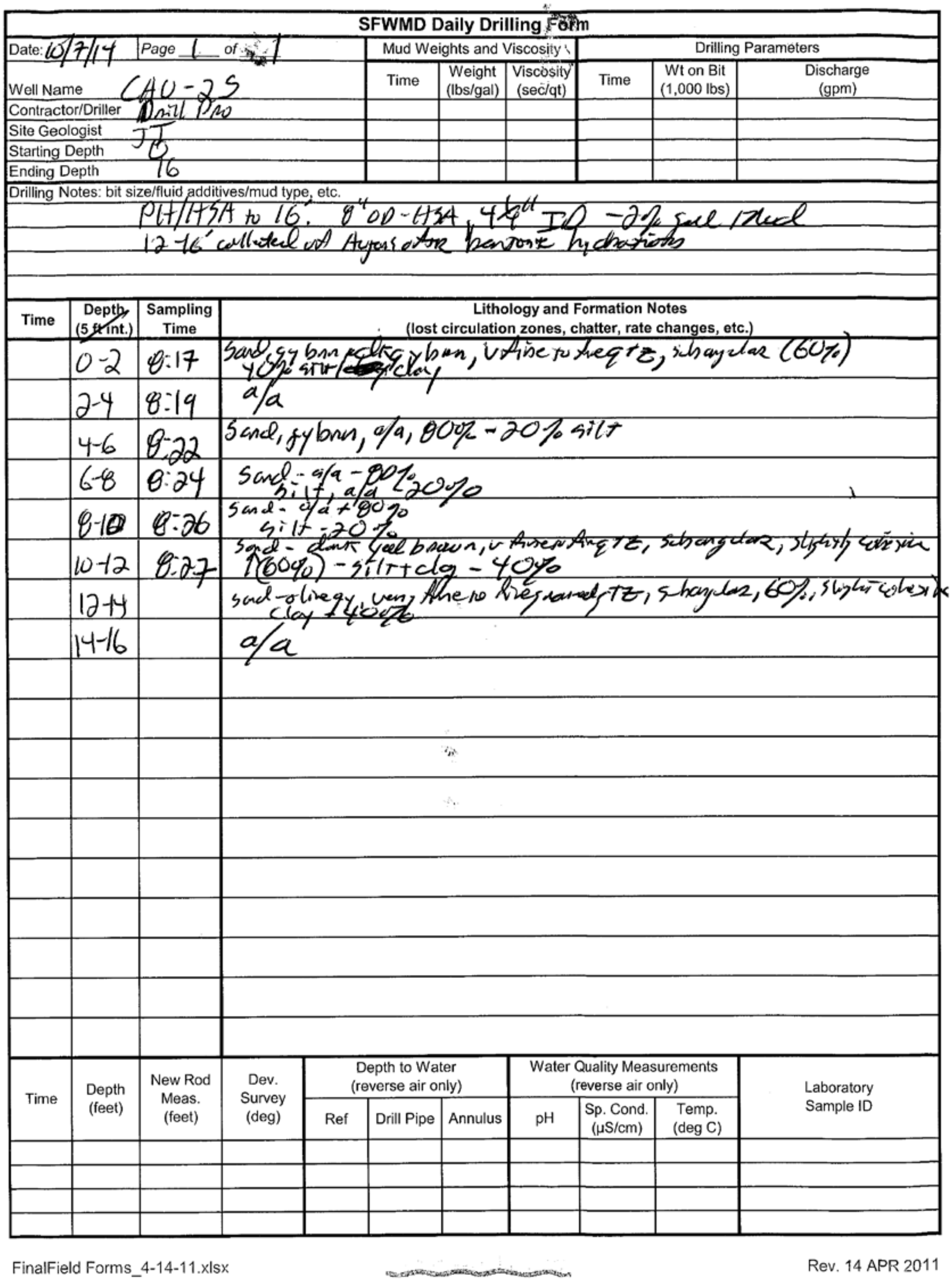

SFWMD Daily Drilling Form

Date: 10/7/14 Page 1 of 1

Well Name CAU-2S

Contractor/Driller Drill Pro

Site Geologist JJ

Starting Depth 0

Ending Depth 16

Mud Weights and Viscosity			Drilling Parameters		
Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc.

