Seepage Investigation of the Caulkins Water Farm Pilot Project
Final Report

Martin County, Florida

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EXECUTIVE SUMMARY

The Caulkins Water Farm Pilot Project (WFPP), 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. The WFPP was constructed between August and December 2013; water began pumping into the impoundment on February 2, 2014 and continued intermittently through October 26, 2016 (approximately 33 months). Approximately 39,542 acre-feet (ac-ft) of water was pumped into the impoundment, and total seepage of 38,129 ac-ft (38 ac-ft/day) was estimated based on residuals present in the water budget (**Appendix A**). The impoundment was maintained at or near full capacity, between 27.7 and 29 ft NGVD 1929, for approximately 18 months.

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 compared to 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 as well as published values from nearby aquifer tests. As part of this investigation, 6 surface water stage monitoring stations and 14 groundwater monitoring wells were installed within and adjacent to the WFPP in October and November 2014 and February 2015. Groundwater monitoring wells were installed within the surficial aquifer system (SAS) at depths between 9 and 130 ft below land surface (bls). Stations were fitted with continuous data loggers, which recorded data at 15-minute intervals and were downloaded monthly for data evaluation. Stage and rainfall data from a monitoring station installed within the impoundment in February 2014 by the property owner were used as well. Site-specific surveys, including transects across the water farm and the C-44 Canal, were completed by the SFWMD. These surveys, along with existing landowner survey data and SFWMD light detection and radar (LiDAR) data, were used to develop a stage-storage relationship for the surface water budget and seepage analysis.

Water level data collection for all stations except the deep well cluster (CAU-1) in the center of the impoundment began in November 2014. The First Annual Seepage Report (Janzen et al., 2015) included seepage analysis from November 13, 2014 through January 31, 2015. Surrogate water level data for the deep well cluster were used for that report as CAU-1 was not installed until February 2015. This report includes water level data and seepage analysis from February 2015 through October 2016, and does not rely on surrogate data. Water level data also were reviewed from two well clusters recently installed at the C-44 Reservoir/Stormwater Treatment Area (STA), approximately 2 miles northwest and 1 mile west, which included well screens in the intermediate, deep, and lower deep zones.

While the impoundment was maintained at nearly full capacity (loaded), hydraulic gradients and seepage were compared to gradients when the impoundment was dry (baseline period). During loaded conditions, seepage averaged 51 ac-ft/day; this estimate was used to calibrate a seepage model for generating average daily seepage estimates.

Lithology of the shallow sediments includes thin, sandy clay and clayey sand interbeds from approximately 4 to 13 ft bls, which appear to be discontinuous and at variable depths. The presence of lower permeability clayey zones may attenuate downward seepage from the water farm and increase seepage to perimeter canals. Lithology of deeper sediments consists of silty and shelly sand. Best estimates for hydraulic conductivity in the shallow, intermediate, and deep SAS were used to calculate relative vertical and horizontal seepage from each zone. Vertical seepage through the base of the shallow SAS is limited by higher clay content, and seepage is more easily accommodated in the lower zones. Therefore, the relative estimates for horizontal and vertical hydraulic conductivity (Kh and Kv, respectively) of the shallow SAS are the most critical variables. The best estimate used for Kh and Kv in the shallow SAS were 10 and 1 ft/day, an anisotropic ration of 0.1. Hydraulic conductivities of the intermediate and deep zones were 30 and 50 ft/day, respectively.

Approximately 47 ac-ft/day (92 percent) of seepage from the impoundment was vertical, and approximately 4 ac-ft/day (8 percent) was lateral into the shallow SAS to the north as well as the west, east, and south perimeter canals. Most vertical seepage from the impoundment is estimated to have flowed into the lower deep aquifer, then horizontally to the south towards the C-44 Canal. Water takes an estimated 11 years to travel from the center of the impoundment to the C-44 Canal, while it takes water from the southern edge of the impoundment approximately 3.5 years to reach the C-44 Canal.

The short-term effects of loading the impoundment on increased ambient seepage/recharge to the C-44 Canal induced by upgradient head, compared to long-term flow from the impoundment, were evaluated using relative water levels from monitoring wells adjacent to the C-44 Canal. Discharge estimates varied from 0.88 to 2.58 ac-ft/day during loaded conditions and 0.26 to 1.03 ac-ft/day during baseline conditions.

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ACRONYMS AND ABBREVIATIONS

ac-ft	acre-feet
ac-ft/day	acre-feet per day
APT	aquifer performance test
bls	below land surface
ET	evapotranspiration
ft/ft	hydraulic gradient (vertical distance/horizontal distance)
gpm	gallons per minute
K	hydraulic conductivity
Kh	horizontal hydraulic conductivity
Kv	vertical hydraulic conductivity
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
SAS	surficial aquifer system
SFWMD	South Florida Water Management District
WFPP	Water Farm Pilot Project

1 INTRODUCTION

The Caulkins Water Farm Pilot Project (WFPP) is located on 414 acres (ac) in the southwestern portion of the Caulkins Citrus Company Ltd. property, a former citrus grove (Caulkins Citrus Grove), located in Martin County, Florida (**Figure 1**). The Caulkins WFPP was designed and constructed as part of the South Florida Water Management District (SFWMD or District) Dispersed Water Management Program 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 Lake Okeechobee, approximately 16 miles to the west, and flows into the St. Lucie Estuary, approximately 14 miles east. Construction of the expanded Caulkins water farm project is expected to commence in 2017 and will consist of approximately 3,000 ac, encompassing the entire Caulkins Citrus Grove.

The Caulkins WFPP was constructed between August and December 2013, and pumping into the impoundment began February 10, 2014. In order to develop a water budget, pump inflow, surface water stage, and rain (one station) have been monitored in the Caulkins WFPP since initial pumping through October 31, 2016. Pumping ceased on October 26, 2016. During the operational period, 39,542 acre-feet (ac-ft) of water was pumped into the impoundment, and a seepage volume of 38,129 ac-ft (38 ac-ft/day) was estimated based on residuals in the budget (**Appendix A**). The first Caulkins WFPP annual report (Janzen et al., 2015) examined groundwater seepage rates and direction from October 2014 through January 2015, using continuously monitored groundwater levels to characterize the quantity and direction of seepage from the impoundment. The first annual report relied on estimated groundwater levels in the center of the impoundment using surrogate analysis because interior wells had not been installed at that time. The period of record for this report is from February 2015 through October 2016, and includes all available data from the center well cluster. In addition, limited geochemical sampling was conducted to aid in characterizing groundwater flow and obtain preliminary water quality and nutrient data, presented in **Appendix B**.

The first Caulkins WFPP annual report (Janzen et al., 2015) included a detailed discussion of permitted water users within a 1-mile radius of the Caulkins WFPP for 2014, staff gauge and monitoring well installation, procedures for data collection and processing, and SFWMD survey and water volume calculations that are not included in this report.

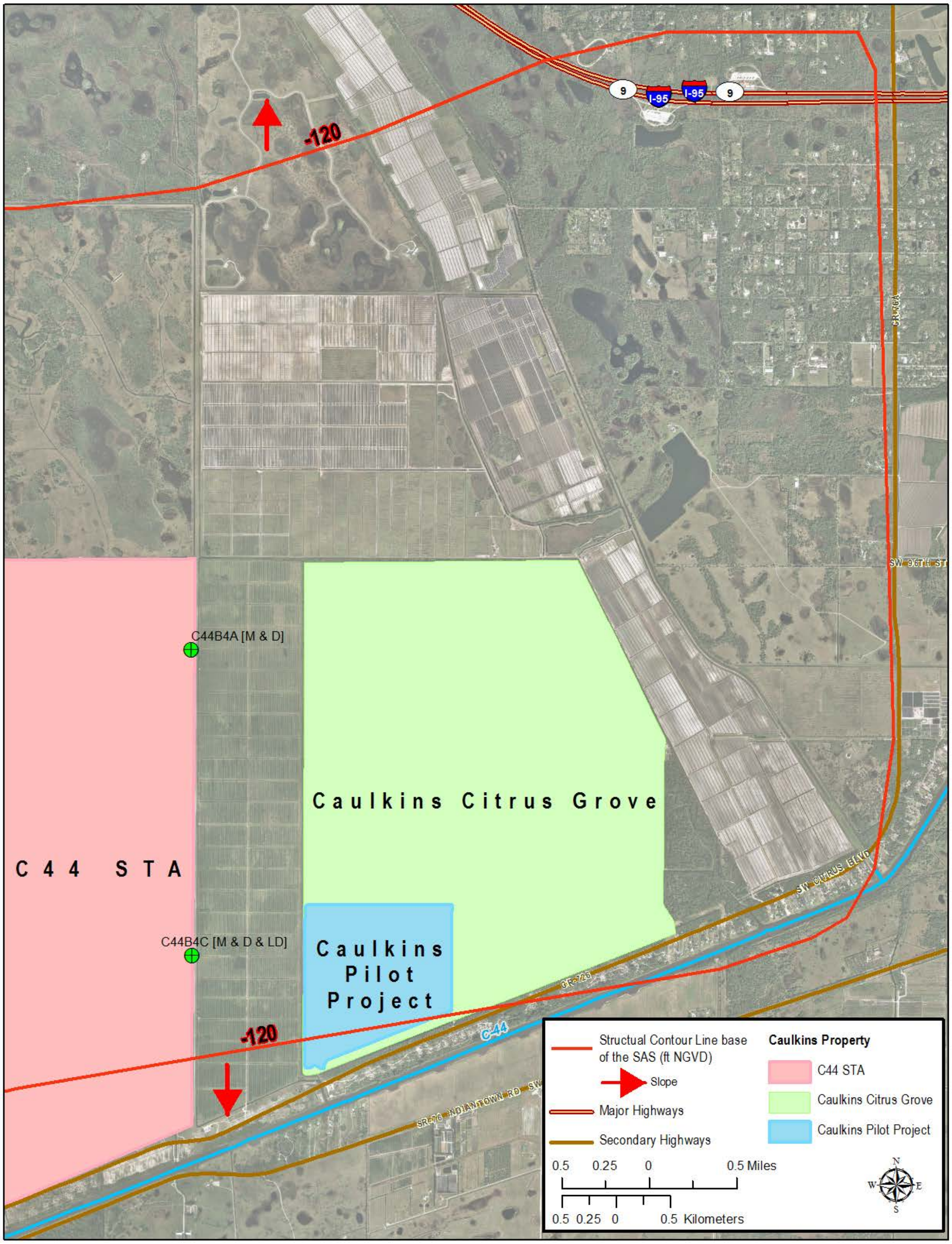

Figure 1. Location of Caulkins Water Farm Pilot Project within the Caulkins Citrus Grove.

2 SITE SETTING AND DESCRIPTION

2.1 Site Setting

The Caulkins Citrus Grove comprises approximately 3,275 ac of former agricultural property, and is bordered by groves/agricultural land to the north, east, and west. To the south is County Highway 726 (Citrus Boulevard), beyond which is undeveloped land and the C-44 Canal. Approximately one-third of the Caulkins Citrus Grove was leased for corn, pepper, cabbage, lettuce, and spinach farming until 2015. Irrigation was 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 was controlled by vertical risers, with stop logs and at least one portable pump.

The Caulkins WFPP withdrew irrigation supply water via two canal pumps that lifted water from the C-444 Canal (connected to the C-44 Canal) in a pump station approximately 300 ft southeast of the southwestern portion of the Caulkins WFPP (**Figure 2**). Through October 2014, the pumps consisted of one 100-horsepower (hp) diesel and one 100-hp electric pump. Each pump operated at a flow rate of approximately 15,000 gallons per minute (gpm). In October 2014, the diesel pump was replaced by a 200-hp electric pump operated at a flow rate of approximately 30,000 gpm. The pump station pumped water into the southernmost irrigation canal that borders the southern edge of the Caulkins Citrus Grove, also known as the feeder canal. The pump station can receive water from the Caulkins Citrus Grove via the westernmost irrigation canal, also known as the drainage canal. Four 54-inch gates with stop logs at the pump station connect and control flow to/from the C-444 Canal, feeder canal, and drainage canal. Discharge from the drainage canal to the C-444 Canal was not recorded; however, the gates that control water from the drainage canal were closed during the operational period (pers. comm., Ron Hataway, Caulkins Citrus Company Ltd.).

The citrus grove irrigation canals discharged water from the irrigation network to the C-444 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.

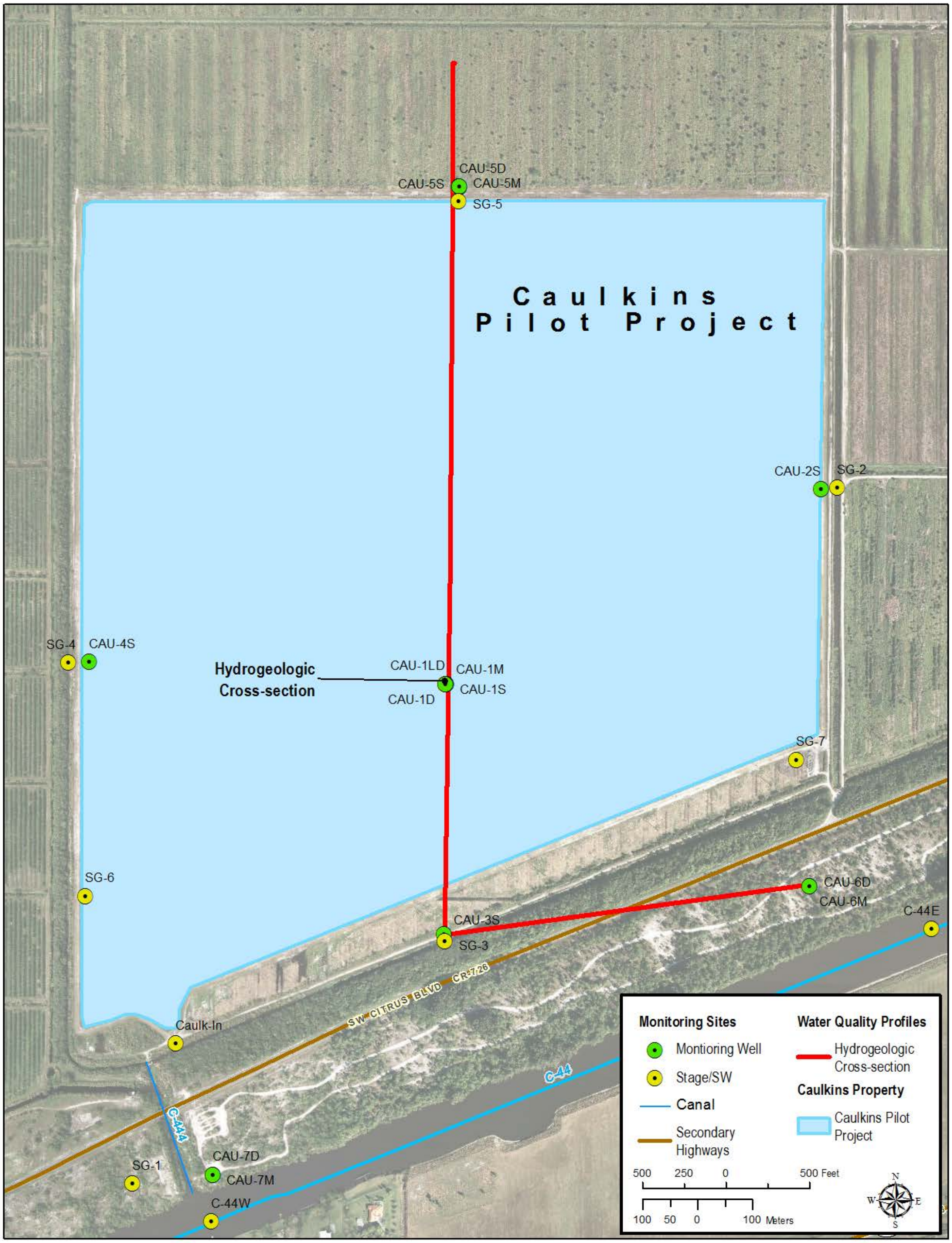

Figure 2. Site diagram showing the Caulkins Water Farm Pilot Project, monitoring stations, and adjacent canals. Hydrogeologic cross-section is shown in **Figure 5**.

2.2 Water Farm Description and Operation

The impoundment consists of a four-sided polygon with an exterior earthen levee approximately 7 ft above grade that encloses approximately 414 ac (**Figure 2**). The interior of the impoundment was 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 ft below grade, border the interior of each levee and were excavated to provide fill. Ground elevations range from approximately +21.4 ft National Geodetic Vertical Datum of 1929 (NGVD29) at the bottom of the ditches, to approximately +23.4 to +26.4 ft NGVD29 at the interior of the water farm, to +32.4 ft NGVD29 at the top of the levees. The impoundment is approximately 350 ft north of the feeder canal (south perimeter canal), 70 ft west of the main north-south irrigation canal (east perimeter canal), and 70 ft east of the drainage canal (west perimeter canal). The adjacent canals are approximately 40 ft wide and 10 to 15 ft deep. The lowest measurable water level elevation within the impoundment is approximately +23.5 ft NGVD29, as measured at SG-7. The stage elevation of +23.5 ft NGVD29 at SG-7 represents the bottom of the pressure transducer and the ability to record further data. The control elevation for the Caulkins WFPP was 29.4 ft NGVD29, which is maintained by two riser culverts on the west side of the farm and discharged (when needed) to the west perimeter ditch. Operationally, the Caulkins WFPP was maintained at a maximum stage of approximately 29 ft NGVD29 to allow 0.5 ft of freeboard as a storm event contingency. Based on the stage-storage relationship developed to facilitate the water budget (Janzen et al., 2015), the Caulkins WFPP contains approximately 27 ac-ft of water at a minimal water level of +23.4 ft NGVD29, and approximately 1,280 ac-ft of water at a maximum water level of +28.9 ft NGVD29. Based on an approximate surface area of 414 ac, the average water depth was approximately 3 ft when at capacity.

One diesel-powered vertical intake pump, located in the western part of the southern feeder canal, pumped water into the southwestern portion of the Caulkins WFPP. Pumping generally occurred during regional high-stage levels and discharge from Lake Okeechobee, and the pump typically operated at a flow rate of approximately 125 ac-ft/day. When pumping, the pump typically was operated on a 24-hour basis until the maximum level of approximately 29 ft NGVD29 is reached, then the pump was turned off until a minimum level of approximately 27.7 ft NGVD29 was reached (minimum loaded stage). Pumping was cyclic, pumping for 1 to 2 weeks until capacity was reached followed by non-pumping for 1 to 2 weeks until water levels dropped approximate 1 ft. **Figure 3** shows pumping into the impoundment with impoundment stage, rainfall, and the minimum loaded stage during the period of record. Land surface elevation at the intermediate well in the center well cluster (CAU-1M) is shown for comparison with stage.