PH/HSA to 16'. 8" OD-HSA, 4 1/4" ID - 2% gel 1 Mud

12-16' collected w/ Aquastore bentonite hydrations

Time	Depth (5 ~~ft~~ int.)	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	0-2	8:17	Sand, gy brn [illegible] gy brn, v fine to fine qtz, subangular (60%) 40% silt/[illegible] clay
	2-4	8:19	a/a
	4-6	8:22	Sand, gy brn, a/a, 80% - 20% silt
	6-8	8:24	Sand - a/a - 80% silt, a/a 20%
	8-10	8:26	Sand - a/a + 80% silt - 20%
	10-12	8:27	Sand - dark yell brown, v fine to fine qtz, subangular, slightly cohesive (60%) - silt + clay - 40%
	12-14		sand - olive gy, very fine to fine grained, qtz, subangular, 60%, slight cohesive clay + 40%
	14-16		a/a

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only) Ref	Drill Pipe	Annulus	Water Quality Measurements (reverse air only) pH	Sp. Cond. (µS/cm)	Temp. (deg C)	Laboratory Sample ID

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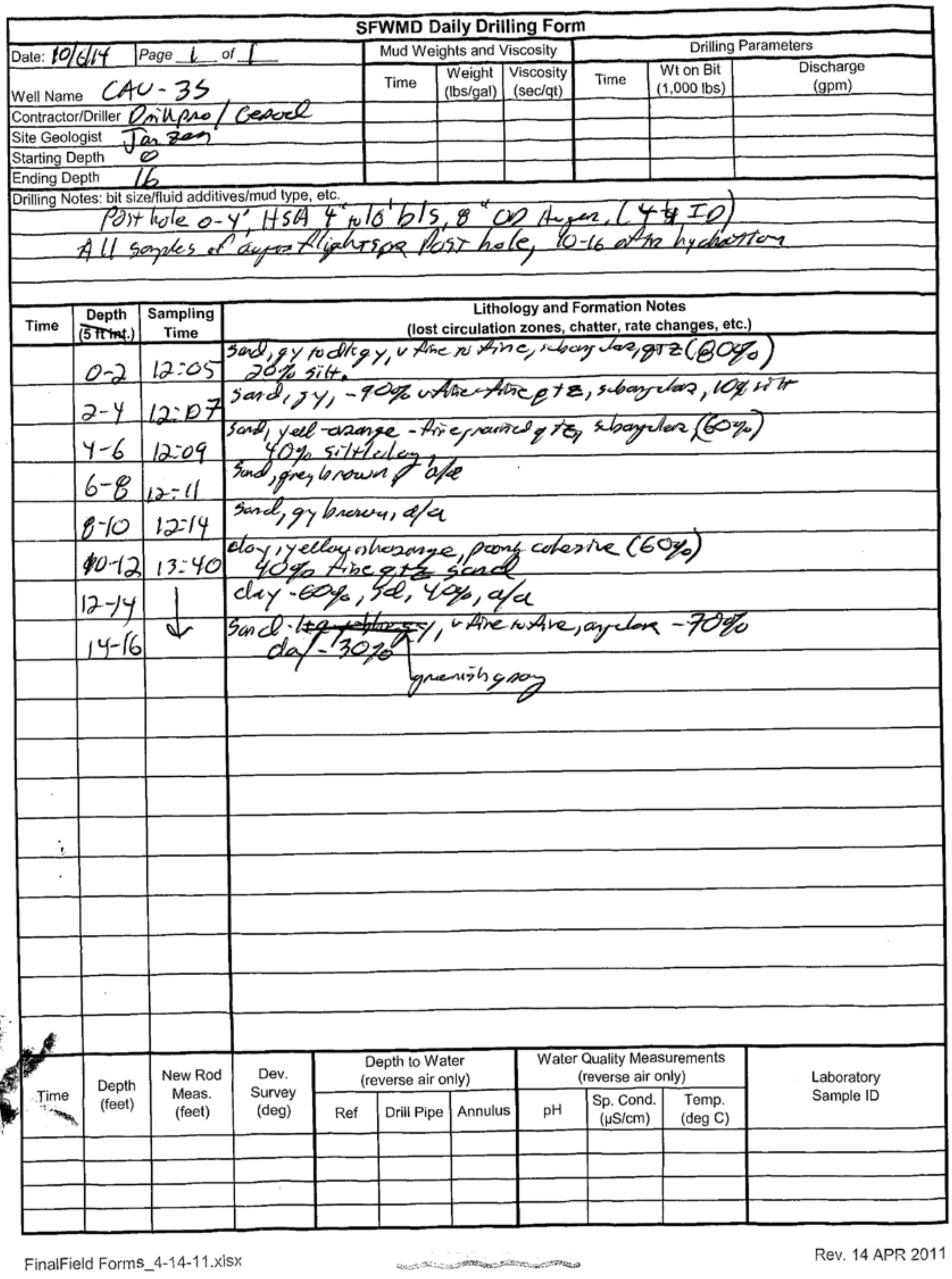

SFWMD Daily Drilling Form

Date: 10/6/14 Page 1 of 1

Well Name CAU-35

Contractor/Driller Drillpro / Geosol

Site Geologist Jan Zan

Starting Depth 0

Ending Depth 16

Mud Weights and Viscosity			Drilling Parameters		
Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc.