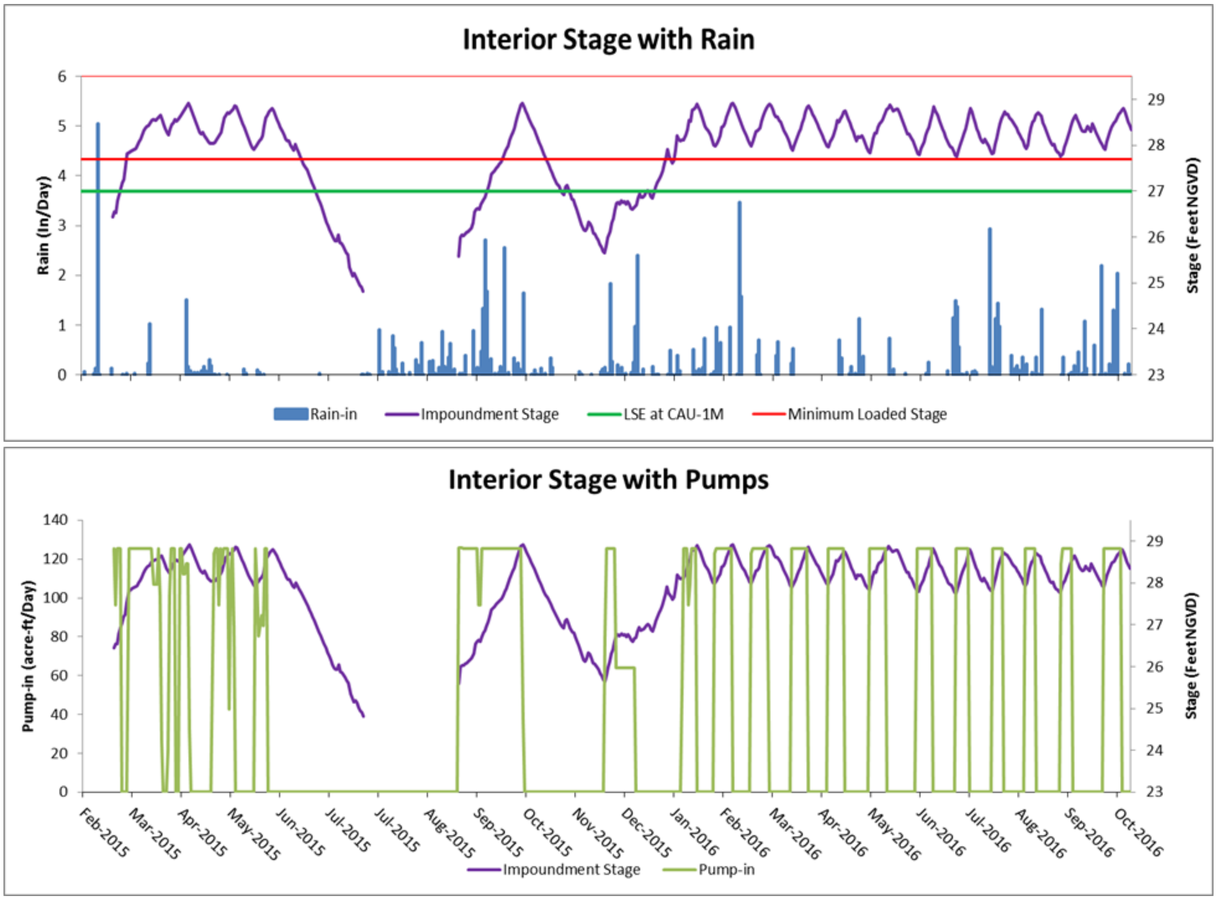

Figure 3. Pumping with impoundment stage and rain (upper chart), showing approximate land surface elevation in the center of the impoundment.

2.3 Summary of Surface Water Budget

The surface water budget (**Appendix A**) estimates residuals, which include groundwater seepage, ungauged surface flows, and errors, by calculating the difference between system gains (the sum of the pump inflow and rainfall) and losses (evapotranspiration) as well as change in storage. As errors and ungauged surface flows are not quantified in this study, the residual amount is used as total seepage out. Total seepage from February 10, 2014 through October 26, 2016 was calculated to be 38,129 ac-ft, an average of approximately 38 ac-ft/day. Rainfall, evapotranspiration, and change in storage combined accounted for a loss of less than 2 ac-ft/day.

The impoundment was at or near maximum stage (loaded) within the period of record, defined as an impoundment stage greater than 27.7 ft NGVD29, from March 1 to June 4, 2015; October 15 to November 8, 2015; and January 28 to October 31, 2016 (a total of 309 days). An average seepage rate of approximately 51 ac-ft/day was estimated during loaded conditions.

3 SITE HYDROGEOLOGY

3.1 Geologic Framework

The surficial aquifer system (SAS) in Martin County is a sequence of unconsolidated sand, silt, and shell 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 compose 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 making up 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 (Pliocene). The Anastasia formation constitutes the bulk of the SAS in the project area.

The SAS is estimated to be approximately 145 ft below land surface (bls) in the vicinity of the Caulkins WFPP based on a structural contour map of the base of the SAS (Hittle, 1999), and lithologic descriptions of boreholes in the surrounding area.

The lithology of the SAS in the vicinity of the Caulkins WFPP is described as consisting of three informal layers: Layer 1 comprises approximately 20 ft of olive-green sandy clay; Layer 2 comprises approximately 90 ft of shell and sand; and Layer 3 comprises approximately 30 ft of limestone with sand and calcareous clay (Lukasiewicz and Adams-Smith, 1996; Adams, 1992).

Hydrogeologic characterization of the planned C-44 Reservoir and Stormwater Treatment Area (STA) Project, approximately 0.5 to 7 miles west and northwest of the Caulkins WFPP, divides the SAS into three informal units (U.S. Army Corps of Engineers [USACE], 2014). Units A and B extend from surface to approximately 8 to 18 ft bls and mostly consist of sand with varying percentages of silt, clay, and shell as well as cemented sand, limestone, and clay. Unit C is present to at least a depth of approximately 50 ft bls, the maximum depth drilled over most of the site. Unit C mostly is a mixture of gray, fine sand and/or silty sand with variable shell content (some intervals are mostly shell) as well as cemented fragments and limestone. The investigation identified the base of the SAS at approximately 140 to 160 ft bls based deep soil borings.

The SFWMD installed 14 groundwater monitoring wells, including 4 well clusters, as part of this investigation. Well construction details are provided in **Table** 1 and site coordinates are provided in **Table 5**. During well installation, samples were collected for lithologic description using the standard penetration test (SPT) method with plastic lined cores and drill cuttings. A hydrogeologic cross-section is provided in **Figure 4**, and lithologic descriptions are provided in the first annual report (Janzen et al., 2015). Lithology beneath the Caulkins WFPP consists of silty sand with interbeds of sandy clay grading to clayey sand and sandy, calcareous clay from approximately 4 to 13 ft bls; silty sand and shell as well as poorly graded sand with shell is present to a depth of approximately 130 ft bls, the deepest boring drilled. In general, very fine to fine quartz sand predominates the sand and shell layers above 70 ft bls, and fine to medium shell sand predominates from 70 to 130 ft bls. Up to 6 ft of sandy silt was encountered from 60 to 72 ft bls at CAU-1 in the center of the Caulkins WFPP. A few intervals of sandy and shelly limestone less than 2 ft thick were encountered from 17 to 86 ft bls.

Table 1. SFWMD Caulkins Citrus Grove well construction table.

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

Note: Elevations are provided in ft NGVD29. Casing for all wells was polyvinyl chloride (PVC). All wells were PVC threaded 2 inches in diameter. Filter pack for all wells was 6/20 silica sand.

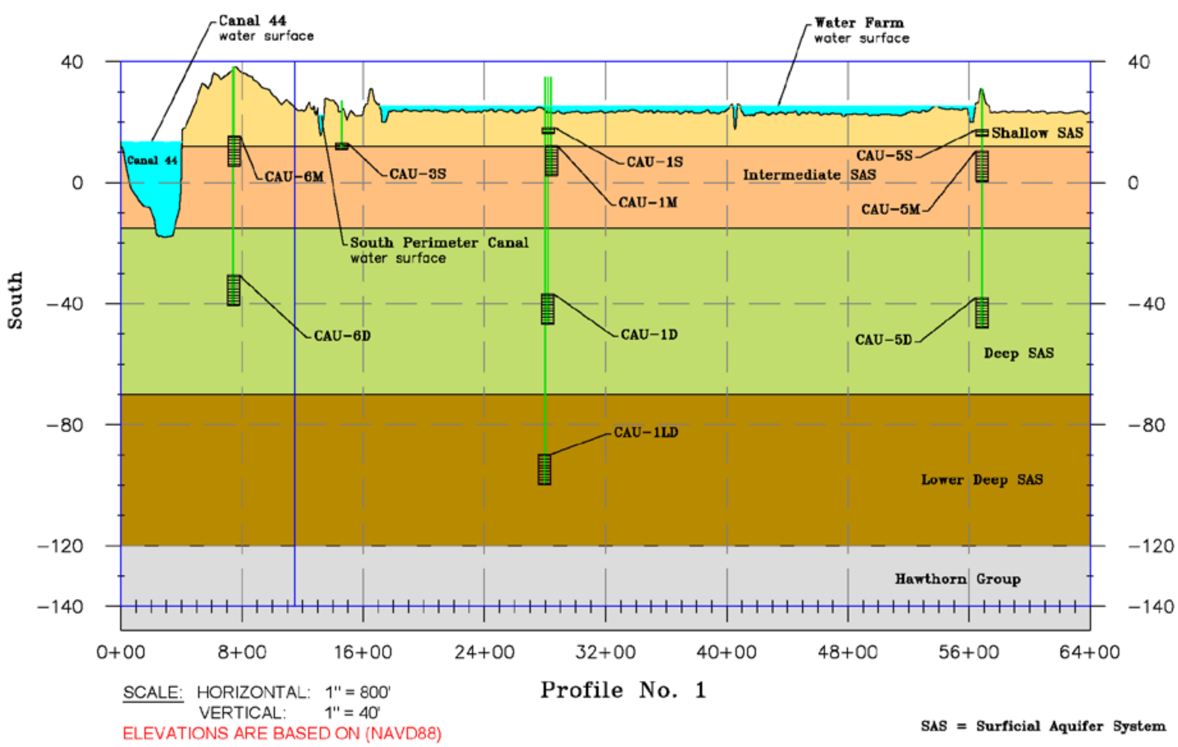

Figure 4. Generalized north-south hydrogeologic cross-section through the Caulkins Water Farm Pilot Project and C-44 Canal. (Note: NAVD88 = North American Vertical Datum of 1988; NAVD88 = NGVD29 – 1.40 ft.)

For purposes of this investigation, the SAS is divided into the shallow SAS from surface to 13 ft bls (+13.4 ft NGVD29), the intermediate SAS from 13 to 40 ft bls, the deep SAS from 40 to 95 ft bls, and the lower deep SAS from 95 to 145 ft bls. The shallow SAS corresponds to Layer 1 described by Lukasiewicz and Adams-Smith (1996) and Units A and B described by the USACE (2014). The intermediate, deep, and lower deep SAS appear to correspond to Layer 2 described by Lukasiewicz and Adams-Smith (1996) and Unit C described by the USACE (2014). Layer 3 described by Lukasiewicz and Adams-Smith (1996) was not encountered at the site.

Automated water level data from five wells installed as part of monitoring the C-44 Reservoir/STA west of the Caulkins WFPP were used to calculate groundwater gradients to the west and northwest. The wells are in two well clusters and provide continuous data available via DBHYDRO from February 12, 2016 to present. Wells C44B4A1 and C44B4A2 are approximately 12,000 ft north-northwest of the Caulkins WFPP and are screened in the intermediate and deep SAS, respectively. Wells C44B4C1, C44B4C2, and C44B4C3 are approximately 5,870 ft west of the Caulkins WFPP and are screened in the intermediate, deep, and lower deep SAS, respectively. **Table 2** provides construction information for these wells.

Table 2. C-44 Reservoir/Stormwater Treatment Area monitoring wells used in gradient analysis.

Monitor Well	Total Depth (ft bls)	Cased Depth (ft)	SAS Interval	Distance and Direction from CAU-1
C44B4A1	26.3	16.3	Intermediate	12,000 ft north-northwest
C44B4A2	55.2	45.2	Deep	12,000 ft north-northwest
C44B4C1	26.5	16.5	Intermediate	5,870 ft west
C44B4C2	60.5	50.5	Deep	5,870 ft west
C44B4C3	101.5	91.5	Lower Deep	5,870 ft west

Note: All wells are 4 inches in diameter.

3.2 Regional Groundwater Flow

Water levels were used to calibrate models that simulated groundwater flow in Layers 1, 2, and 3 within Martin County (Adams, 1992). Modeled and observed groundwater elevations indicate a southerly groundwater flow within Layer 2, the major flow layer, in the vicinity of the Caulkins WFPP. Vertical flow was downward in the Caulkins WFPP area between Layers 1 and 2, and between Layers 2 and 3, except in areas 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 area that may influence groundwater flow include the C-44 Canal approximately 1,000 ft south of the Caulkins WFPP; the Green Ridge, a topographic ridge and likely drainage divide approximately 1.7 miles northeast; and a large drainage canal approximately 0.5 miles west, which will be used as a seepage collection canal for the C-44 Reservoir/STA project that is currently under construction (Brown, 2015). Additionally, combined surface water pumping from the C-444 Canal by the Caulkins Citrus Grove (grove intake pump) and the Indiantown Grove, located near the southwestern corner of Caulkins Citrus Grove, was 6,655 million gallons (approximately 20,400 ac-ft) in 2014. Together, these factors may add a western component to the predominately southern regional groundwater flow.

The structural configuration of the SAS base may influence groundwater flow as well. According to the structural contour map in Hittle (1999), the base of the SAS slopes south towards the C-44 Canal near the Caulkins WFPP, consistent with observed groundwater flow direction at the site. Hittle (1999) also shows an inferred east-to-west structural divide approximately 2 to 4 miles north of the Caulkins WFPP, north of which the base of the SAS is inferred to slope towards the north. Well control for these contours is limited.

3.3 Hydraulic Conductivity

SFWMD staff conducted slug tests and short-term aquifer performance tests (APTs) in the newly installed wells at the Caulkins WFPP. Published hydraulic conductivity (K) data for similar lithology and aquifer test data in the vicinity of the Caulkins WFPP were reviewed and are described in detail in Janzen et al. (2015). Additional short-term pump tests of the shallow and intermediate wells at CAU-1 were performed in November 2015 and are described in **Appendix C**.

Hydraulic conductivity values have been derived from slug tests in the area, APTs, and laboratory permeability tests in the footprint of the planned C-44 Reservoir/STA project, 0.5 to 5 miles west of the Caulkins WFPP (USACE, 2014), and from an APT conducted by the SFWMD approximately 1 mile north of the Caulkins WFPP (Lukasiewicz and Adams-Smith, 1996; **Figure 5**). Results for horizontal hydraulic conductivity (Kh) and vertical hydraulic conductivity (Kv) are summarized in **Tables 3** and **4**.

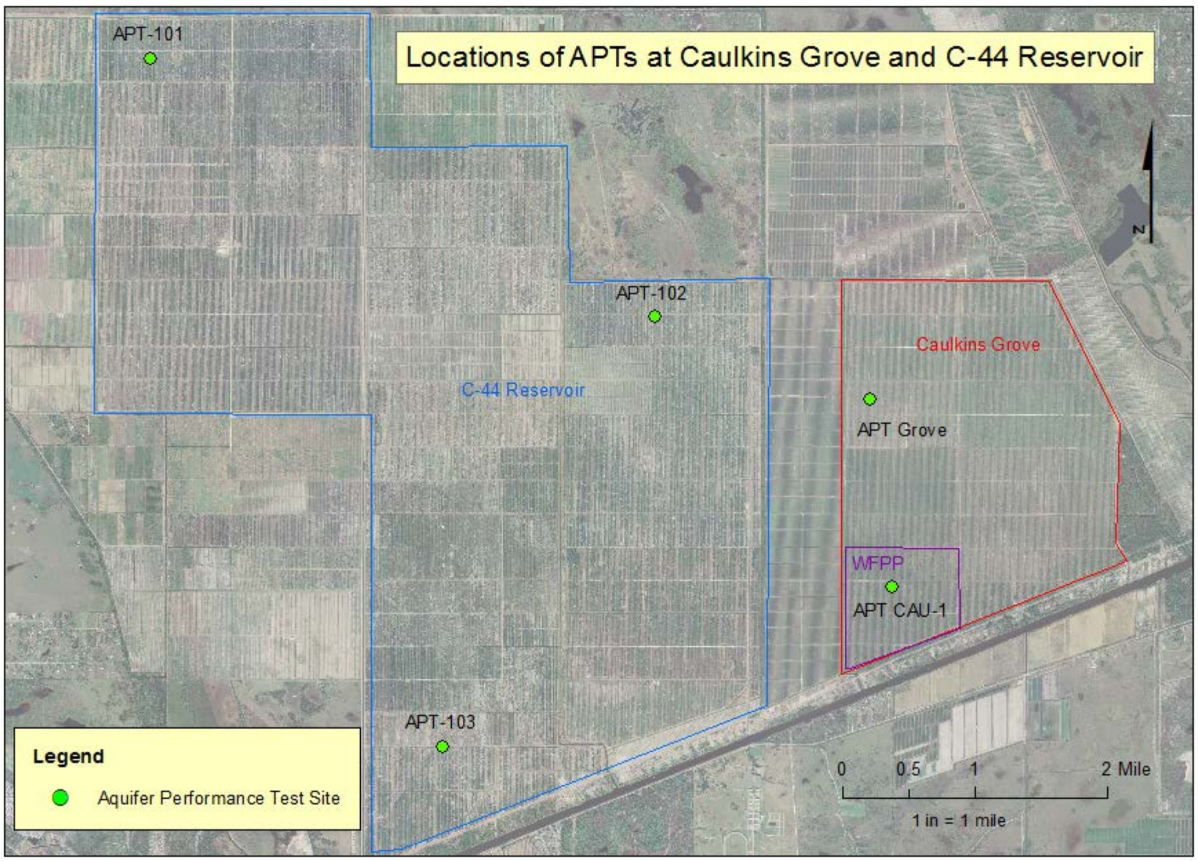

Figure 5. Location of previous and current aquifer performance tests (APTs) at the Caulkins Citrus Grove and the C-44 Reservoir and Stormwater Treatment Area Project.

Table 3. Comparison of horizontal hydraulic conductivity (Kh) values (ft/day).

<table>
<tr><th>Zone</th><th>On-site Aquifer Tests</th><th>On-site Slug Tests (Average)</th><th>Caulkins Citrus Historical Aquifer Performance Test</th><th>C-44 Field Permeability Tests and Aquifer Performance Tests</th></tr>
<tr><td>Shallow</td><td>7 to 10</td><td>77</td><td>No Data</td><td>0.4 to 4.0</td></tr>
<tr><td>Intermediate</td><td>3 to 11</td><td>26</td><td rowspan="3">51</td><td rowspan="3">24</td></tr>
<tr><td>Deep</td><td>27</td><td>10</td></tr>
<tr><td>Lower Deep</td><td>5</td><td>49</td></tr>
</table>

Table 4. Comparison of vertical hydraulic conductivity (Kv) values (ft/day).

<table>
<tr><th>Zone</th><th>C-44 Lab Hydraulic Conductivities</th><th>C-44 Field Permeability Tests</th><th>C-44 Aquifer Performance Tests</th></tr>
<tr><td>Shallow</td><td>0.003 to 1.2</td><td>0.02 to 0.04</td><td>No Data</td></tr>
<tr><td>Intermediate</td><td rowspan="3">No Data</td><td rowspan="3">No Data</td><td rowspan="3">0.7</td></tr>
<tr><td>Deep</td></tr>
<tr><td>Lower Deep</td></tr>
</table>

On-site slug tests were performed at each well except CAU-1S in October 2014 and February 2015. Short-term aquifer tests were performed on CAU-1S, CAU-1M, CAU-1D, and CAU-1LD in February and May 2015, and are described in detail in the first annual report (Janzen et al., 2015). Additional short-term aquifer tests were conducted in November 2015 at CAU-1S and CAU-1M, and are included in **Appendix C**.

Average hydraulic conductivity from the slug tests was 77 ft/day for shallow wells, 26 ft/day for intermediate wells, 10 ft/day for deep wells, and 49 ft/day for lower deep wells. Slug tests provide reasonable estimates of order of magnitude for hydraulic conductivity values (Thompson, 1987).

At site CAU-1, average hydraulic conductivity from the aquifer tests was 7 to 10 ft/day for the shallow zone, 3 to 11 ft/day for intermediate zone, 27 ft/day for the deep zone, and 5 ft/day for the lower deep zone. **Tables 3** and **4** provide a comparison of results for slug tests and APTs at the Caulkins WFPP, the 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 published test data; however, the aquifer test results appear low based on other tests in the area. No slug tests were conducted at CAU-1S.

The APTs at the C-44 Reservoir/STA project (USACE, 2014), and Caulkins Citrus Grove (Lukasiewicz and Adams-Smith, 1996) included observation wells and were much longer tests (24 hours minimum), thus they 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. Hydrogeologic characterization at the C-44 Reservoir/STA included field permeability tests for horizontal and vertical hydraulic conductivity as well as laboratory tests for vertical hydraulic conductivity in the upper clayey interval of the SAS (USACE, 2014). The C-44 tests represent the only data found for vertical hydraulic conductivity. Together, the on-site aquifer tests and off-site APTs provide reasonable ranges for hydraulic conductivity to be used in seepage analysis (**Section 6**).

4 HYDROLOGIC DATA COLLECTION AND PROCESSING

One automated water level station (SG-7) initiated data collection when the Caulkins WFPP became operational on February 10, 2014. From September 2014 through February 2015, 7 surface water stage stations, 1 rain station, and 14 groundwater monitoring wells were installed to collect automated water level and rain data. Data were collected continuously through the end of pumping on October 31, 2016. A detailed description of stations and the monitoring process is presented in the first annual report (Janzen et al., 2015). The wells provide continuous data available via DBHYDRO beginning February 12, 2016. Automated monitoring stations are described in **Table 5** and shown in **Figure 2**.

Table 5. Automated monitoring stations.

Station Name[1]	Station Type	Latitude (N)	Longitude (W)	Monitoring Initiated	Station Location
CAUSG1	Surface Water	27°02'39.0"	80°22'19.8"	11/17/2015	C-44 Canal
CAUSG2		27°03'20.0"	80°21'36.8"	11/13/2015	East perimeter canal stage
CAUSG3		27°02'55.1"	80°21'58.0"	11/13/2015	South perimeter canal stage
CAUSG4		27°03'09.4"	80°22'27.7"	11/13/2015	West perimeter canal stage
CAUSG5		27°03'36.8"	80°22'01.4"	11/13/2015	North interior stage
CAUSG6		27°02'56.1"	80°22'26.7"	11/13/2015	Southwest interior stage
CAUSG7		27°03'05.9"	80°21'38.5"	02/10/2014	Southeast interior rain and stage, installed by Milcor Group, Inc.
CAU-1S	Groundwater	27°03'08.9"	80°22'00.9"	02/20/2015	Center of WFPP
CAU-1M		27°03'08.9"	80°22'00.9"	02/20/2015	Center of WFPP
CAU-1D		27°03'08.9"	80°22'00.9"	02/20/2015	Center of WFPP
CAU-1LD		27°03'08.9"	80°22'00.9"	02/20/2015	Center of WFPP
CAU-2S		27°03'19.9"	80°21'37.7"	10/24/2014	East of WFPP
CAU-3S		27°02'55.4"	80°21'58.1"	10/24/2014	South of WFPP
CAU-4S		27°03'09.3"	80°22'27.0"	10/24/2014	West of WFPP
CAU-5S		27°03'37.3"	80°22'01.6"	10/24/2014	North of WFPP
CAU-5M		27°03'37.3"	80°22'01.6"	10/24/2014	North of WFPP
CAU-5D		27°03'37.3"	80°22'01.5"	10/24/2014	North of WFPP
CAU-6M		27°02'55.3"	80°21'39.7"	10/23/2014	North of C-44 Canal (east)
CAU-6D		27°02'55.4"	80°21'39.7"	10/23/2014	North of C-44 Canal (east)
CAU-7M		27°02'40.2"	80°22'18.0"	10/23/2014	North of C-44 Canal (west)
CAU-7D		27°02'40.2"	80°22'18.1"	10/23/2014	North of C-44 Canal (west)
C44B4A1 (M)		27°04'53.5"	80°23'04.4"	02/12/2016	12,000 ft north-northwest of WFPP
C44B4A2 (D)		27°04'53.5"	80°23'04.4"	02/12/2016	12,000 ft north-northwest of WFPP
C44B4C1 (M)		27°03'22.3"	80°23'04.7"	02/12/2016	5,870 ft west of WFPP
C44B4C2 (D)		27°03'22.3"	80°23'04.7"	02/12/2016	5,870 ft west of WFPP
C44B4C3 (LD)		27°03'22.3"	80°23'04.7"	02/12/2016	5,870 ft west of WFPP

[1] S = shallow; M = intermediate; D = deep; LD = lower deep.
WFPP = Water Farm Pilot Project.

5 HYDRAULIC GRADIENT ANALYSIS

5.1 Hydrographic Periods

Hydrographs from February 2015 through October 2016 were reviewed, including 309 days when the impoundment was loaded (full or nearly full), defined as when stage in the impoundment was 27.7 ft NGVD29 or greater. Water levels were monitored during this period for all wells except the intermediate, deep, and lower deep wells to the west (C-44 Reservoir/STA), which were not operational until January 2016. For these wells, the loaded period included the 278 days from January 28 through October 31, 2016. A baseline period discussed in this report includes the period in which the impoundment was nearly dry and groundwater levels were lowest, from August 15 through September 16, 2015 (33 days). The baseline period is defined as when water levels at the shallow well in the center well cluster (CAU-1S) were at, or nearly at, their lowest for the period of record, at or below 20 ft NGVD29 (**Section 5.3**). This section compares lateral and vertical hydraulic gradients between wells during baseline and loaded conditions in order to characterize groundwater flow patterns.

5.2 Surface Water and Shallow SAS Hydraulic Gradients

Hydrographs representative of impoundment stage; perimeter canals on the east, south, and west sides; and the shallow perimeter well (CAU-5S) on the north side of the impoundment are shown in **Figures 6** to **9**, and relative gradients are presented in **Table 6**. A consistent outward gradient is indicated by elevated stage inside the impoundment relative to perimeter monitoring stations. Of the perimeter canals, gradient was significantly higher between the west perimeter canal (the return irrigation canal) and the impoundment. The highest gradient was between the impoundment and the north shallow monitoring well (CAU-5S), which may be biased upward because the well is only 18 ft from the impoundment, and it is the only lateral shallow seepage calculation using a monitoring well instead of a perimeter canal stage. The lowest gradient was between the impoundment and the south perimeter canal, which receives water from the C-444 Canal and therefore is the up-gradient canal. The west perimeter canal was nearly dry, and water levels were not recorded in the canal during the period of record, so a default level of +19 ft NGVD29 was used.

Table 6. Shallow lateral hydraulic gradients.

Description	Stations	Loaded (ft/ft)
Impoundment to east perimeter canal	CAUSG7, CAUSG5 and/or CAUSG6 to CAUSG2	0.056
Impoundment to south perimeter canal	CAUSG7, CAUSG5 and/or CAUSG6 to CAUSG3	0.013
Impoundment to west perimeter canal	CAUSG6 to CAUSG4*	0.080
Impoundment to north well	CAUSG5 to CAU-5S	0.154

* West perimeter canal was below sensor, default value of +19 ft NGVD29 was used.

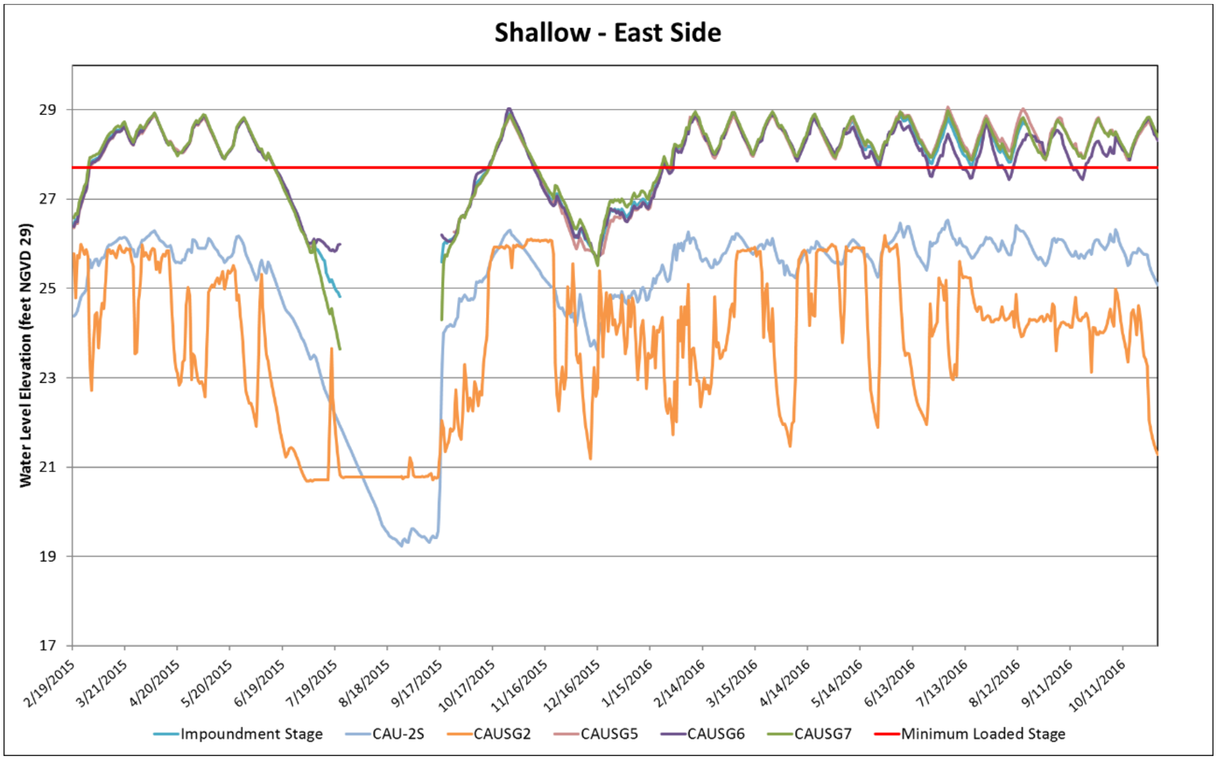

Figure 6. Hydrograph of CAUSG7 (impoundment), CAU-2S, and CAUSG2 (east perimeter canal).

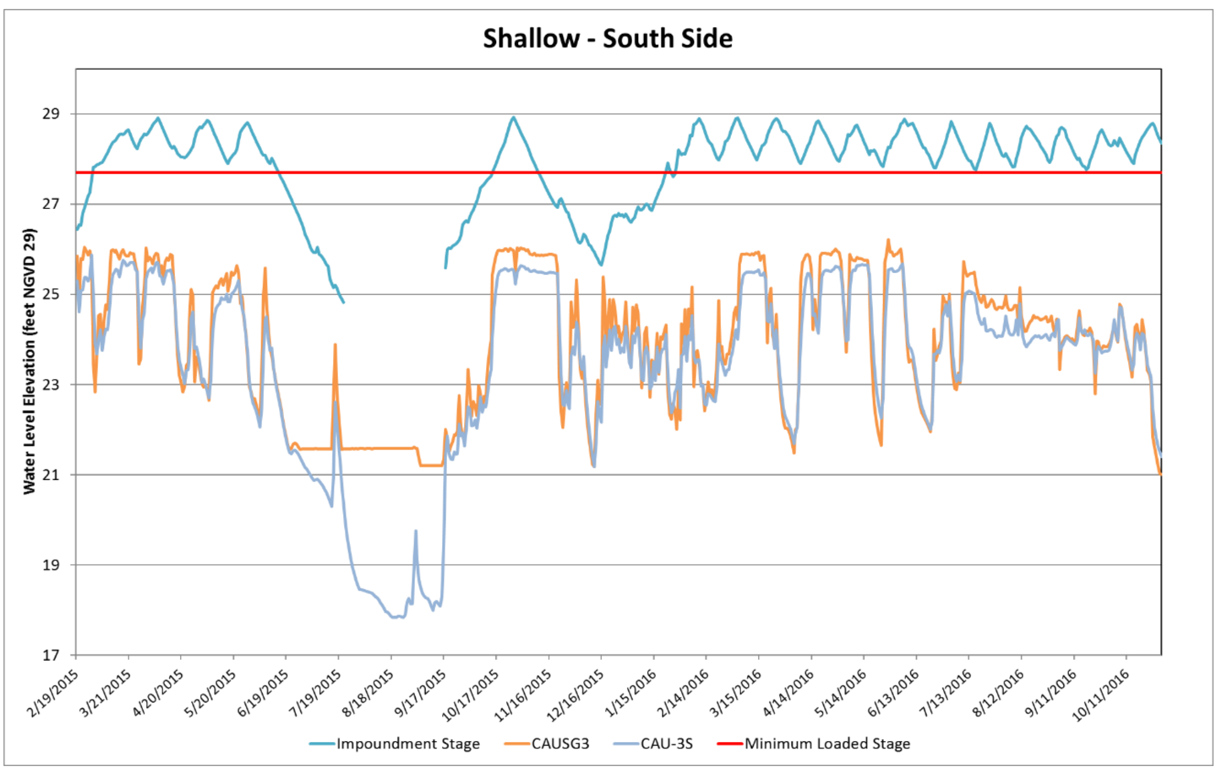

Figure 7. Hydrograph of CAUSG7 (impoundment), CAU-3S, and CAUSG3 (south perimeter canal).

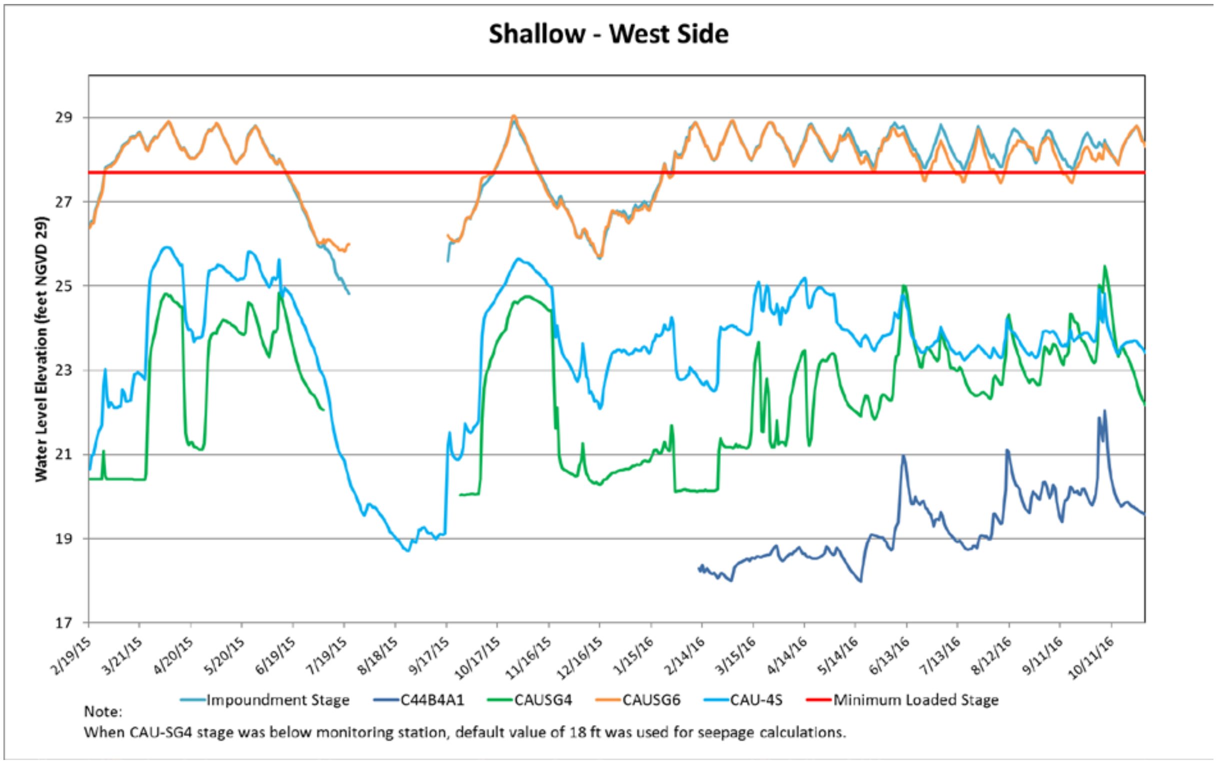

Figure 8. Hydrograph of CAUSG6 (impoundment), CAU-4S, CAUSG4 (west perimeter canal), and C44B4A1 (shallow wells at C-44 Reservoir/Stormwater Treatment Area).

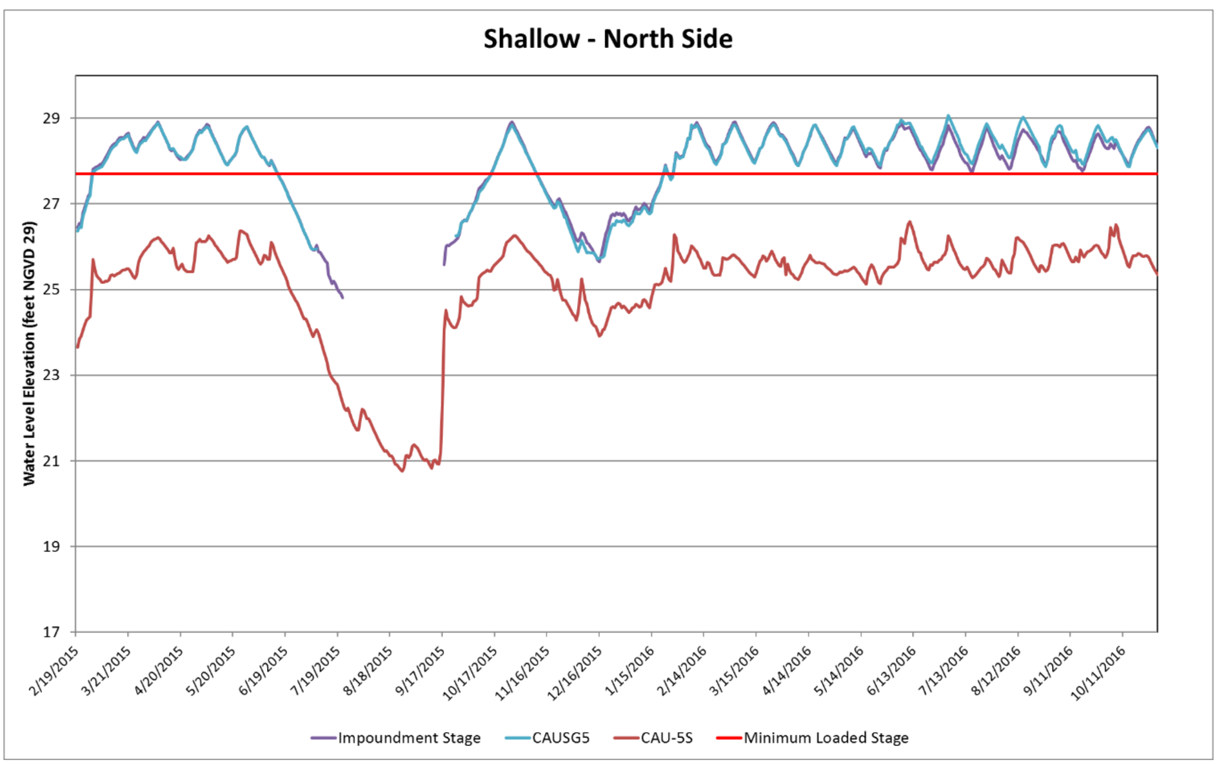

Figure 9. Hydrograph of well cluster CAU-5, including surface water at CAUSG5 (impoundment).

5.3 Vertical Hydraulic Gradient Analysis

Relative water levels were reviewed in well clusters CAU-1 inside the impoundment, CAU-5 north of the impoundment, and CAU-6 and CAU-7 south of the impoundment near the C-44 Canal to characterize vertical hydraulic gradient relationships. This analysis includes comparisons of lateral and vertical gradients between groundwater wells during the baseline period for analysis of changes in groundwater flow due to operation of the Caulkins WFPP.