Post hole 0-4', HSA 4' to 16' bls, 8" OD Auger, (4¼ ID)

All samples of auger flights or Post hole, 10-16 after hydration

Time	Depth ~~(5 ft int.)~~	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	0-2	12:05	sand, gy to dk gy, v fine to fine, sbang-lar, qtz (80%) 20% silt.
	2-4	12:07	sand, gy, -90% v fine-fine qtz, sbang-lar, 10% silt
	4-6	12:09	sand, yell-orange - fine grained qtz, sbang-lar (60%) 40% silt/clay
	6-8	12:11	Sand, grey brown, a/a
	8-10	12:14	sand, gy brown, a/a
	10-12	13:40	clay, yellowish orange, poorly cohesive (60%) 40% fine qtz sand
	12-14	↓	clay -60%, sd, 40%, a/a
	14-16		Sand - ~~lt g yellow gy~~, v fine to fine, ang-lar -70% clay -30% greenish gray

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

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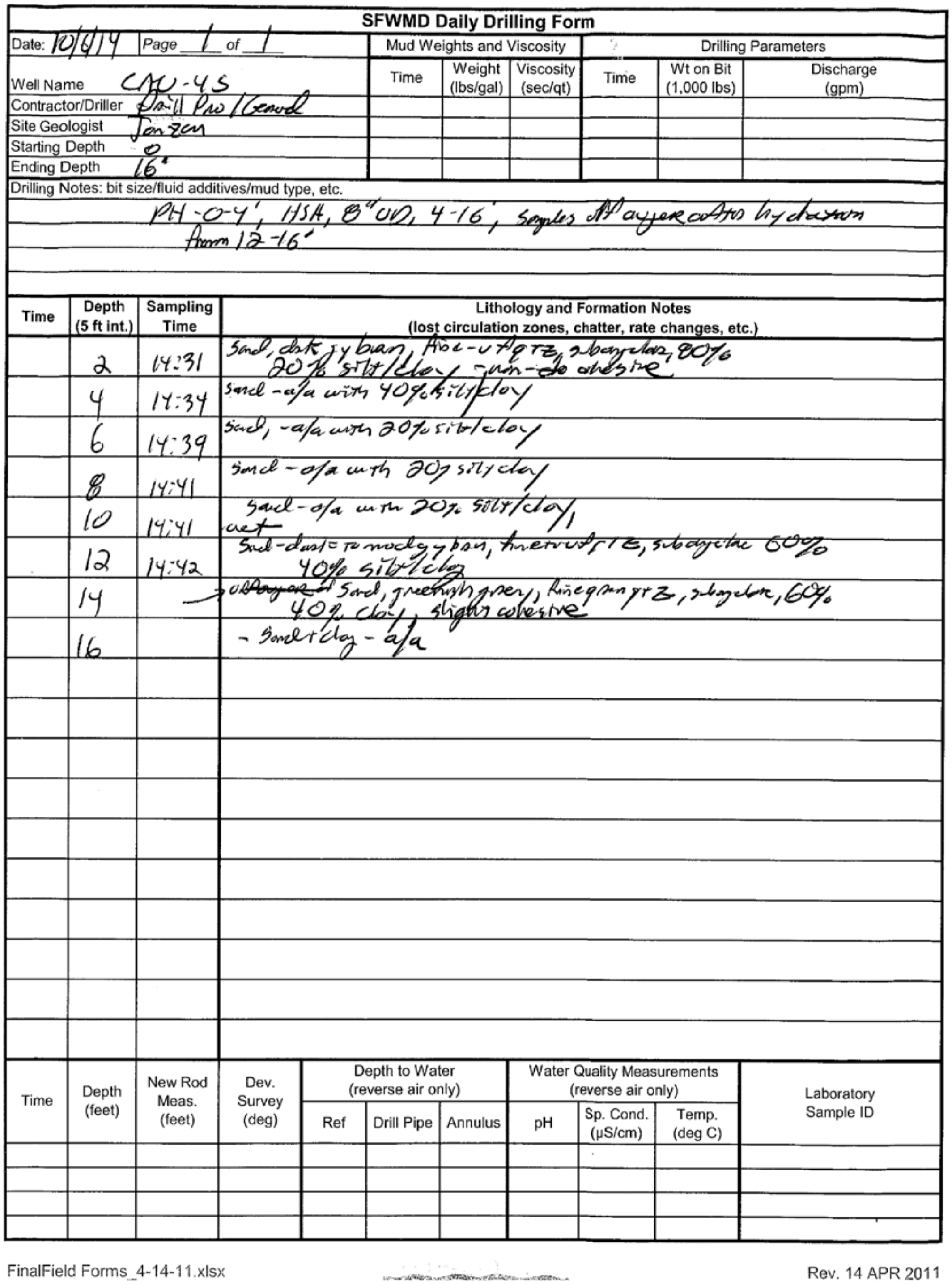

SFWMD Daily Drilling Form

Date: 10/6/14 Page 1 of 1

Well Name CAU-4S

Contractor/Driller Drill Pro / Geosol

Site Geologist Janzen

Starting Depth 0

Ending Depth 16'

Mud Weights and Viscosity			Drilling Parameters		
Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc.