During loaded conditions, maximum stage was approximately 29 ft NGVD29, 2 ft above land surface (approximately 27 ft NGVD29) at CAU-1. Groundwater levels at the shallow well (CAU-1S) also were above land surface. During the baseline period, the impoundment was dry at CAU-1, and groundwater level was as low as 19 ft NGVD29. The total increase in head during loaded conditions was as much as 10 ft. Average surface water stage at SG-1 near the C-44 Canal was approximately 14 ft NGVD29 during baseline and loaded conditions. Therefore, the difference between water levels in the impoundment and the C-44 Canal was approximately 15 ft during loaded conditions and 5 ft during baseline conditions, resulting in approximately three times the driving head.

5.3.1 CAU-1

CAU-1 is the only well cluster directly below surface water in the impoundment and provides direct evidence of a downward hydraulic gradient from the impoundment. Hydrographs of the CAU-1 well cluster are shown in **Figure 10**, and relative gradients between wells are presented in **Table 7**.

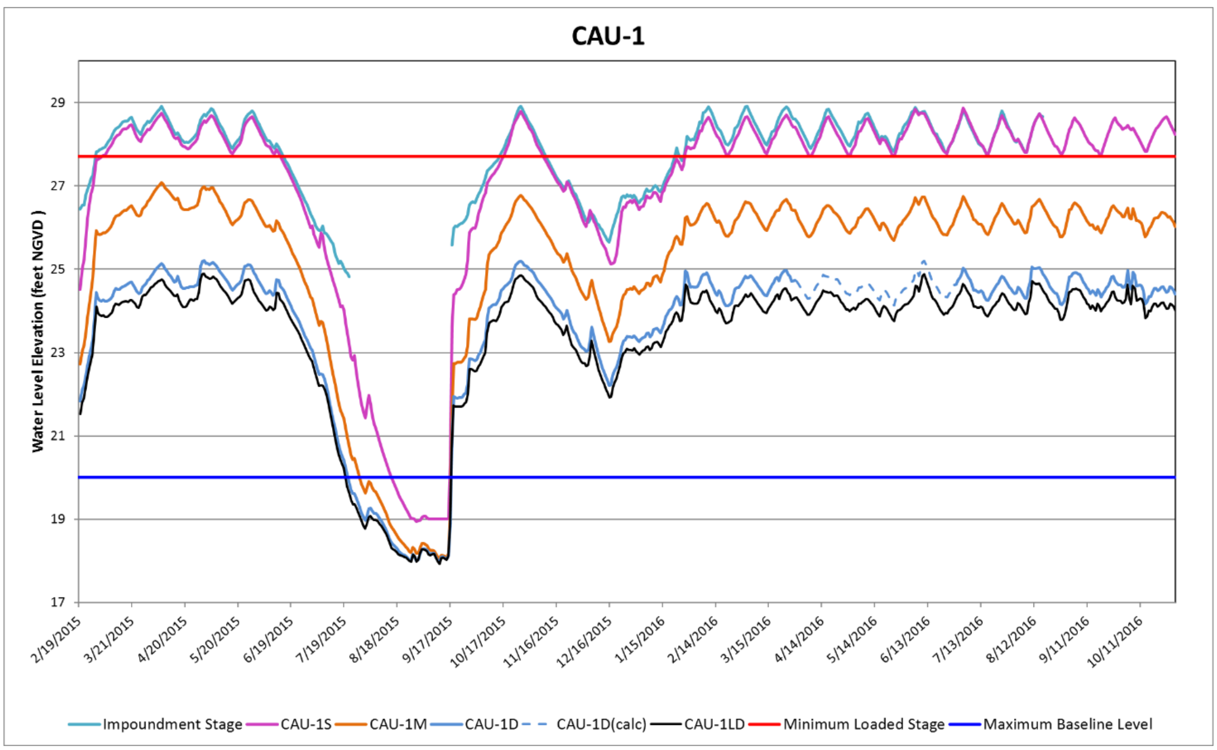

Figure 10. Hydrograph of impoundment stage and well cluster CAU-1.

Table 7. Mean vertical hydraulic gradients in well cluster CAU-1.

Description	Stations	Loaded (ft/ft)	Baseline (ft/ft)	Baseline/Loaded
Surface water to shallow SAS	CAUSG7, CAUSG5, and/or CAUSG6 to CAU-1S	0.02	N/A	N/A
Surface water to intermediate SAS	CAUSG7, CAUSG5, and/or CAUSG6 to CAU-1M	0.11	N/A	N/A
Shallow to intermediate SAS	CAU-1S to CAU-1M	0.19	0.09	47%
Intermediate to deep SAS	CAU-1M to CAU-1D	0.035	0.004	11%
Deep to lower deep SAS	CAU-1D to CAU-1LD	0.006	0.001	16%

N/A = not applicable (no surface water during baseline conditions); SAS = surficial aquifer system.

A downward hydraulic gradient was evident among all surface water wells and each of the four well screens during loaded periods. There is little hydrographic separation between the impoundment stage and the shallow well (screened approximately 7 to 9 ft bls) during loaded conditions, which may be due to vertical conduits such as furrows and depressions enhancing hydraulic connection. Under loaded and baseline conditions, hydrographic separation and higher gradients were observed between the shallow well and intermediate well, compared to the gradient between the intermediate and deep wells as well as the deep and lower deep wells, suggesting semi-confinement due to higher clay content above the intermediate well (**Table 7**).

When comparing the intermediate to deep and deep to lower deep zones, a higher gradient during loaded conditions, in contrast to convergence during baseline conditions, may be a function of higher hydraulic conductance below the shallow zone. The lowest gradient between the deep and lower deep zones is likely due to a change in flow direction from vertical to lateral, considering the lower deep zone is underlain by the Hawthorn Group.

5.3.2 CAU-5

CAU-5 is a deep well cluster adjacent to the north edge of the impoundment. As at CAU-1, a consistent downward gradient is evident between stage in the impoundment (CAUSG5) and CAU-5S, CAU-5M, and CAU-5D (**Figure 11**). However, water level in the shallow well at CAU-5 tracks very closely with the intermediate well, in contrast with the shallow well at CAU-1, which tracked very closely with impoundment stage. CAU-5 is adjacent to the impoundment rather than under it (as CAU-1 is), which suggests a lower vertical head component. The intermediate and deep wells track closer to each other than their counterparts at CAU-1, which likely is a function of an increased component of lateral flow.

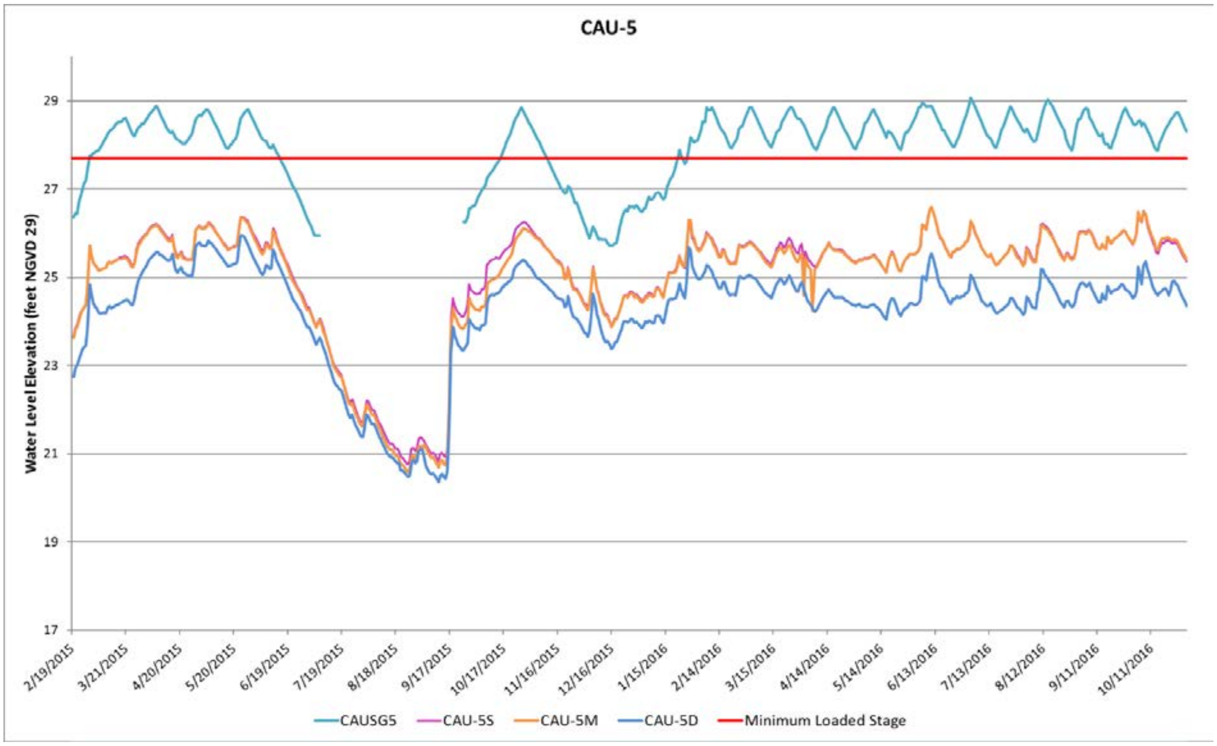

Figure 11. Hydrograph of well cluster CAU-5, including surface water of the impoundment (CAUSG5).

5.3.3 CAU-6 and CAU-7

Water levels in the intermediate and deep zones at CAU-6 and CAU-7, approximately 160 and 300 ft north of the C-44 Canal, respectively, tracked closely together (**Figures 12** and **13**). Gradient between the intermediate and deep wells at CAU-6 varied between slightly upward and slightly downward. In contrast, a consistent upward hydraulic gradient is evident between CAU-7D and CAU-7M, likely because the well cluster is closer to the C-44 Canal. Because the screen intervals in the deep wells are far below the surface water levels in the C-44 Canal, a partially upward gradient from the deep wells towards the canal is evident.

Vertical gradients up toward the C-44 Canal at CAU-7 during loaded and unloaded conditions were approximated so induced seepage into the C-44 Canal due to loading could be estimated. To calculate vertical gradient, the average daily difference between stage at SG-1, adjacent to the C-44 Canal, and CAU-7D was divided by 34 ft (the distance from the vertical midpoint of the wetted area of the C-44 Canal to the center of the CAU-7D well screen). Estimates of upward vertical gradient towards the C-44 Canal were 0.005 ft/ft under baseline conditions and 0.017 ft/ft under loaded conditions, an approximate three-fold increase (**Table 8**).

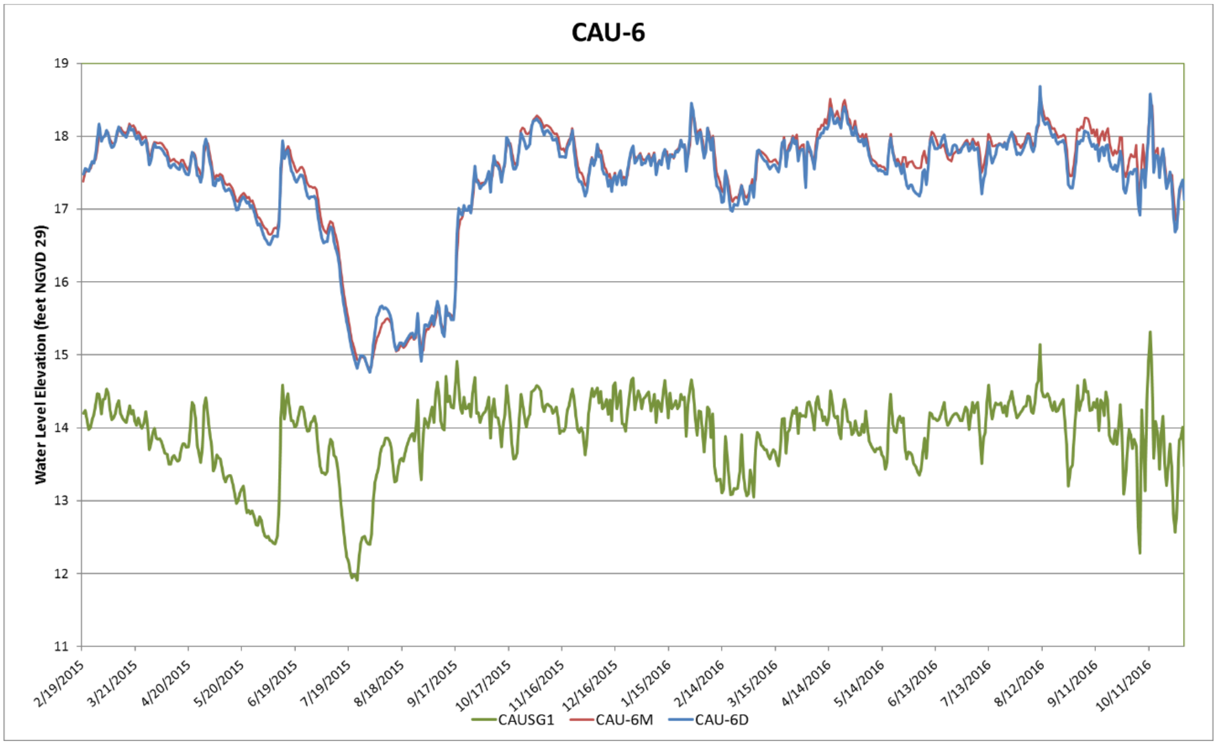

Figure 12. Hydrograph of well cluster CAU-6, including surface water at the C-44 Canal (CAUSG1).

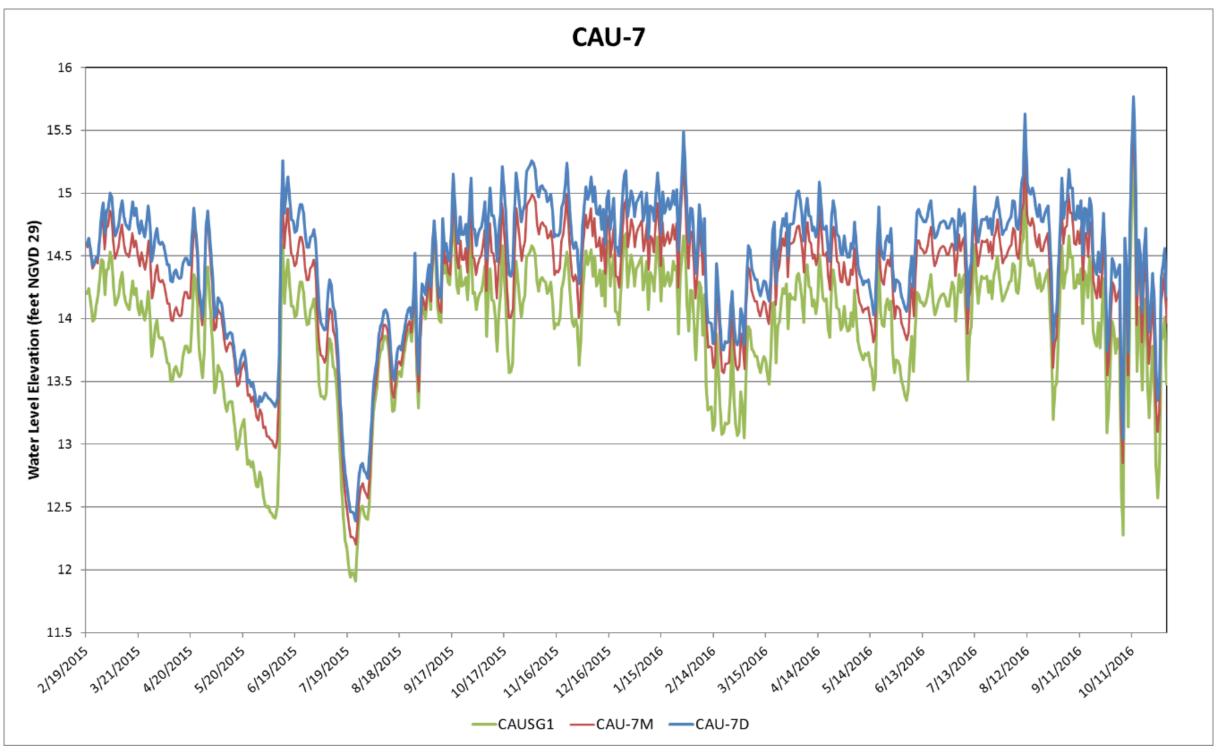

Figure 13. Hydrograph of well cluster CAU-7, including surface water at the C-44 Canal (CAUSG1).

Table 8. Mean upward hydraulic gradients in CAU-7 during loaded and unloaded conditions.

Description	Stations	Vertical Gradient (ft/ft)
Upward to the C-44 Canal - Baseline	CAU-7D to C-44 Canal	-0.005*
Upward to the C-44 Canal - Loaded	CAU-7D to C-44 Canal	-0.017*

* A negative gradient indicates upward flow.

5.4 Lateral Hydraulic Gradients in the Intermediate and Deep SAS

Lateral hydraulic gradients in the intermediate, deep, and lower deep zones were estimated by comparing wells at well clusters CAU-1, CAU-5, CAU-6, and CAU-7 as well as five wells recently activated at the C-44 Reservoir/STA 0.5 miles west (**Section 3.1**). None of the C-44 Reservoir/STA wells provided data prior to February 12, 2016. Hydrographs for monitoring wells are shown in **Figures 14** and **15**, and average daily hydraulic gradients are presented in **Tables 9** and **10**.

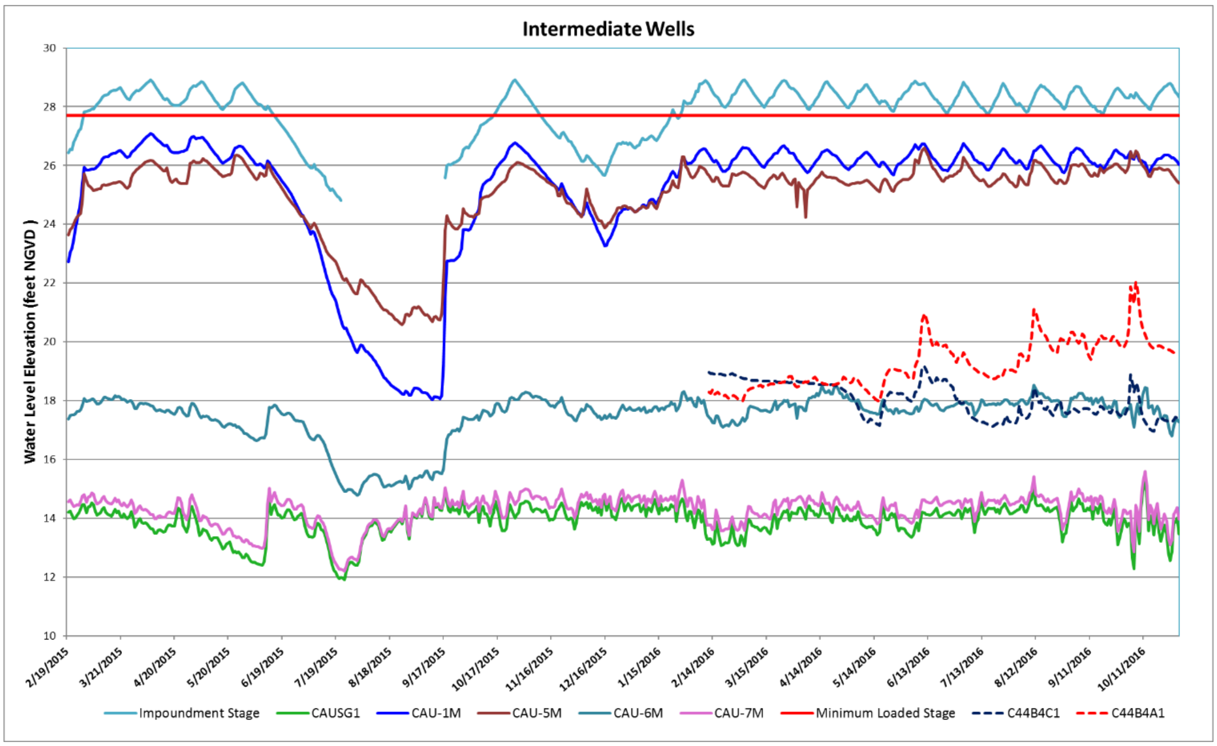

Figure 14. Hydrograph of intermediate wells and stage in the Caulkins Water Farm Pilot Project and C-44 Reservoir and Stormwater Treatment Area.

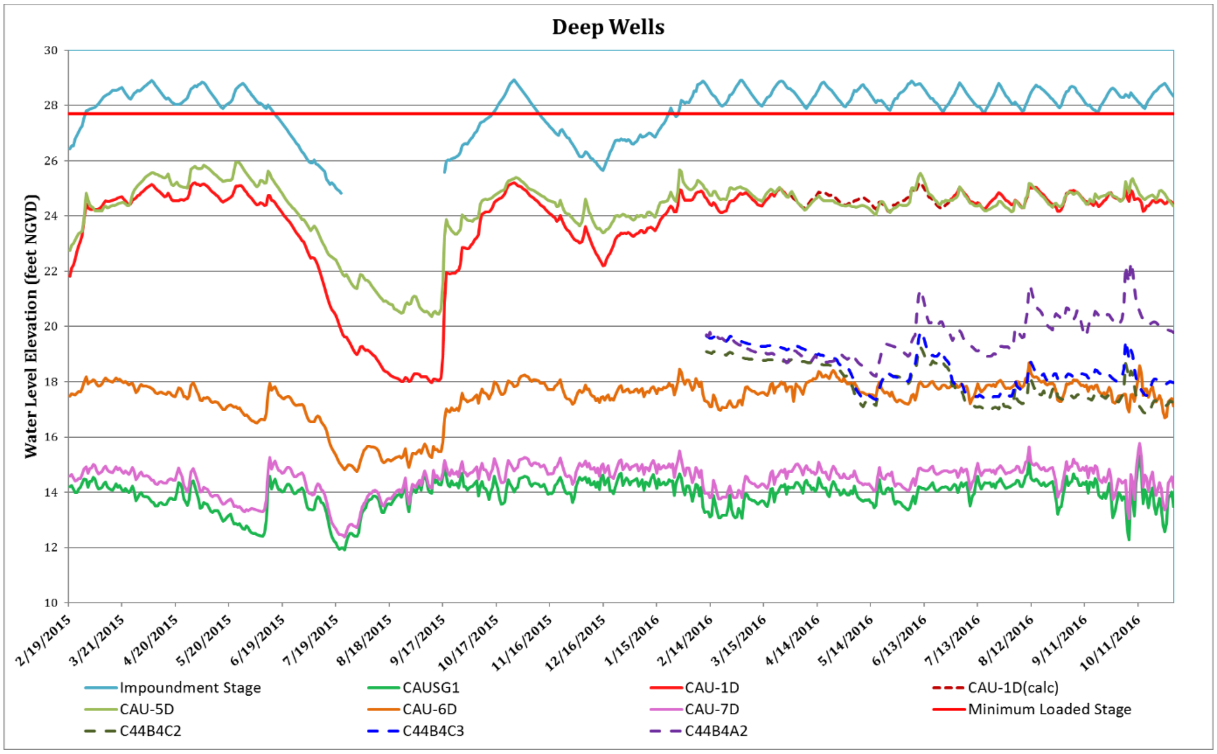

Figure 15. Hydrograph of deep wells and stage in the Caulkins Water Farm Pilot Project and C-44 Reservoir and Stormwater Treatment Area.

Table 9. Mean lateral hydraulic gradients in the intermediate surficial aquifer system.

Description	Stations	Loaded (ft/ft)	Baseline (ft/ft)
Intermediate South	CAU-1M to CAU-6M/CAU-7M	0.0038	0.0014
Intermediate North	CAU-1M to CAU-5M	0.0003	-0.0002*
Intermediate Northwest	CAU-1M to C44B4A1**	0.0006	ND
Intermediate West	CAU-1M to C44B4C1**	0.0014	ND

* A negative value indicates a southerly gradient.
** Period of record for wells on the C-44 Reservoir/Stormwater Treatment Area was February 12 through October 31, 2016.
ND = no data; wells in the C-44 Reservoir/Stormwater Treatment Area were not active during the baseline period.

Table 10. Mean lateral hydraulic gradients in the deep and lower deep surficial aquifer system.

Description	Stations	Loaded (ft/ft)	Baseline (ft/ft)
Deep South	CAU-1D to CAU-6D/CAU-7D	0.0031	0.0013
Deep North	CAU-1D to CAU-5D	<0.0001	-0.0009*
Deep Northwest	CAU-1D to C44B4A2**	0.0004	ND
Deep West	CAU-1D to C44B4C2**	0.0011	ND
Lower Deep West	CAU-1LD to C44B4C3**	0.0010	ND

* A negative value indicates a southerly gradient.
** Period of record for wells on the C-44 Reservoir/Stormwater Treatment Area was February 12 through October 31, 2016.
ND = no data; wells in the C-44 Reservoir/Stormwater Treatment Area were not active during the baseline period.

The greatest lateral gradients were southerly from the intermediate and deep zones at CAU-1 to CAU-6 and CAU-7, under loaded and baseline conditions. The loaded gradient (0.038 and 0.031 ft/ft, respectively), was approximately twice the baseline (water levels at CAU-6 and CAU-7 were averaged for calculation of southern gradient). In the intermediate and deep zones between CAU-1 and CAU-5, the gradients were nearly flat under loaded conditions (0.0003 or less) and had a slight southerly gradient under baseline conditions, reflective of a regional southerly flow.

The intermediate and deep wells at CAU-1 compared to the C44B4A1 (intermediate) and C44B4A2 (deep) wells 12,000 ft north-northwest under loaded conditions showed consistent gradients toward the north-northwest of 0.0006 and 0.0004 ft/ft, respectively. The wells were not active during the baseline period. The intermediate and deep wells at CAU-1 compared to the C44B4C1 (intermediate) and C44B4C2 (deep) wells 5,870 ft west under loaded conditions showed consistent gradients toward the west of 0.0014 and 0.0010 ft/ft, respectively. The lower deep wells at CAU-1 compared to the C44B4C3 well, also 5,870 ft west, under loaded conditions showed a consistent gradient towards the west of 0.0010 ft/ft, equivalent to the deep well.

6 SEEPAGE MODEL DEVELOPMENT AND ANALYSIS

6.1 Conceptual Model

A conceptual model was developed to characterize seepage and groundwater flow from the Caulkins WFPP into adjacent surface water and groundwater. The conceptual model relies on data from the hydrostratigraphic framework (**Section 3**) and hydrographic data collected during the period of record (**Section 5**).

Lateral seepage from the Caulkins WFPP impoundment is assumed to flow through the shallow SAS and into perimeter canals to the east, south, and west, and towards the north into the shallow SAS. All downward seepage from the impoundment is assumed to flow through the shallow SAS and into the intermediate SAS. Similarly, all vertical flow from the intermediate SAS and deep SAS is assumed to flow to the next lower zone, and all lateral flows are assumed to flow north, east, south, or west. Gradients to the east are not known due to lack of well control; therefore, all flow estimates are based on the assumption that eastern flow represents a minimal component.

The lower boundary of the impoundment 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 ft NGVD29) to an elevation of +12 ft NGVD29, a depth of approximately 13 ft 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 ft NGVD29, at depth of approximately 40 ft bls. Lithology consists of silty, quartz, and shell sand to poorly graded sand. The deep SAS includes the base of the intermediate SAS to an elevation of -68.6 ft NGVD29, a depth of approximately 95 ft bls. Lithology consists of 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 ft bls. Lithology consists of predominately silty sand composed of mostly shell fragments.

6.2 Seepage Calculation Formulas

A spreadsheet model was developed to calculate daily average values for the seepage/groundwater flow paths using Darcy's general equation for groundwater flow (Todd, 1980):

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

Where:

K = hydraulic conductivity (either vertical or horizontal) of the media through which water flows (ft/day)
A = cross-sectional area of the face through which the water flows
dh= change in head between the upgradient and downgradient measurement stations based on daily average water levels
dl = distance, either vertical or horizontal, between the upgradient and downgradient measurement stations

6.2.1 Downward Seepage from the Impoundment

Calculation of seepage through the bottom face of the impoundment was modified from the first annual report (Janzen et al., 2015). Daily mean water level for CAU-1M was substituted for CAU-1S as better representative of vertical gradient. Vertical seepage was calculated by subtracting daily mean water levels in the impoundment (represented by SG-5, SG-6, and SG-7) and daily calculated levels at CAU-1M, screened immediately below the upper clayey sand portion of the SAS, to represent the change in head (dh). When data for one or two of the surface water stations were unavailable, the average of available data was used. The distance (dl) between the bottom of surface water reservoir and the shallow screen interval was used.

Parameters for calculating downward seepage from the impoundment include the following:

- Vertical distance between the impoundment water surface and water levels in CAU-1M (dh);
- Distance between the base of the impoundment and the mid-screen interval of CAU-1M (dl; 18.27 ft); and
- Bottom surface area covered by water as estimated by the stage-bottom area correlation relationship (A).

Due to the uneven surface of the bottom of the impoundment (substrate) at relatively shallow water depths, the bottom area of the impoundment (area covered by water) increases rapidly with increased water depth, until water covers the entire bottom, then increases at a slower rate until the impoundment reaches capacity. Because the downward gradient from the impoundment is calculated using the bottom surface area (A), only the bottom area covered by water, not sub-areal area, can be used. The computer-aiding drafting survey generated for the stage-storage relationship described in Janzen et al. (2015) was used to calculate an impoundment bottom area for each 0.5-ft rise in water elevation from +23.4 to +28.9 ft NGVD29. A ninth-order polynomial regression was used to fit the calculated bottom area curve, which was used to interpolate between each 0.5 ft to calculate bottom areas for each 0.1 ft in water level elevation rise.

6.2.2 Shallow East Face Seepage

Seepage through the east face of the impoundment was derived using water levels on the eastern side, represented by CAUSG7, and water levels in the east perimeter canal, represented by CAUSG2.

This calculation assumed that all seepage through the eastern face traveled 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 impoundment and east perimeter canal (dlse) = 70 ft
- Height of east seepage face (dH) = the water level in the impoundment (CAUSG7) = 12 ft NGVD29 (elevation of the base of the shallow SAS)
- Length of eastern seepage face (EFL) = 3,120 ft

6.2.3 Shallow South Face Seepage

Seepage through the south face of the impoundment was derived using water levels on the southern side, represented by CAUSG7 and CAUSG6, and in the south perimeter canal (feeder canal), represented by SG-3. This calculation assumed that all seepage through the southern face traveled through the shallow portion of the SAS. Other parameters for calculation of southern seepage include the following:

- Distance between the impoundment and south perimeter canal (dlss) = 300 ft
- Length of southern seepage face (SFL) = 4,320 ft
- Height of seepage face (dH) is the water level in the impoundment (average of CAUSG7 and CAUSG6) = 12 ft NGVD29 (elevation of the base of the shallow SAS)

6.2.4 Shallow West Face Seepage

Seepage through the west face of the impoundment was derived using water levels on the western side, represented by CAUSG6, and in the west perimeter canal (drainage canal), represented by CAUSG4. This calculation assumed that all seepage through the western face traveled within the shallow portion of the SAS.

The west perimeter canal typically contains very little water, and water levels were below the CAUSG4 stage recording device during the period of record. The west perimeter canal consists of the southern portion of the return canal from the Caulkins Citrus Grove, and is controlled by irrigation ditch gates that minimize return flow. Based on visual observation, under these "almost dry" conditions, there is a small amount of water (1 ft or less) in topographic lows at the bottom of the canal. The bottom of the canal is approximately 19 ft NGVD29 elevation. Therefore, when the water level was below the recording device at CAUSG4, a default water level of +19 ft NGVD29 was used for gradient calculation. Other parameters for calculation of western seepage include the following:

- Distance between the impoundment and west perimeter canal (dlsw) = 71 ft
- Length of western seepage face (WFL) = 5,690 ft
- Height of seepage face (dH) is the water level in the impoundment (CAUSG6) = 12 ft NGVD29 (elevation of the base of the shallow SAS)

6.2.5 Shallow North Face Seepage

Seepage through the north face of the impoundment was derived using water levels on the northern side, represented by CAUSG5, and shallow groundwater to the north, represented by CAU-5S. This calculation assumed that all seepage through the northern face traveled within the shallow portion of the SAS. Other parameters for calculation of northern seepage include the following:

- Distance between the impoundment and CAU-5S (dlsn) = 18 ft
- Length of northern seepage face (NFL) = 4,320 ft
- Height of seepage face (dH) is the water level in the impoundment (CAUSG5) = 12 ft NGVD29 (elevation of the base of the shallow SAS)

6.2.6 Downward Flow from Intermediate SAS

Groundwater flow through the bottom face of the intermediate SAS was derived from water levels in the monitoring well CAU-1M, screened at a depth of 15 to 25 ft bls, and well CAU-1D, screened at a depth of 62 to 72 ft 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 ft
- Bottom area beneath the outer edges of the Caulkins WFPP = 414 ac

6.2.7 Lateral Flow from Intermediate SAS

Calculation of lateral flow from the intermediate SAS beneath the impoundment was limited in this investigation to southerly, northerly, and westerly flow. Lateral flow to the east was not estimated due to a lack of monitoring wells. Lateral flow through the southern face of the intermediate SAS was derived using water levels represented by monitoring well CAU-1M, screened at a depth of 15 to 25 ft bls, and downgradient 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) = 2,700 ft
- Length of southern seepage face (SFL) = 4,320 ft
- Height of seepage face (dH) = 27 ft

Lateral flow through the northern face of the intermediate SAS was derived using water levels represented by monitoring wells CAU-1M and 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) = 2,000 ft
- Length of southern seepage face (SFL) = 4,320 ft
- Height of seepage face (dH) = 27 ft

6.2.8 Downward Flow from Deep SAS

Downward flow through the bottom face of the deep SAS towards CAU-1LD was calculated using water levels for monitoring well CAU-1D, screened at a depth of 62 to 72 ft bls, and CAU-1LD, screened at a depth of 120 to 130 ft 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 = 58.5 ft
- Bottom area beneath the outer edges of the Caulkins WFPP = 414 ac

6.2.9 Lateral Flow from Deep SAS

Calculation of lateral flow from the deep SAS beneath the impoundment was limited in this investigation to southerly, northerly, and westerly flow. Lateral flow to the east was not estimated due to a lack of well control. Lateral flow to the southern face of the deep SAS was calculated using water levels represented by monitoring well CAU-1D, screened at a depth of 62 to 72 ft bls, and downgradient water levels represented by CAU-6D and CAU-7D (averaged) near the C-44 Canal, screened at depths of 69 to 79 ft bls. Parameters for calculation of southerly flow include the following:

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

Lateral flow through the northern face of the deep SAS primarily was driven by water levels represented by monitoring well CAU-1D, and water levels downgradient were represented by CAU-5D on the north levee, screened from 69 to 79 ft bls. Parameters for calculation of intermediate northerly lateral flow include the following:

- Distance between CAU-1D and CAU-5D (dlin) = 2,700 ft
- Length of northern face (SFL) = 4,930 ft
- Height of seepage face (dH) = 50 ft

6.2.10 Lateral Flow from Lower Deep SAS

The lack of monitoring wells screened in the lower deep interval lateral to the impoundment precludes calculation of the lateral component of flow.

6.3 Development of Seepage Estimates

Lateral and vertical (downward) seepage estimates were developed for the impoundment, intermediate SAS, and deep SAS using seepage formulas described earlier. Estimates were developed when the impoundment was full (i.e., loaded condition) using the best fit period of record based on the seepage estimate (**Appendix A**) from February through October 2016. Stage relationships and relative gradients associated with loaded conditions are described in more detail in **Section 5.1**. Seepage estimates were calibrated by varying Kh and Kv parameters while satisfying the following flow conditions based on the conceptual model:

- The average daily residual seepage during the period of record representative of loaded conditions (51 ac-ft/day) (**Appendix A**) is equivalent to total seepage from the impoundment, which is equivalent to seepage from each of the four side faces (lateral seepage) plus seepage from the bottom face.
- Downward flow from the impoundment is equivalent to all flow from the intermediate SAS, in addition to eastern flow, which was not quantified in this report.

- Downward flow from the intermediate SAS is equivalent to all flow from the deep SAS, in addition to eastern flow, which was not quantified in this report.
- Downward flow from the deep SAS is equivalent to all flow from the lower deep SAS, which was assumed to be lateral due to the underlying Hawthorn Group, a confining unit. Lateral flow from the lower deep SAS (approximately 50 ft thick) was not estimated in this report due to a lack of well control.

The shallow SAS has a higher clay content and lower K values compared to deeper zones, and vertical seepage through the base of the shallow SAS is more easily accommodated in the lower zones. Therefore, the relative estimates for horizontal and vertical hydraulic conductivity of the shallow SAS are most critical variables. The best estimates for horizontal and vertical hydraulic conductivity in the shallow, intermediate, and deep zones based on testing on and near the site (**Section 3**) were used to develop lateral and vertical seepage estimates for each zone (**Tables 11** and **12**). Seepage estimates to the east in the intermediate and deep zones, and all lateral seepage estimates in the lower deep zone, were not estimated due to a lack of lateral well control.

Table 11. Seepage estimates for each zone using a horizontal hydraulic conductivity value of 10 ft/day in the shallow SAS with an anisotropic ratio of approximately 0.1.

Shallow SAS			Intermediate SAS			Deep SAS		
Kh	Kv	AR	Kh	Kv	AR	Kh	Kv	AR
10	1.0	0.1	30	3.4	0.11	50	19	0.38

AR = anisotropic ratio (Kv to Kh); Kh = horizontal hydraulic conductivity (ft/day); Kv = vertical hydraulic conductivity (ft/day); SAS = surficial aquifer system.

Table 12. Seepage estimates from impoundment as a percentage of total seepage using shallow horizontal and vertical hydraulic conductivity values of 10 ft/day and 1.12 ft/day, respectively.

Flow Source	Downward Seepage (ac-ft/day)	Downward Seepage Percent	Lateral Seepage (ac-ft/day)	Lateral Seepage Percent (Total)	North Seepage Percent	West Seepage Percent	East Seepage Percent	South Seepage Percent
Impoundment	51	92%	4	8%	4%	3%	1%	<1%
Intermediate	47	99%	<1	<1%	<1%	ND*	ND*	<1%
Deep	47	99%	<1	<1%	<1%	ND*	ND*	<1%

*East and west lateral seepage was not calculated, assumed to be minimal.

The relative percentages of lateral and downward seepage during loaded conditions from the impoundment, intermediate zone, and deep zone are presented in **Table 12** and shown graphically in **Figure 16**. Approximately 92 percent of seepage from the impoundment was vertical. Lateral seepage in the shallow SAS towards perimeter canals to the east, west, and south, and towards the shallow aquifer to the north, constituted the remaining 8 percent. The greatest lateral seepage in the SAS was to the north and west (4 and 3 percent of total seepage, respectively) because the perimeter canals to the south and east were closest to the source and hydraulically upgradient. The predominant flow direction in the intermediate and deep SAS was downward. Lateral flow was less than 1 percent of the total flow in each zone, and most lateral flow was to the south towards the C-44 Canal. Flow to the east and west were not estimated due to a lack of well control, but were assumed to be minimal. Flow from the lower deep zone was expected to be lateral because it is underlain by the Hawthorn confining layer. Lateral flow estimates were not made for the lower deep zone due to a lack of well control; however, based on regional gradients, lateral flow most likely was southerly towards the C-44 Canal.