PH-0-4', HSA, 8" OD, 4-16', samples off auger cuttings by character from 12-16'

Time	Depth (5 ft int.)	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	2	14:31	Sand, dark gy brown, fine-v fine qtz, subangular, 80% 20% silt/clay, non-cohesive
	4	14:34	Sand - a/a with 40% silt/clay
	6	14:39	Sand, - a/a with 20% silt/clay
	8	14:41	Sand - a/a with 20% silty clay
	10	14:41	Sand - a/a with 20% silt/clay, wet
	12	14:42	Sand - dark to medium gy brown, fine-v fine qtz, subangular 60% 40% silt/clay
	14	→	~~[illegible]~~ Sand, greenish grey, fine grain qtz, subangular, 60% 40% clay, slightly cohesive
	16		- Sand + clay - a/a

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (μS/cm)	Temp. (deg C)	

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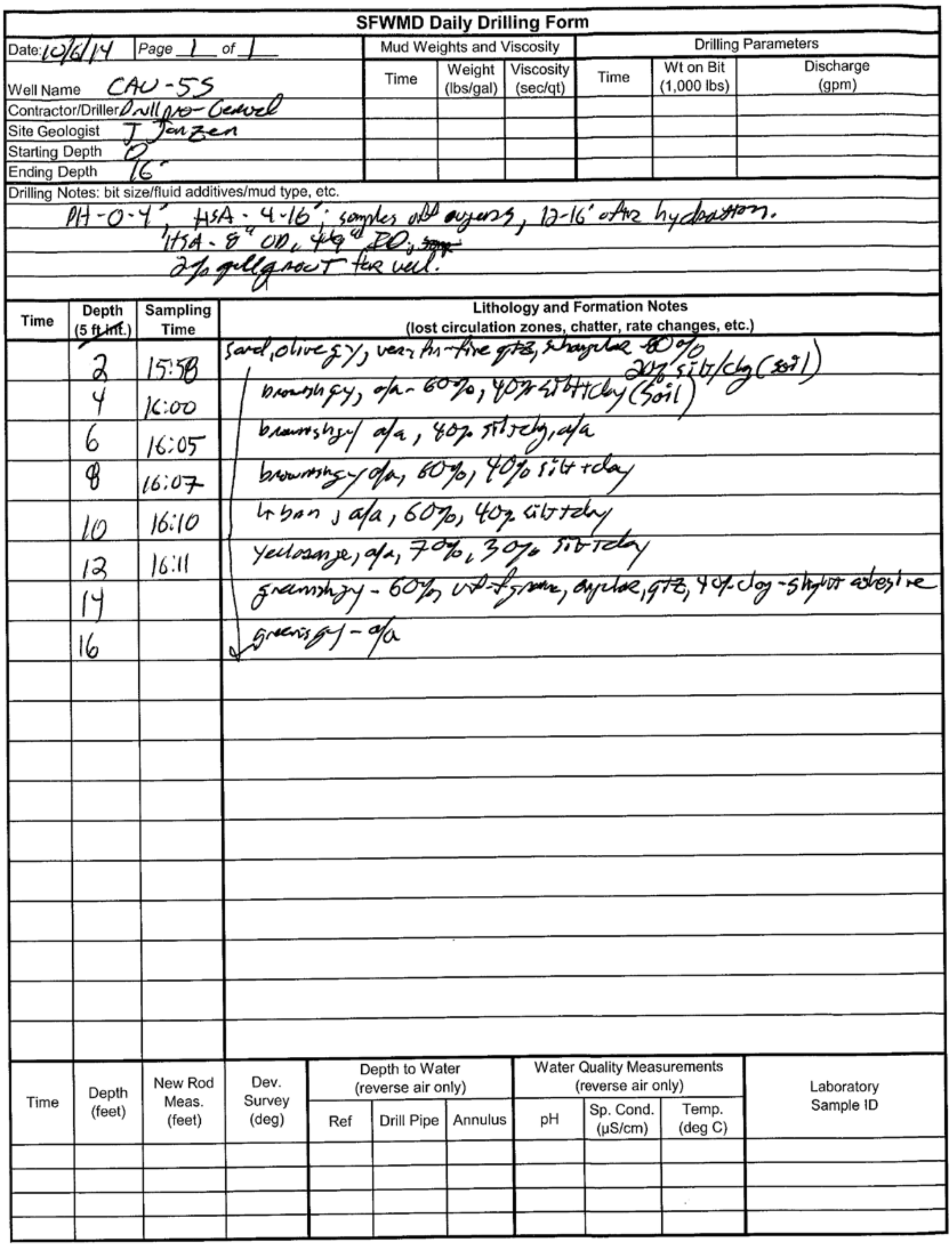