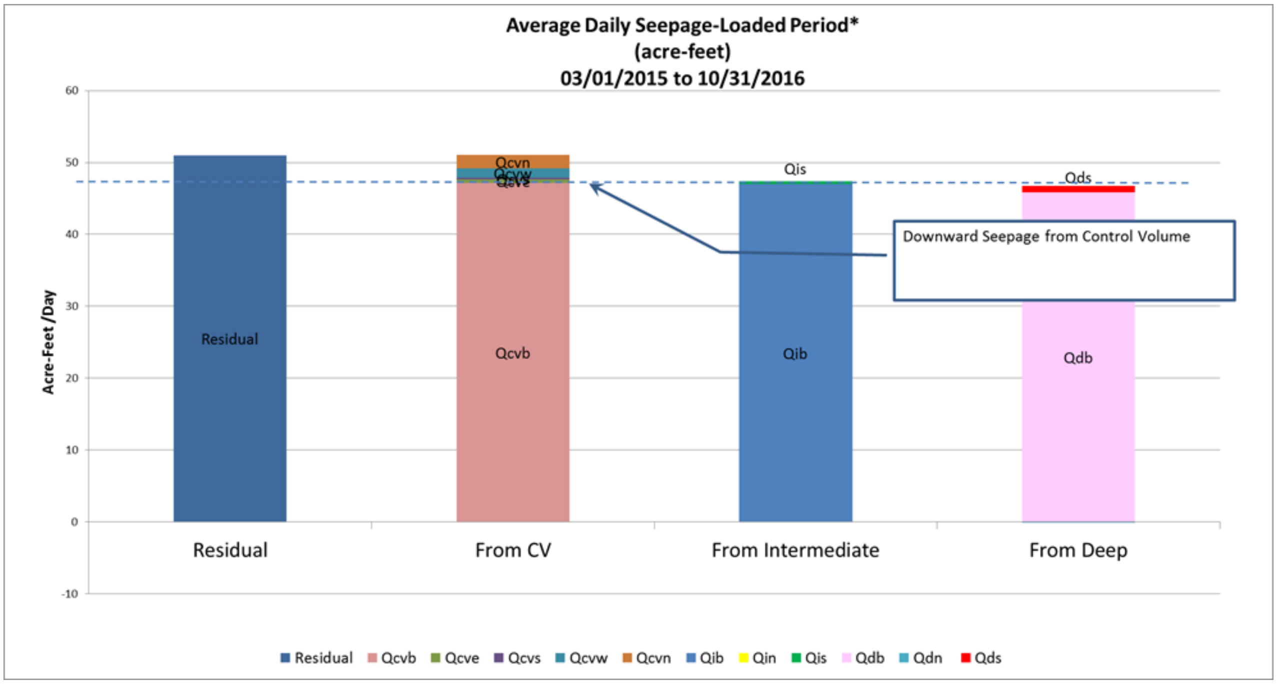

Figure 16. Graphical representation of seepage and groundwater flow using horizontal and vertical hydraulic conductivity values of 10 ft/day and 1.0 ft/day, respectively, for the shallow SAS. *Loaded period includes March 1 through June 14, 2015; October 15 through November 8, 2015; and January 28 through October 31, 2016.

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

Average flow velocities from the impoundment to the C-44 Canal were calculated assuming most flow occurred through the lower deep SAS and towards the C-44 Canal. Most downward seepage from the impoundment presumably will flow below the screen interval of the deep well CAU-1D (approximately 72 ft bls) south towards the C-44 Canal, representing a section approximately 73 ft thick, assuming the base of the SAS is at 145 ft bls. Downgradient wells were not installed in the lower deep zone, so there are no gradient data; however, the gradient for the deep zone was substituted using CAU-1 and CAU-6/7 during loaded conditions.

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

$$v = \frac{K(dh \div dl)}{n} \tag{2}$$

Where:

K = hydraulic conductivity of the media through which water flows (ft/day)
dh = change in head between the upgradient and downgradient measurement locations

dl = distance, either vertical or horizontal, between the upgradient and downgradient measurement locations
n = effective porosity

An estimate of 50 ft/day was used for hydraulic conductivity (K) based on the results of on-site aquifer tests and APTs in the vicinity as well as 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 (n) of sand (Fetter, 1980). The average gradient in the deep zone between CAU-1D and the midpoint of CAU-5D and CAU-6D adjacent to the C-44 Canal during the period of record was 0.0031 ft/ft. The resultant velocity and travel time from the center of the impoundment to the C-44 Canal, a distance of approximately 2,700 ft, was 0.7 ft/day and 11 years, respectively. This is an average travel time for the entire impoundment. The southern edge of the impoundment is approximately 900 ft from the C-44 Canal. Using a velocity of 0.7 ft/day, it would take approximately 3.5 years for the nearest water in the impoundment to reach the C-44 Canal.

6.5 Ambient Seepage into the C-44 Canal

An analysis was conducted to examine the short-term effects of loading the impoundment on increased ambient seepage/recharge to the C-44 Canal induced by upgradient head. Pumping water into the impoundment increased groundwater gradients between the intermediate and deep wells in the impoundment (CAU-1) and wells adjacent to the C-44 Canal (CAU-6 and CAU-7) nearly instantaneously. The implication being increased recharge of ambient water near the C-44 Canal, as compared to the travel time of water from the impoundment to the C-44 Canal. An analysis was conducted to estimate the short-term increase in seepage groundwater into the C-44 Canal due to loading the impoundment compared to seepage under baseline conditions based on groundwater gradients. Two discharge estimates were made for comparison: 1) using lateral gradient from the impoundment to the C-44 Canal, and 2) using upward gradient from the deep aquifer at CAU-7 into the C-44 Canal.

The first estimate combines the calculated flow southward in the intermediate and deep SAS (Qis and Qds). For this analysis, the intermediate zone and the deep zones were combined, and an aquifer thickness of 134 ft was used, which is the length of wetted surface of the C-44 Canal, from the top of the bank on the north side to the deepest point on the canal bed, based on a surveyed cross-section of the C-44 Canal.

As described previously, southerly flow in the intermediate and deep SAS was calculated using the formula:

$$Q = -KA(dh/dl)$$

Other values used to derive discharge (Q) are as follows:

Kh – In the intermediate and deep zones, horizontal hydraulic conductivity (Kh) values were assumed to be 50 ft/day based on published APTs in the vicinity and on regional modeling.

dh/dl – The gradient (dh/dl) for the intermediate and deep zones was taken from the average gradients between CAU-1 and CAU-6/7 (**Table 10**), 0.0035 for loaded and 0.0014 for baseline conditions.

A – A width of 134 ft is the length from the top of the bank to the canal bed, based on a surveyed cross-section of the C-44 Canal, and a length of 4,800 ft parallel to the south face of the impoundment was used to calculate a wetted area of 643,200 ft^3.

The following discharges are calculated:

- Q_{loaded} = 2.58 ac-ft/day
- $Q_{baseline}$ = 1.03 ac-ft/day
- Net discharge due to pumping into impoundment (Q_{net}) = 1.45 ac-ft/day = approximately 3 percent of the average pump rate into the impoundment (51 ac-ft/day) during loaded conditions.

The second estimate is based on the upward gradient from deep monitor well CAU-7D, approximately 160 ft north of the C-44 Canal, to surface water stage in the C-44 Canal as measured at SG-1.

$$Q = -K\ (dh/dl)\ A$$

Values used to derive Q are as follows:

K – The vertical hydraulic conductivity (Kv) in the deep zone was estimated to be 3.5 ft/day based on calibration of the seepage model.

dh/dl – The gradient (difference in height of water levels/difference in length between measurement points [dh/dl]) was taken from the average gradients from CAU-7D to stage at SG-1, -0.017 for loaded and -0.005 for baseline. A dl of 34 ft was used from the vertical midpoint of the wetted area of the C-44 Canal to the center of the well screen at CAU-7D.

A = Wetted area of 643,200 ft^3 as calculated previously.

The following discharges were calculated:

- Q_{loaded} = 0.88 ac-ft/day
- $Q_{baseline}$ = 0.26 ac-ft/day
- Net discharge (Q_{net}) = 0.62 ac-ft/day = approximately 1 percent of the average pump rate into the impoundment (51 ac-ft/day) during loaded conditions

7 SUMMARY AND CONCLUSIONS

The Caulkins WFPP was constructed from August through December 2013, and pumping into the impoundment began February 2, 2014, continuing intermittently through October 26, 2016 (approximately 33 months). Approximately 39,542 ac-ft of water were pumped into the impoundment, and total seepage of 38,129 ac-ft (38 ac-ft/day) was estimated based on residuals presented in the water budget (**Appendix A**). The impoundment was maintained at or near full capacity, between 27.7 and 29 ft NGVD29, for approximately 18 months.

Seven surface water stage stations and 14 groundwater monitoring wells were installed in and around the Caulkins WFPP to characterize groundwater seepage flow patterns. Each station was equipped with data loggers, and water levels were monitored continuously. Groundwater well screens were installed in four zones within the SAS, referred to as shallow (0 to 13 ft bls), intermediate (13 to 40 ft bls), deep (40 to 85 ft bls), and lower deep (85 to 145 ft bls) in this report. Water level data were reviewed from two well clusters recently installed at the C-44 Reservoir/STA, approximately 2 miles northwest and 1 mile west, including well screens in the intermediate, deep, and lower deep zones.

Water level data collection for all stations except the deep well cluster (CAU-1) in the center of the impoundment began in October 2014, and seepage analysis through January 2015 is included in the first annual seepage report (Janzen et al., 2015). Surrogate water level data for the deep well cluster were used for the first annual report. This report contains water level data and seepage analysis from February 2015 through October 2016, including all groundwater data since the CAU-1 well cluster in the center of the impoundment was installed. Hydraulic gradients and seepage while the impoundment was maintained at nearly full capacity (loaded) are compared to the baseline period when the impoundment effectively was dry. During loaded conditions, seepage averaged 51 ac-ft/day. Seepage was not estimated for the baseline period.

Maximum stage in the impoundment was approximately 2 ft above land surface in the center of the impoundment, at an elevation of approximately 29 ft NGVD29, up to 10 ft above baseline groundwater levels. Based on relative water levels during loaded conditions, surface water from the impoundment flowed downward into deeper portions of the aquifer and outward into perimeter canals to the east, south, and west, and to the shallow aquifer to the north. Under loaded and baseline conditions, hydrographic separation and higher gradients were observed between the shallow well and the intermediate well, compared to intermediate to deep wells and deep to lower deep wells, suggesting semi-confinement due to higher clay content above the intermediate well. The lowest gradient between the deep and lower deep zones was likely due to a change in flow direction from vertical to lateral, considering the lower deep zone is underlain by the Hawthorn Group, a confining unit.

The difference between water stage in the impoundment and in the C-44 Canal was approximately 15 ft during loaded conditions and 5 ft during baseline conditions, resulting in approximately three times the driving head. The highest lateral gradients in the intermediate and deep zones were to the south and more than double the next highest gradients to the west during loaded conditions. Lateral gradients to the north were less than 10 percent of gradient to the south during loaded conditions and were reversed during baseline conditions, suggesting regional groundwater flow to the south. Lateral gradients to the east in the intermediate and deep zones, and to the north, east, and south in the lower deep zone, were not quantified due to a lack of well control.

Horizontal and vertical seepage and groundwater flow estimates were developed using the Darcy general equation for groundwater flow, relative surface and groundwater levels, and a range of hydraulic conductivity estimates from on-site testing and published values from nearby tests. A spreadsheet model was developed to calibrate daily average seepage estimates using the seepage estimate developed in the surface water budget. Best estimates for hydraulic conductivity for the shallow, intermediate, and deep SAS were used to calculate relative vertical and horizontal seepage from each zone. Vertical seepage through the base of the shallow SAS was limited by a higher clay content, and seepage was more easily accommodated in the lower zones. Therefore, the relative estimates for horizontal and vertical hydraulic conductivity in the shallow SAS are critical variables, and best estimates were 10 and 1 ft/day, respectively. Hydraulic conductivities of the intermediate and deep zones were 30 and 50 ft/day, respectively.

Approximately 47 ac-ft/day (92 percent) of seepage were vertical from the impoundment, with approximately 4 ac-ft (8 percent) lateral seepage into the shallow SAS to the north, west, east, and south perimeter canals. Approximately 99 percent of vertical flow from the impoundment was into the lower deep aquifer, with approximately 1 percent flowing towards the south and the north. Gradients to the west were less than one-half gradient to the south, suggesting western flow is less than 1 percent. Groundwater flow to the east and from the lower deep zone was not estimated due to a lack of well control. Because the underlying Hawthorn Group is a confining unit, and because regional groundwater gradients are southerly towards the C-44 Canal, most flow from the lower deep zone is likely to the south.

Travel time from the impoundment to the C-44 Canal was calculated assuming most flow toward the C-44 Canal occurred through the lower deep portion of the SAS. Based on an estimated hydraulic conductivity value of 50 ft/day and the average groundwater gradients between deep wells in the center well cluster and wells near the C-44 Canal, a travel time of approximately 11 years was estimated as an average for the entire impoundment. The southern edge of the impoundment is approximately 900 ft from the C-44 Canal. The estimate for the nearest water in the impoundment to reach the C-44 Canal is approximately 3.5 years.

Short-term effects of loading the impoundment on increased ambient seepage/recharge to the C-44 Canal induced by upgradient head was compared to long-term flow from the impoundment. Two discharge estimates were made; the first estimate compared horizontal gradient between the intermediate and deep wells in the center of the impoundment to average of wells near the C-44 Canal, resulting in a seepage of 2.58 ac-ft/day during loaded conditions and 1.03 ac-ft/day during baseline conditions. The second estimate compared upward vertical gradient between the deep well adjacent to the C-44 Canal and the stage in the canal, resulting in a seepage of 0.88 ac-ft/day during loaded conditions and 0.26 ac-ft/day during baseline conditions. Net seepage induced by loading using the two estimates ranged from 1.45 to 0.62 ac-ft/day.

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APPENDIX A

Caulkins Water Farm Pilot Project Surface Water Budget Evaluation

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Data from February 10, 2014 to October 31, 2016

January 10, 2017

This is a preliminary evaluation of surface water budget using data from February 10, 2014 to October 31, 2016. Subsurface and perimeter canal monitoring and data analysis by groundwater experts are required to fully characterize the water flow pattern at the site and determine the direction of storage losses. This summary is limited to observed/recorded surface water parameters and estimates for storage change. Storage losses are estimated as surface water balance residuals.

I HYDROLOGICAL OBSERVATIONS AND ESTIMATIONS

Sources of Data

Daily water level data for the Caulkins Water Farm Pilot Project (WFPP) that represent water storage level at site SG-7, daily pumping volume into the Caulkins WFPP, and daily rainfall data for the site were provided by the project manager. Evapotranspiration (ET) estimates were used from the closest weather station with data, ACRAWX (dbkey UA588 in DBHYDRO). Hydrologic data for the whole period and monthly values are provided in **Tables A-1** and **A-2**, respectively. **Figure A-1** depicts monthly inflow pumping, rainfall, and ET.

Table A-1. Summary of hydrologic observations (February 10, 2014 to October 31, 2016).

Source	Volume (ac-ft)	Depth of Water on Surface Area (ft)	Depth of Water on Surface Area (in.)
Pumping	39,542	95.51	--
Rainfall	--	11.84	142.11
Evapotranspiration	--	12.35	148.23
Change in storage	--	2.90	34.8

Area = 414 acres.

Table A-2. Monthly summary of hydrologic observations.

Year	Month	Pump Inflow (ac-ft)	Rainfall (in.)	ET (in.)	Storage Losses (ac-ft)
2014	February	850	2.53	2.693	671
	March	748	1.55	4.999	376
	April	679	1.01	5.566	940
	May	436	4.09	6.032	1,193
	June	0	11.76	5.645	62
	July	2,076	5.57	5.04	625
	August	1,804	3.64	5.656	1,540
	September	1,398	8.52	4.397	1,416
	October	1,980	2.95	4.691	1,912
	November	1,674	2.71	3.352	1,425
	December	9	1.34	3.27	1,068
2015	January	0	0.69	3.598	873
	February	1,429	7.43	3.733	-78
	March	2,958	1.46	5.1	2,443
	April	1,897	2.71	4.934	1,783
	May	1,192	0.3	6.033	1,039
	June	0	0.03	5.156	775
	July	0	1.88	5.282	1,054
	August	0	4.95	4.701	9
	September	1,603	11.03	3.932	527
	October	3,273	3.12	3.966	2,449
	November	0	3	3.012	786
	December	1,411	4.94	2.599	1,371
2016	January	192	9.27	2.595	-78
	February	2,137	2.92	3.84	1,861
	March	1,630	3.05	4.535	1,645
	April	1,381	0.88	5.511	1,491
	May	2,009	5.15	5.608	1,786
	June	1,507	8.64	5.046	1,573
	July	1,256	4.25	5.453	1,343
	August	1,381	9.68	4.581	1,528
	September	1,248	5.05	3.905	1,196
	October	1,381	6.01	3.77	1,525

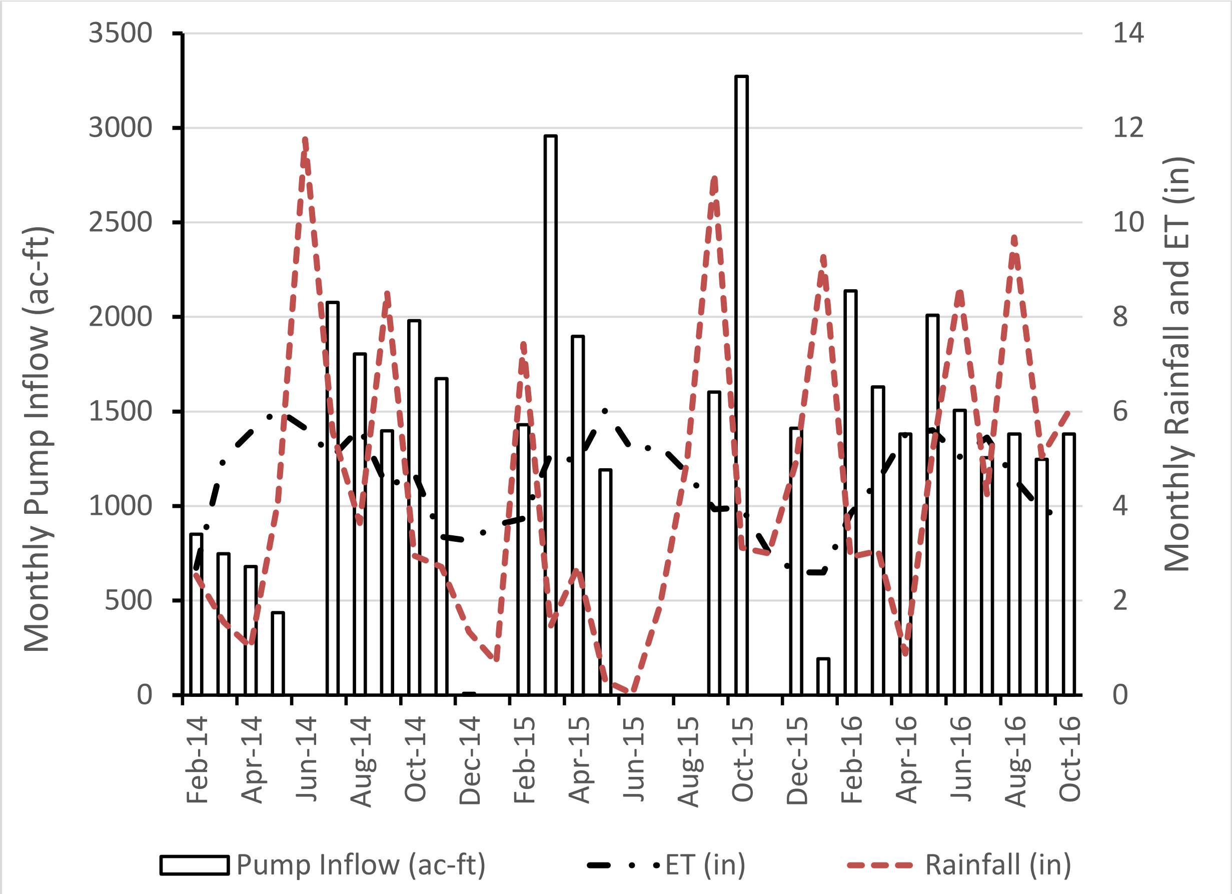


Figure A-1. Monthly inflow pumping, rainfall, and evapotranspiration.

Surface Water Budget Analysis

Water budget analysis for a storage farm is subject to residuals due to ungauged surface and subsurface 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 1. The unit for each parameter can be volume of water or depth of water on the surface area of the site (414 acres).

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

Where ΔS is change in storage as a difference between ending and beginning storage for the analysis period; Є is errors associated with measurements and ungauged surface and subsurface flows. At the Caulkins WFPP, surface outflow is not recorded and surface water discharge is not part of the operation, so the water balance equation is modified as follows (Equation 2) where residuals are measurement errors as well as ungauged surface and subsurface flows.

$$\Delta S = \text{Surface Water Inflow} + \text{Rainfall} - \text{ET} \pm \text{Residuals} \quad (2)$$

Because the rest of the parameters in Equation 2 are recorded or calculated values, the unknown residuals can be calculated by Equation 3 as system losses or gains.

$$\text{Residuals} = \text{Surface Water Inflow} + \text{Rainfall} - \text{ET} - \Delta S \quad (3)$$

Positive residuals indicate there are unaccounted outflows, and negative residuals indicate unaccounted inflows. Residuals for the analysis period are shown in **Table A-3** with the water budget components. Change in storage is the difference between the ending and beginning stages of the analysis period. A positive change in storage represents an increase in stage while a negative change represents a decline in stage or storage. If water levels fall below ground at the end of the period, subsurface storage can be estimated for the soil at the site (fine sand and slightly clay fine sand). Change in storage from February 10, 2014 to October 31, 2016 was 2.90 ft as the difference of the ending stage (28.40 ft NGVD29) and the beginning stage (25.50 ft NGVD29) (**Figure A-1**). The positive residual indicates that 92.1 ft (38,129 ac-ft) have left the surface system, and direction of flow cannot be determined from the surface water budget analysis.

Table A-3. Period of record residuals and water budget parameters (in ft of depth of water) over the 414-acre site (February 10, 2014 to October 31, 2016).

Parameters	Volume (ac-ft)	Depth of Water on Surface Area (ft)
Pump Inflow	39,542	95.51
Rainfall	4,902	11.84
Evapotranspiration	5,113	12.35
Change in Storage	1,201	2.90
Water Budget Residual	38,129	92.1

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-2**. Net inflow is the balance of pumping and rainfall as inflows and ET as outflow (dashed purple line). A negative value in **Figure A-2** means outflow is higher than inflow for a day where ET is higher than inflow pumping and rainfall combined. A rapid drop in measured water level was observed when inflows were reduced, indicating water levels will fall without continuous pumping.

The site can respond to inflows in two ways. First, with no storage losses from the site and/or with high inflows, the water level can reach the riser (overflow stage in **Figure A-3**). Second, pumping control, meteorological conditions, and unmeasured storage losses can keep the water level below the riser overflow stage. Monthly storage loss for the period of analysis calculated by the water budget is shown in **Figure A-4**. Daily average storage loss was 38.3 ac-ft, and monthly average storage loss was 1,167 ac-ft.

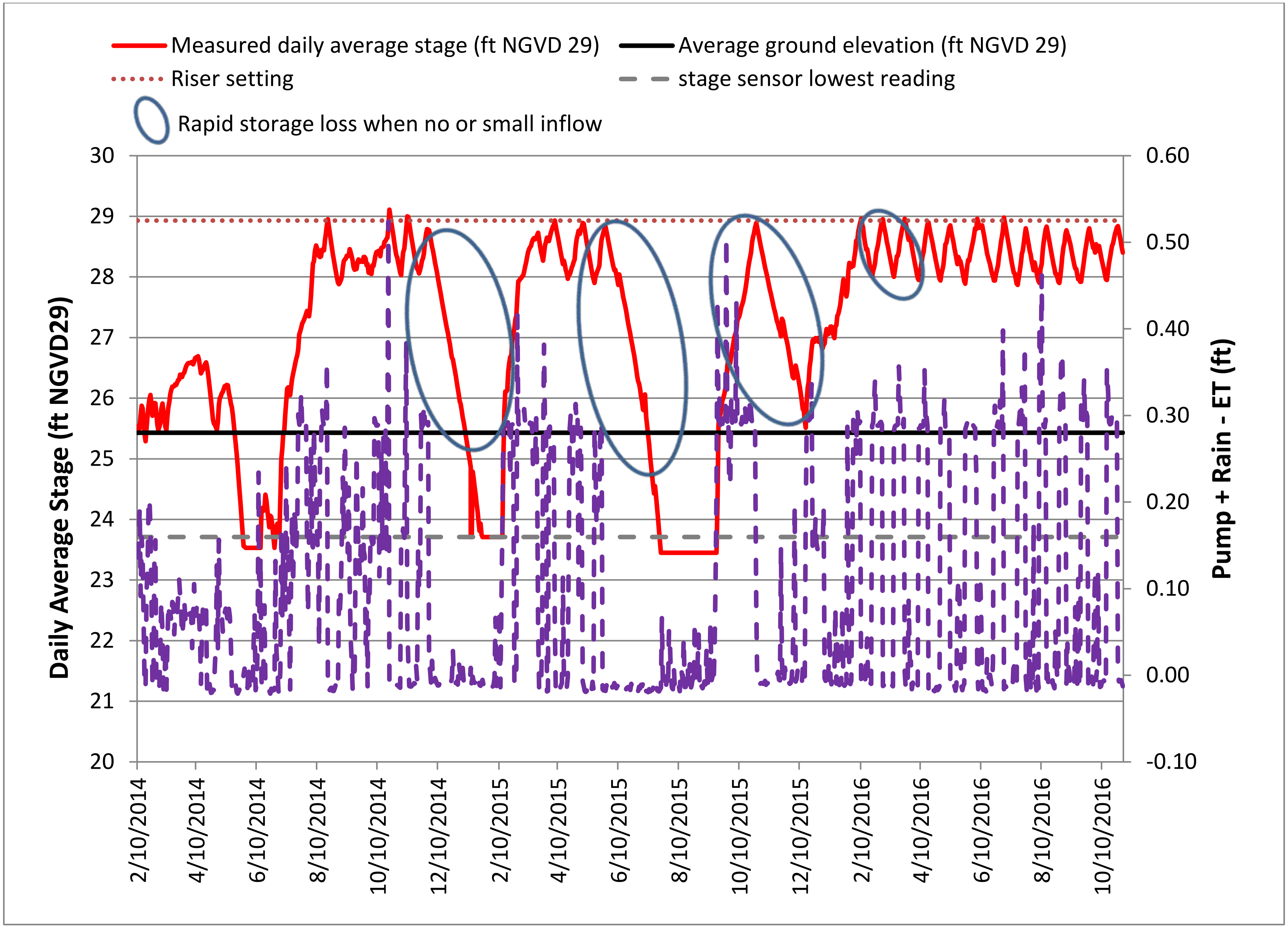


Figure A-2. Daily water level fluctuation and net inflows.

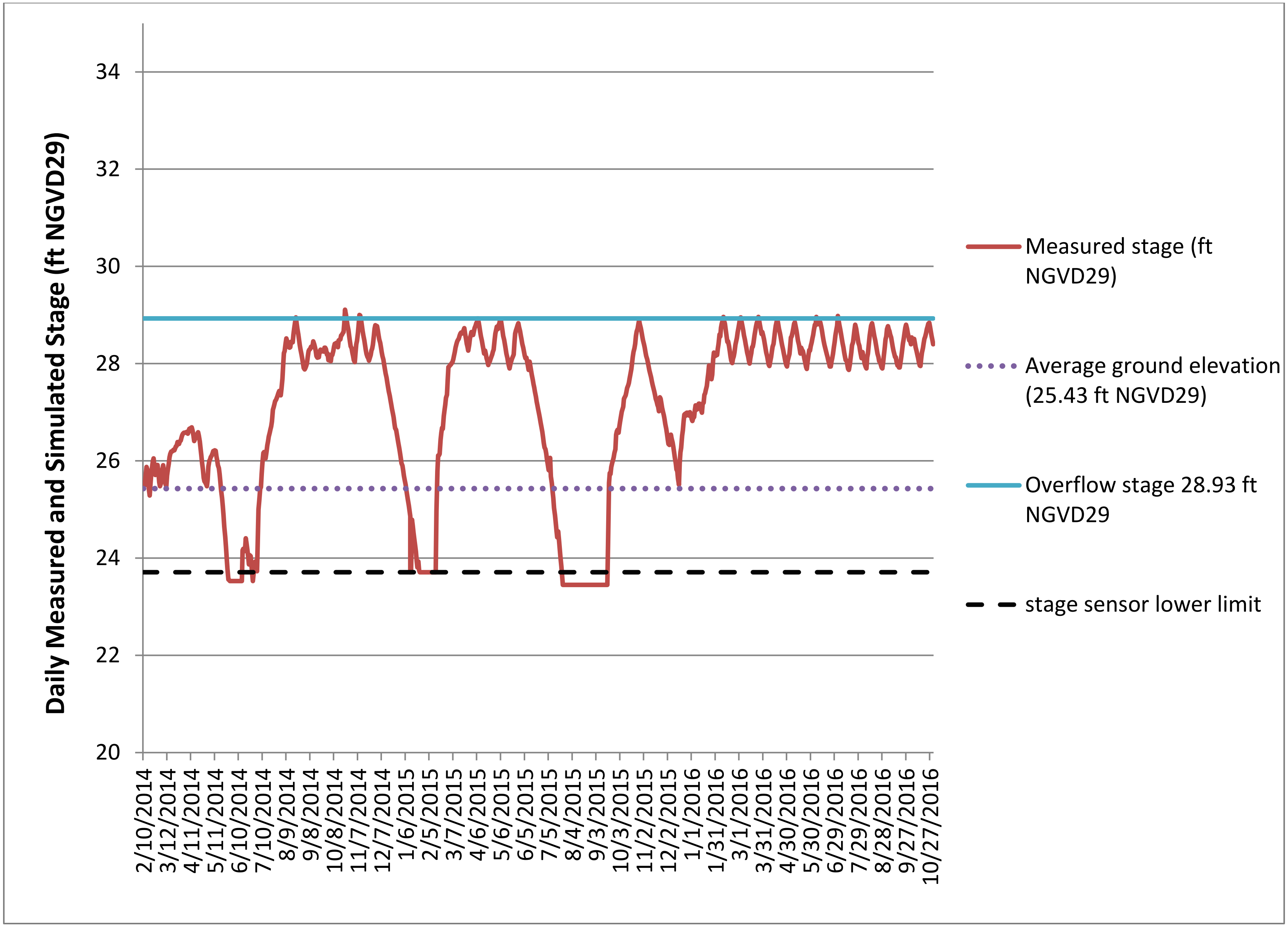


Figure A-3. Daily stage fluctuations influenced by inflow pumping, rainfall, evapotranspiration, and storage losses.

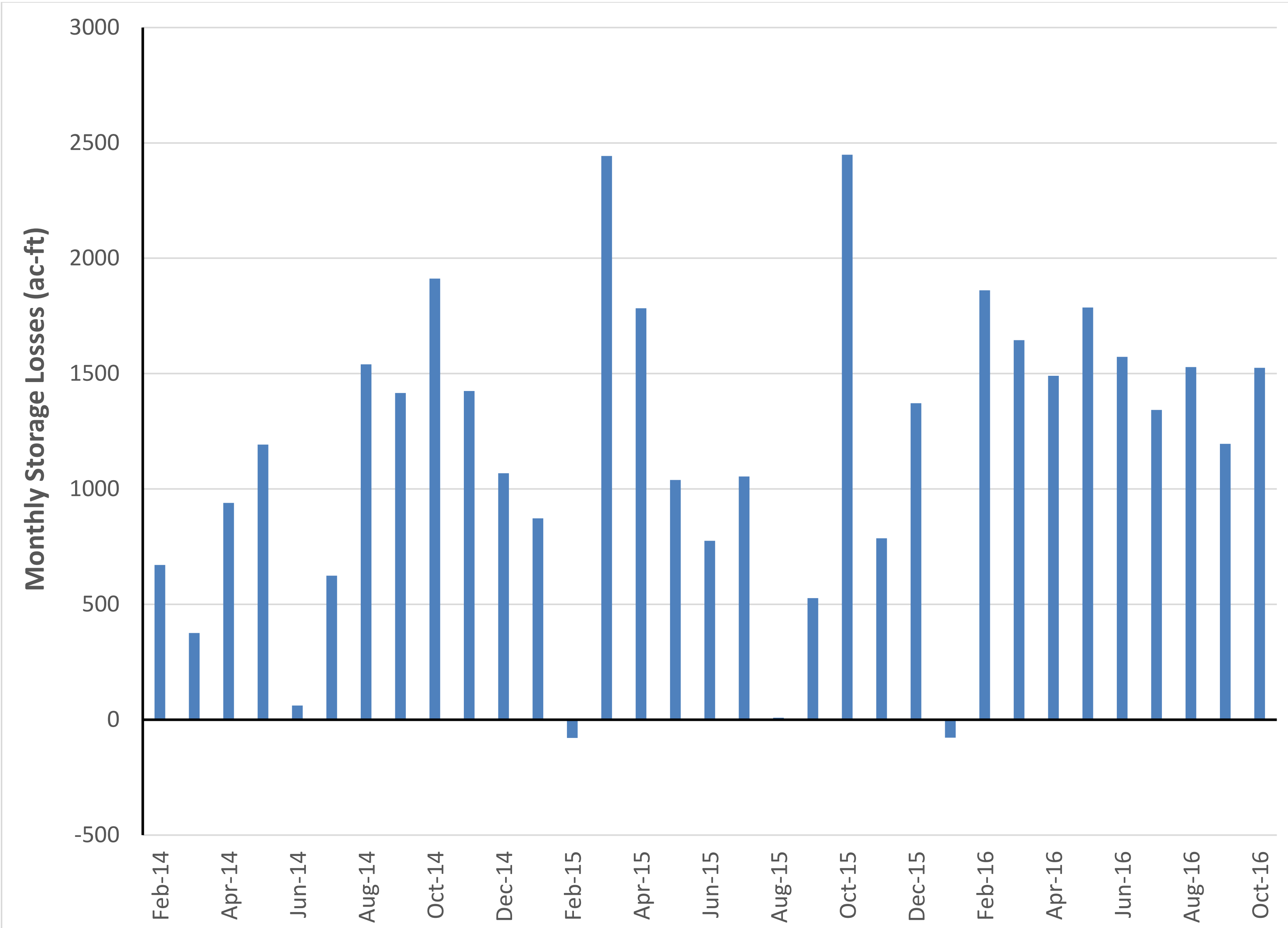


Figure A-4. Monthly storage losses calculated from the water budget (February 2014 through October 2016).

APPENDIX B

Water Quality Results

ACRONYMS AND ABBREVIATIONS

µS/cm	microsiemens per centimeter
Ca	calcium
$CaCO_3$	calcium carbonate
Cl	chloride
DO	dissolved oxygen
HCO_3	bicarbonate
K	potassium
Mg	magnesium
mg/L	milligrams per liter
Na	sodium
NH_4	ammonium
$NO_3 + NO_2$	nitrate + nitrite
SO_4	sulfate
SRP	soluble reactive phosphorus
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TP	total phosphate

INTRODUCTION

The purpose of water quality sampling at the Caulkins Water Farm Pilot Project (WFPP) was to "fingerprint" surface and groundwater sources as well as characterize nutrient concentrations within the project area and the C-44 Canal. Four rounds of sampling were conducted: February 2015 (Site CAU-1 only); August 2015; October 2015; and March/April 2016. The temporal spread of sampling events allowed for qualitative analyses of water types under loaded (impoundment filled) and unloaded scenarios. Nutrient concentrations in and around the impoundment were quantified and compared with observed concentrations from the C-44 Canal.

Overview of Sample Stations

Surface water stations were grouped to represent the following water bodies, which are shown in Figure 1 of the main report:

- **Impoundment** – The water farm impoundment covers approximately 414 acres and receives water from the C-44 Canal via the south perimeter canal. Water quality samples representative of the impoundment include CAU-1RES, SG-5, SG-6, and SG-7.
- **C-44 Canal** – The C-44 Canal is located approximately 1,100 feet south of the impoundment and is the primary source of water pumped into the impoundment. Water flows from the C-44 Canal through a distribution canal (C-444) southwest of the impoundment, where it is pumped into the south perimeter canal via an irrigation pump station. Stations representative of the C-44 Canal include CAUC44W, CAUC44E, and SG-1. In addition, nutrient data from stations S308C and C44SC4 were used as part of the study. Station S308C is where Lake Okeechobee and the C-44 Canal meet and is representative of upstream water quality. Station C44SC4 is in the mouth of a tributary to the C-44 Canal, 1.8 miles to the east. Stations CAUC44W and CAUC44E each include top and bottom samples for each event. There was no significant difference between the top and bottom samples, so the top values were used in the results.
- **CAULK-IN** – This station is located within the south perimeter canal near the pump intake to the impoundment.
- **Perimeter canals** – Perimeter canal stations include SG-2 in the east perimeter canal, SG-3 in the south perimeter canal, and SG-4 in the west perimeter canal. Water in the south perimeter canal flows eastward from the irrigation pump station, to the impoundment, and into the distribution system for farm irrigation. The east perimeter canal flows north from the south perimeter canal along the east side of the impoundment. Residual irrigation water flows southward from the farm via the west perimeter canal and back towards the irrigation pump station southwest of the impoundment.

Locations of the groundwater stations and surface water sampling sites are shown in Figure 2 of the main report and station grouping is presented in **Table B-1**. A detailed description of well construction and lithology is presented in Section 3.1 of the main report.

Table B-1. Caulkins Well Table

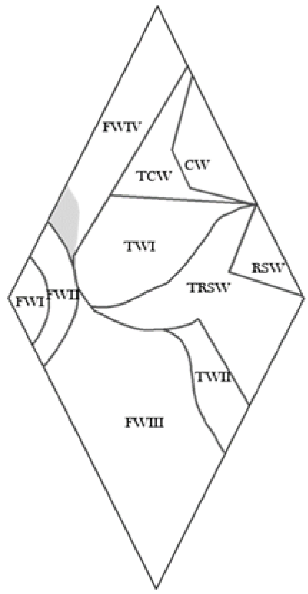
Location	Wells	Comments
Impoundment	CAU-1S, CAU-1M, CAU-1D, CAU-1LD	Near center of impoundment
Perimeter east of impoundment	CAU-2S	Between impoundment and east perimeter canal
Perimeter south of impoundment	CAU-3S	Between impoundment and south perimeter canal
Perimeter west of impoundment	CAU-4S	Between impoundment and west perimeter canal
Perimeter north of impoundment	CAU-5S, CAU-5M, CAU-5D	18 feet north of impoundment
North of C-44 Canal, east side	CAU-6M, CAU-6D	Approximately 300 feet north of C-44 Canal
North of C-44 Canal, east side	CAU-7M, CAU-7D	Approximately 160 feet north of C-44 Canal

Geochemical Overview

Groundwater reacts with the strata it moves through. Using more than 10,000 groundwater samples, Chebotarev (1955) described the evolution of major ions in groundwater. Domenico (1972) later classified this sequence into three zones for sedimentary rocks and described the dominant anions and expected total dissolved solids (TDS) for the three zones. Upper zone groundwater travels through well-leached rock; the dominant ion is bicarbonate (HCO_3) and TDS are low. Intermediate zone groundwater usually is dominated by sulfate (SO_4) ions. Groundwater circulation is far less compared to the upper zone, and TDS tend to be higher. Groundwater flushing is mostly absent in the lower zone, and high concentrations of chloride (Cl) and TDS typically are observed for this zone.