SFWMD Daily Drilling Form

Date: 10/6/14 Page 1 of 1

Well Name CAU-55

Contractor/Driller Drill pro - Cedvel

Site Geologist J Janzen

Starting Depth 0

Ending Depth 16'

Mud Weights and Viscosity		
Time	Weight (lbs/gal)	Viscosity (sec/qt)

Drilling Parameters		
Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc.

PH - 0-4', HSA - 4-16'; samples off augers, 12-16' after hydration.

HSA - 8" OD, 4¼" ID; ~~[illegible]~~

2% gel grout for well.

Time	Depth (5 ft ~~int.~~)	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	2	15:58	sand, olive gy, very fn-fine qtz, subangular 80% 20% silt/clay (soil)
	4	16:00	brownish gy, a/a - 60%, 40% silt+clay (Soil)
	6	16:05	brownish gy a/a, 40% silt+clay, a/a
	8	16:07	brownish gy a/a, 60%, 40% silt+clay
	10	16:10	lt brn, a/a, 60%, 40% silt+clay
	12	16:11	yellorange, a/a, 70%, 30% silt+clay
	14		greenish gy - 60% vf-f grained, angular, qtz, 40% clay - slightly adhesive
	16		greenish gy - a/a

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

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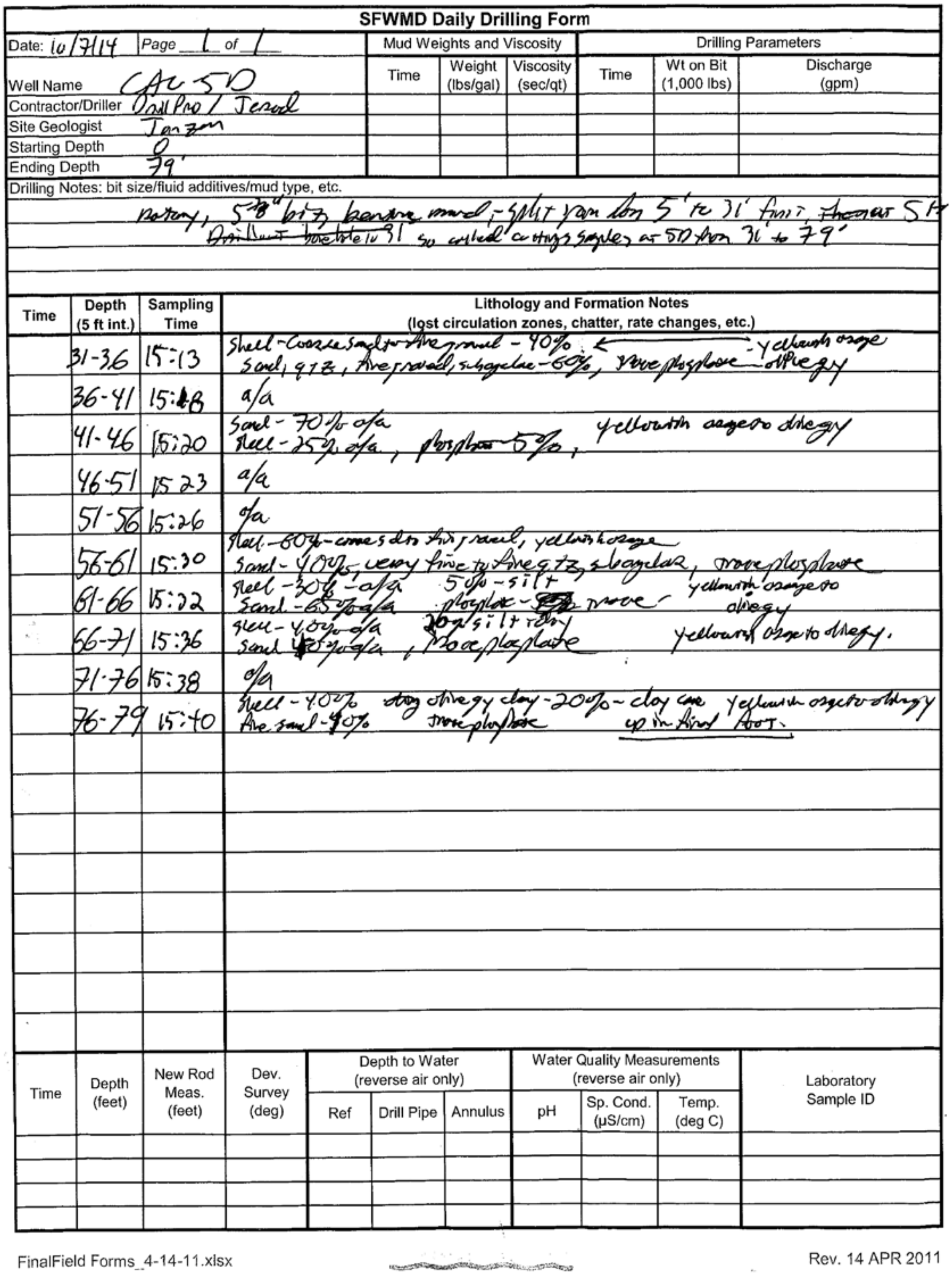

SFWMD Daily Drilling Form

			Mud Weights and Viscosity			Drilling Parameters		
Date: 10/7/14	Page 1 of 1		Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)
Well Name	CAL-5D							
Contractor/Driller	Drill Pro / Jerod							
Site Geologist	Janzen							
Starting Depth	0							
Ending Depth	79'							

Drilling Notes: bit size/fluid additives/mud type, etc.

Rotary, 5 7/8" bit, bentonite mud; split spoon from 5' to 31' first, ~~thereafter~~ 5 ft ~~Drilled out~~ hole to 31' so collected cuttings samples at 5 ft from 31' to 79'

Time	Depth (5 ft int.)	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	31-36	15:13	Shell - coarse sand to fine gravel - 40% ← → yellowish orange - olive gray Sand, qtz, fine gravel, subangular - 60%, trace phosphate
	36-41	15:18	a/a
	41-46	15:20	Sand - 70% a/a Shell - 25% a/a, phosphate 5%, yellowish orange to olive gray
	46-51	15:23	a/a
	51-56	15:26	a/a
	56-61	15:30	Shell - 60% - coarse sand to fine gravel, yellowish orange Sand - 40%, very fine to fine qtz, subangular, trace phosphate
	61-66	15:32	Shell - 30% - a/a 5% - silt Sand - 65% a/a phosphate - ~~5%~~ trace - yellowish orange to olive gray
	66-71	15:36	Shell - 40% a/a 20% silt + clay Sand 40% a/a, trace phosphate yellowish orange to olive gray.
	71-76	15:38	a/a
	76-79	15:40	Shell - 40% stiff olive gray clay - 20% - clay came up in final foot. yellowish orange to olive gray fine sand - 40% trace phosphate

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

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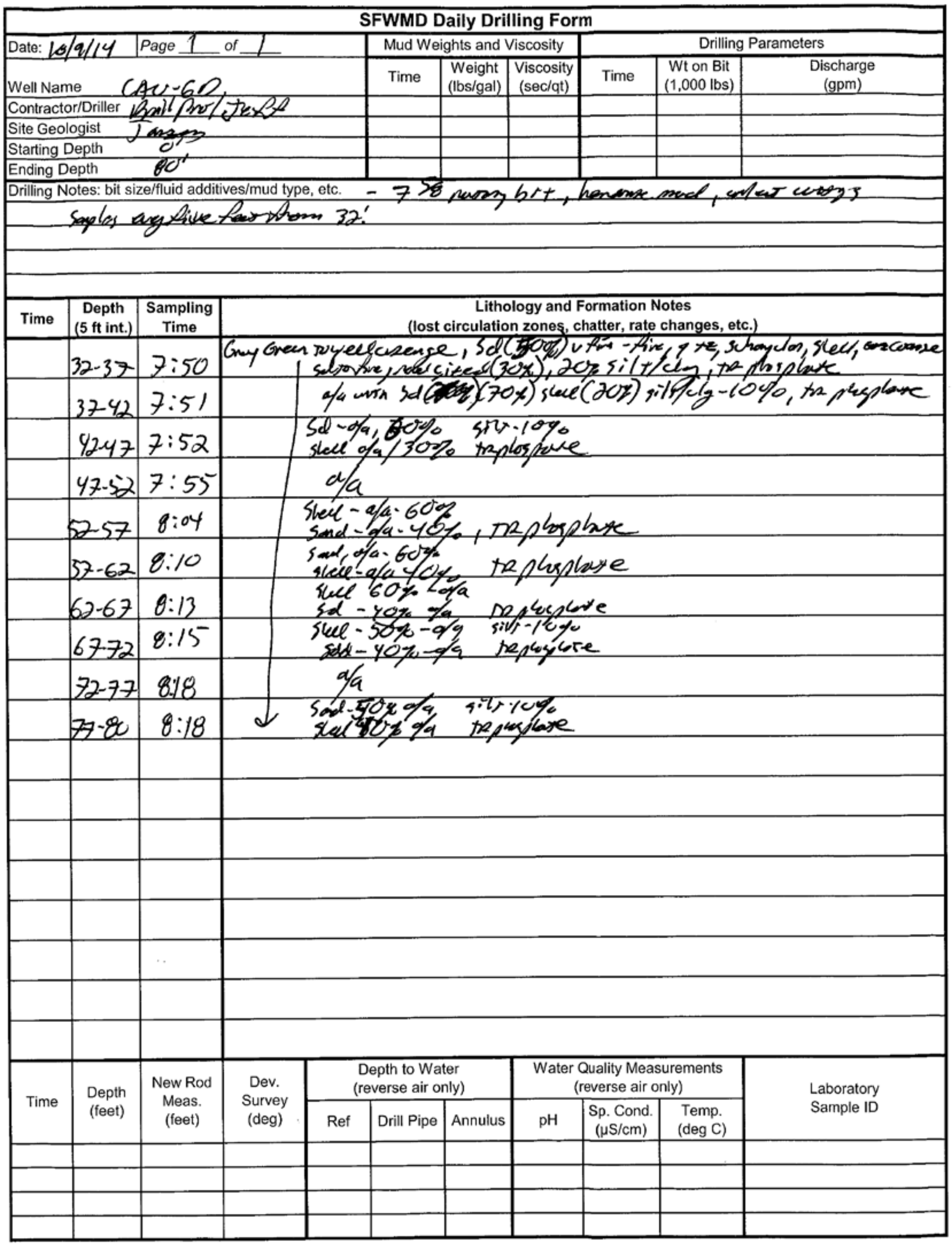

SFWMD Daily Drilling Form

Date: 10/9/14 Page 1 of 1

Well Name CAU-6D

Contractor/Driller Drill Pro/[illegible]

Site Geologist J [illegible]

Starting Depth 0'

Ending Depth 80'

Mud Weights and Viscosity			Drilling Parameters		
Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc. - 7 7/8 [illegible] bit, [illegible] mud, [illegible] samples [illegible] from 32'.

Time	Depth (5 ft int.)	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	32-37	7:50	Gray Green [illegible], Sd (80%) v fine - fine, qtz, [illegible], shell, [illegible] coarse [illegible], [illegible] sized (30%), 20% silt/clay, tr phosphate
	37-42	7:51	a/a with Sd ~~[illegible]~~ (70%) shell (20%) silt/clay - 10%, tr phosphate
	42-47	7:52	Sd - a/a, 60% silt - 10% shell a/a / 30% tr phosphate
	47-52	7:55	a/a
	52-57	8:04	Shell - a/a - 60% Sand - a/a - 40%, TR phosphate
	57-62	8:10	Sand, a/a - 60% shell - a/a 40% tr phosphate
	62-67	8:13	Shell 60% - a/a Sd - 40% a/a tr phosphate
	67-72	8:15	Shell - 50% - a/a silt - 10% Sand - 40% - a/a tr phosphate
	72-77	8:18	a/a
	77-80	8:18	Sand - 50% a/a silt - 10% Shell 40% a/a tr phosphate

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

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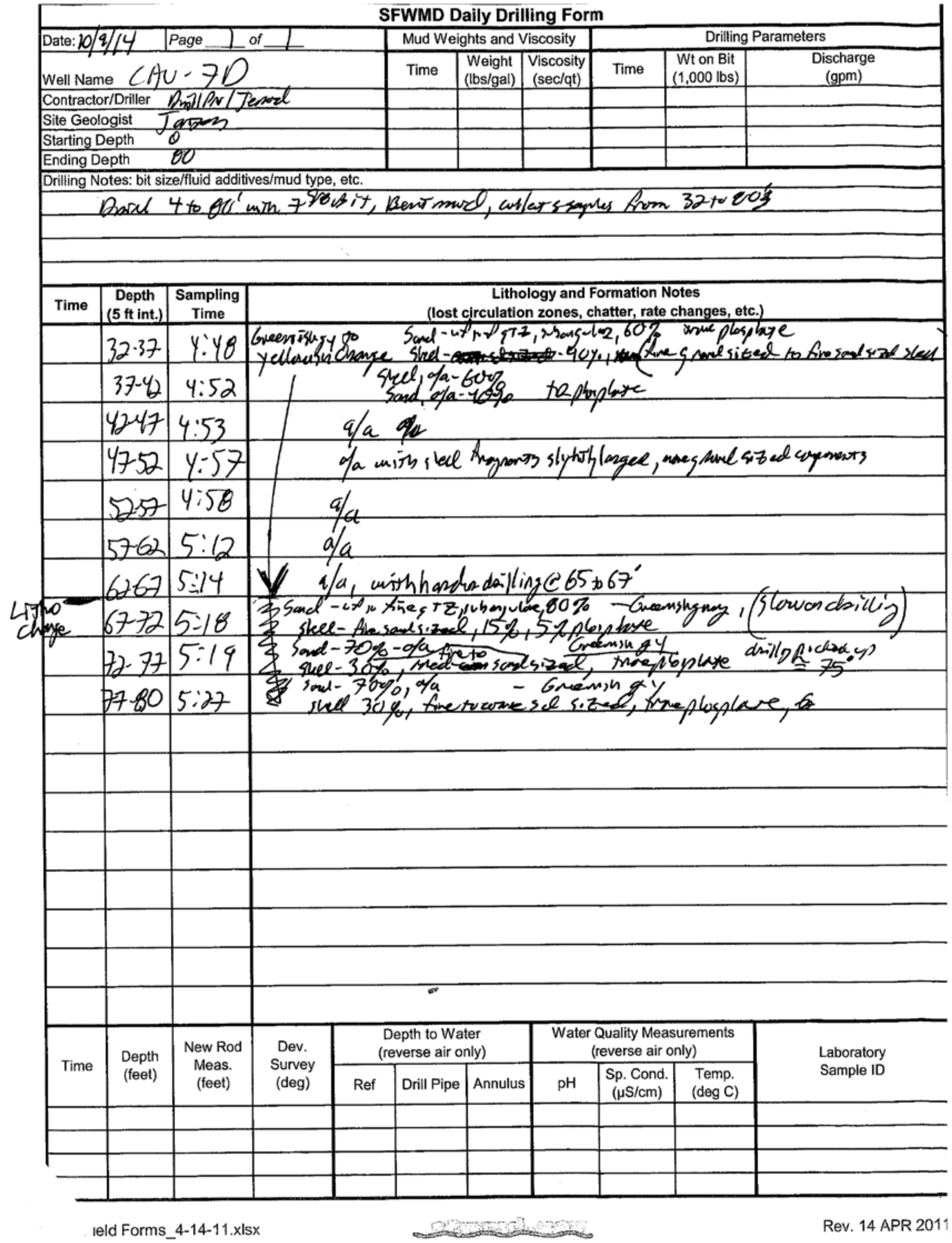

SFWMD Daily Drilling Form

Date: 10/9/14 Page 1 of 1

Well Name CAU-7D

Contractor/Driller Drill Pro / Jerrod

Site Geologist Jason

Starting Depth 0

Ending Depth 80

Mud Weights and Viscosity			Drilling Parameters		
Time	Weight (lbs/gal)	Viscosity (sec/qt)	Time	Wt on Bit (1,000 lbs)	Discharge (gpm)

Drilling Notes: bit size/fluid additives/mud type, etc.

Drld 4 to 80' with 7 7/8 bit, Bent mud, collect samples from 32 to 80'

Time	Depth (5 ft int.)	Sampling Time	Lithology and Formation Notes (lost circulation zones, chatter, rate changes, etc.)
	32-37	4:48	Greenish gray to yellowish orange Sand - vf to f qtz, subangular, 60% some phosphate Shell - ~~[illegible]~~ - 40%, ~~[illegible]~~ (fine g. sand sized to fine sand sized shell
	37-42	4:52	Shell, a/a - 60% Sand, a/a - 40% tr phosphate
	42-47	4:53	a/a ~~a/a~~
	47-52	4:57	a/a with shell fragments slightly larger, more g. sand sized fragments
	52-57	4:58	a/a
	57-62	5:12	a/a
	62-67	5:14	a/a, with harder drilling @ 65 to 67'
Litho change	67-72	5:18	Sand - vf to fine qtz, subangular, 80% - Greenish gray, (slower drilling) Shell - fine sand sized, 15%, 5% phosphate
	72-77	5:19	Sand - 70% - a/a fine to Greenish gy Shell - 30%, med ~~[illegible]~~ sand sized, trace phosphate drilling picked up ≈ 75'
	77-80	5:27	Sand - 70%, a/a - Greenish gy Shell 30%, fine to coarse sd sized, trace phosphate, to

Time	Depth (feet)	New Rod Meas. (feet)	Dev. Survey (deg)	Depth to Water (reverse air only)			Water Quality Measurements (reverse air only)			Laboratory Sample ID
				Ref	Drill Pipe	Annulus	pH	Sp. Cond. (µS/cm)	Temp. (deg C)	

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Rev. 14 APR 2011