Mineral availability and solubility are factors to consider in geochemical analyses. The HCO_3 anion comes from the dissolution of aragonite, calcite, dolomite, and soil, and it typically is dominant in recharge areas. Soluble HCO_3 impacts TDS levels. The SO_4 anion generally is derived from gypsum and anhydrite sources in sedimentary basins (Freeze and Cherry, 1979). The Cl anion is highly soluble and found in the deeper zone. The most probable source of Cl is relict seawater from the last transgressive sequence. Connate water is present in the deeper zone as well. Both relict seawater and connate water have elevated levels of Cl.

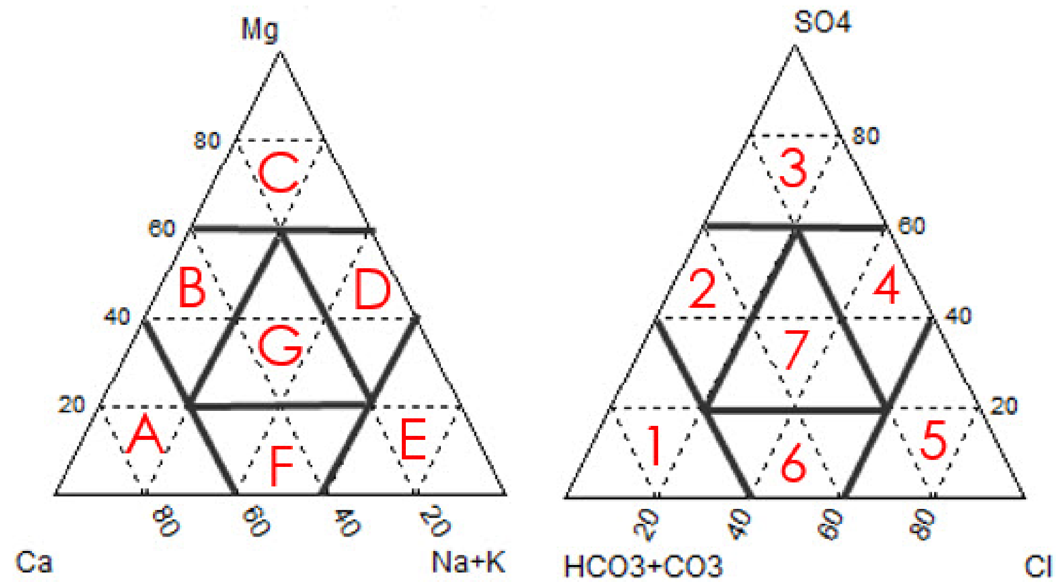
Frazee (1982) developed a method to describe groundwater types based on their geochemical characteristics using a Piper diagram and data from a study of the southeastern United States. As cation and anion data are plotted on a Piper plot, visual patterns emerge for different water types (**Figure B-1**).



Abbreviation	Description	Characteristics
FW-I	Fresh Recharge Water Type I	Rapid infiltration through sands, high calcium bicarbonate ($CaHCO_3$).
FW-II	Fresh Recharge Water Type II	Infiltration through sands and clay lenses, $CaHCO_3$ with sodium (Na), sulfate (SO_4), and chloride (Cl). Marginal type II waters are beginning to transition toward FW-IV.
FW-III	Fresh Recharge Water Type III	Infiltration through clay-silt estuarine depositional environment, high sodium bicarbonate ($NaHCO_3$).
FW-IV	Fresh Recharge Water Type IV	Fresh water, low calcium (Ca), magnesium (Mg), SO_4, and Cl. Vertical infiltration insignificant. Older form of FW-II or FW-III.
TW-I	Transitional Water Type I	Seawater begins to dominate source water; Cl begins to dominate bicarbonate (HCO_3) with increasing salt (NaCl) percentage.
TW-II	Transitional Water Type II	Transitional water with source water still dominant, HCO_3 – SO_4 mixing zone with increasing Cl.
TCW	Transitional Connate Water	Connate water dominates source water, SO_4 begins to dominate HCO_3 with increasing Cl.
TRSW	Transitional Seawater	Transitional water with seawater dominating source water.
CW	Connate Water	Highly mineralized fresh water with high TDS and calcium sulfate ($CaSO_4$) dominance. Presence of highly soluble minerals; hydrogen sulfide (H_2S) gas prevalent.
RSW*	Relict Seawater	Unflushed seawater with NaCl.

Figure B-1. Frazee (1982) groundwater types. *Note: Strongly NaCl-dominant waters may plot as Relict Seawater even if the overall salinity is significantly less than seawater.

Upchurch (1992) also developed a method to classify the hydrogeochemical characteristics of water based on the six major cations and anions present in samples, as a percent of total, and plotted on trilinear diagrams. An example tri-linear plot for cations and anions using Upchurch's (1992) classification method is provided in **Figure B-2**. Typically, the Frazee scheme is used for mapping groundwater results, while the Upchurch classification method is used to visually present surface water results.



Water Type	Cation Percentage			
	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Dominant Ion
A	60-100	0-40	0-40	Ca
B	40-60	40-60	0-20	Mixed Ca-Mg
C	0-40	60-100	0-40	Mg
D	0-20	20-60	20-60	Mixed Mg-Na
E	0-40	0-40	60-100	Na
F	40-60	0-20	20-60	Mixed Ca-Na
G	20-60	20-60	20-60	Mixed Ca-Mg-Na
Water Type	**Anion Percentage**			
	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride	Dominant Ion
1	60-100	0-40	0-40	HCO_3
2	40-60	40-60	0-20	Mixed HCO_3 – SO_4
3	0-40	60-100	0-40	SO_4
4	0-20	20-60	20-60	Mixed SO_4 – Cl
5	0-40	0-40	60-100	Cl
6	40-60	0-20	20-60	Mixed HCO_3 – Cl
7	20-60	20-60	20-60	Mixed HCO_3 – SO_4 – Cl

Figure B-2. Trilinear diagrams of Upchurch (1992) water types based on cation and anion percentages.

METHODS

Surface and groundwater samples were collected by the South Florida Water Management District (SFWMD) in August and October 2015, and March/April 2016. A very limited sampling event at CAU-1 occurred in February 2015. In August 2015, the impoundment was dry, so no surface water sampling was performed inside the impoundment. In contrast, the impoundment was nearly to capacity (29 ft NGVD29) in October 2015 and March/April 2016. **Table B-2** shows the volume of water that was pumped into the water farm the week prior to each sampling event as well as the associated rainfall. Stage elevations for the date ranges listed in **Table B-2** were recorded on the last day of each range.

Table B-2. Stage, rainfall, and pumping data for water quality sampling events.

Date Range	Stage (ft NGVD)	Total Rainfall (inches)	Total Volume Pumped (acre-feet)
February 13-19, 2015	26.44	0.13	831
August 15-21, 2015	Dry	1.21	0
October 24-30, 2015	28.65	0	414
March 26 – April 1, 2016	28.50	1.85	0

Surface water sampling was conducted following SFWMD Field Sampling Quality Manual procedures (SFWMD-FIELD-QM-001-08.2), and groundwater sampling was carried out following FDEP SOP 001/01, Section FS2200 procedures. Surface water samples were collected from three locations in the C-44 Canal, by the intake pump, and at the seven staff gauges. Groundwater sampling was conducted at all the wells installed as part of the WFPP. Additional groundwater sampling was conducted in November 2015 at FLAIRR3, a Floridan aquifer well located on the Caulkins property. All wells were purged for at least three equipment volumes and sampled after field parameters (e.g., pH, specific conductance, TDS, temperature) had stabilized. All samples were preserved and taken to the SFWMD laboratory for analysis. Samples were analyzed for major ion composition, nutrients, pH, and specific conductance. **Table B-3** lists the parameters sampled (not all parameters were sampled at each station for each sampling event).

Table B-3. List of water quality parameters collected during the pilot project.

Cations	Na	Ca	Mg	K
Anions	Cl	SO_4	HCO_3	--
Phosphorus	TP	SRP	--	--
Nitrogen	TN	$NO_3 + NO_2$	NH_4	TKN
Other	Alkalinity	TDS	Temperature	pH

Ca = calcium; Cl = chloride; HCO_3 = bicarbonate; K = potassium; Mg = magnesium; Na = sodium; NH_4 = ammonium; $NO_3 + NO_2$ = nitrate + nitrite; SO_4 = sulfate; SRP = soluble reactive phosphorus; TDS = total dissolved solids; TKN = total Kjeldahl nitrogen; TN = total nitrogen; TP = total phosphorus.

Alkalinity results were converted to HCO_3 before the cation and anion data were imported into AquaChem Version 2014.2 (Schlumberger Water Services, 2014) for further analysis. The charge balance error (CBE) was calculated for each sample (refer to Frazee [1982] for further information). A CBE of 6 percent or less was considered acceptable. Surface water results were plotted in trilinear diagrams, and groundwater results were plotted in Piper plots to “fingerprint” the various water types. Contour plots of nutrient concentrations were generated for each sampling event using Surfer 12 (Golden Software, LLC, 2016a). Stiff plots were generated from ion data collected at each station and sampling event using Grapher 12 (Golden Software, LLC, 2016b). These plots (**Attachment 1**) provide quick visual comparison of temporal (as well as spatial) changes in major cation and anion concentrations (Fetter, 2001). Plots for the remaining parameters were also generated in Grapher 12.

Some water quality results were flagged by the laboratory due to failure of quality assurance and control (QA/QC) requirements. These samples are listed in **Attachment 2** and are not included in the results section. Additional QA/QC checks highlighted an issue with specific conductance in five samples. Ratios of Na to Cl were used to evaluate usability of these data. Any data that did not meet QA/QC requirements were excluded from the results.

RESULTS

Cations and Anions

Results for major cations and anions are presented as trilinear diagrams for surface water results and Piper plots for groundwater results. The Frazee (1982) classification is specific to groundwater, and water types are labeled. The corresponding surface water results are presented on the same style of plot for comparison. **Figure B-3** shows the groundwater results for all sampling events. **Figure B-4** shows the corresponding surface water results.

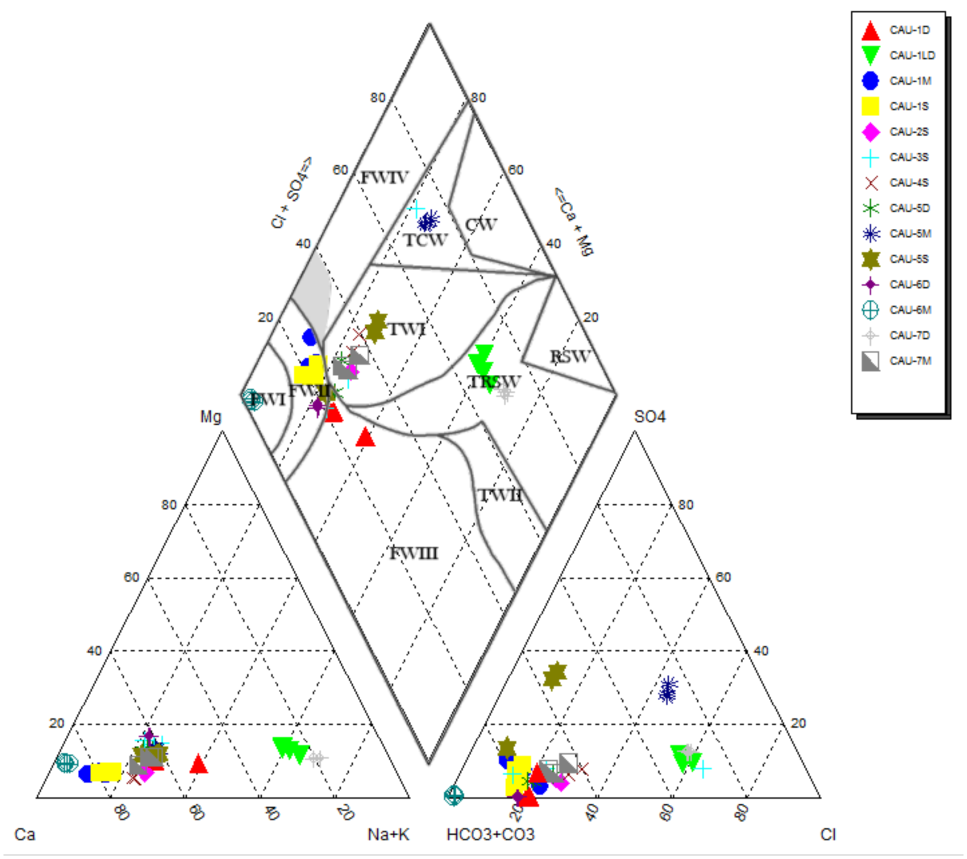


Figure B-3. Groundwater Piper plot of results.

The predominant groundwater types are grouped together near the intersection of Fresh Recharge Water Types II and III (FW-II and FW-III) and Transitional Type I (TW-I). Station CAU-6M is in Fresh Recharge Water Type I (FW-I), station CAU-5M is in the transitional connate water zone (TCW), and stations CAU 1LD and CAU-7D are in the transitional seawater category (TRSW). Station CAU-3S moved from TW-I in August 2015 to TCW in October 2015. By April 2016, groundwater results at station CAU-3S returned to the TW-I water type.

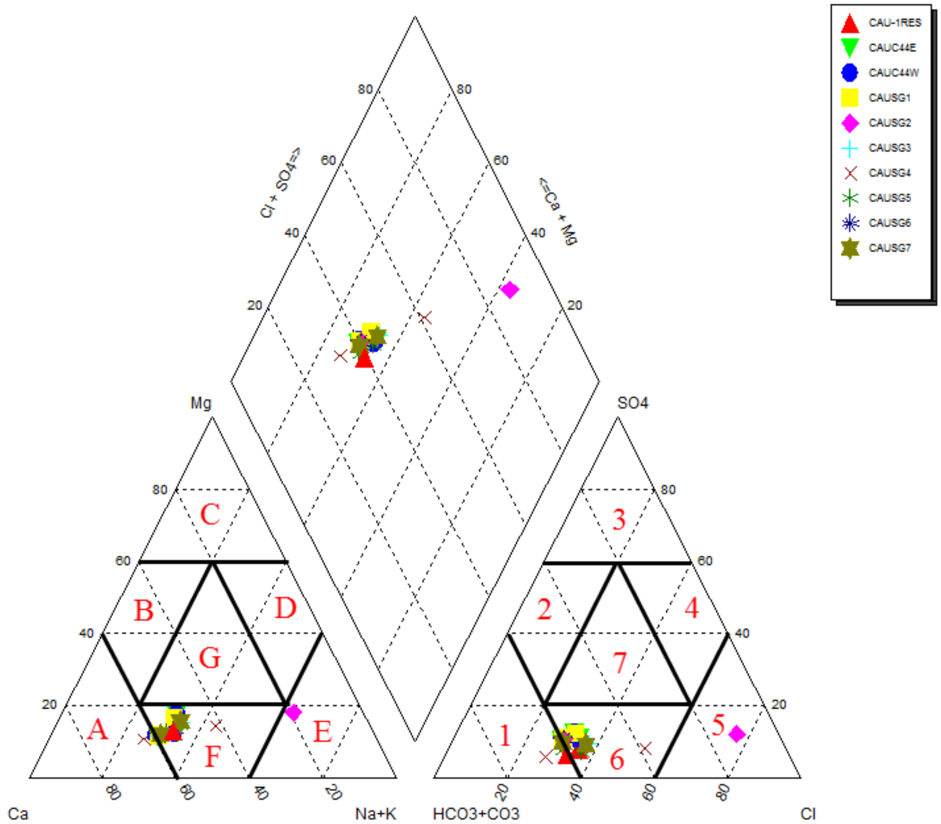


Figure B-4. Surface water trilinear diagrams of results.

The results are clustered around the border of F6 and A1 water types. A1 has dominant Ca cations and HCO_3 anions. F6 water dominant cations are Ca and Na, and the dominant anions are HCO_3 and Cl. CAUSG2 falls into the E5 water type. The predominant cation and anion are Na and Cl, respectively. Stiff plots for CAUSG2 show an increase in Na and Cl ions (between October 2015 and March 2016), indicating a rain-driven system change. The stiff plots for CAUSG4 in October 2015 show Ca and HCO_3 as dominant. By April 2016, the dominant ions had transitioned to a mixed Ca, HCO_3, Na, and Cl system. Stiff plots are presented in **Attachment 1**.

Nutrient Results

Surface water samples generally were taken at two depths, 0.5 meters below the surface and 0.5 meters above the bottom of the canal or impoundment. A comparison of water quality data collected from both depths suggested the water column was relatively well-mixed; therefore, only samples collected 0.5 meters below the surface were used in summarizing the results. **Attachment 3** contains nutrient data for each sampling event. Contour plots of surface water total phosphorus (TP) concentrations for each sampling event are shown in **Figure B-5**. Groundwater TP concentration contour plots for shallow and deep zones are provided in **Figures B-6** and **B-7**, respectively.

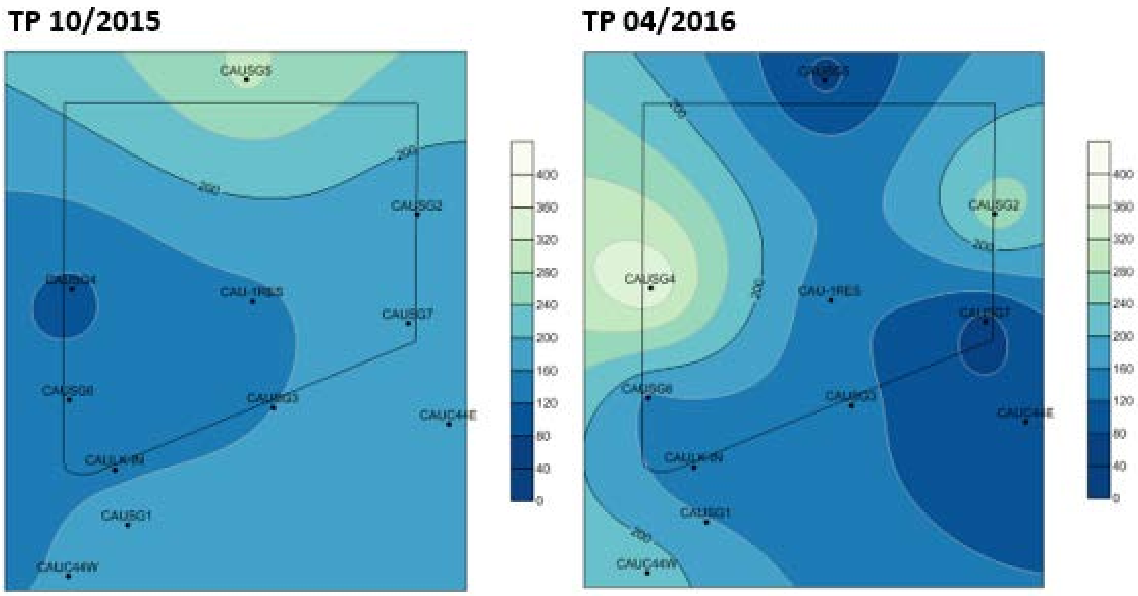


Figure B-5. Total phosphorus contour plots for surface water stations.

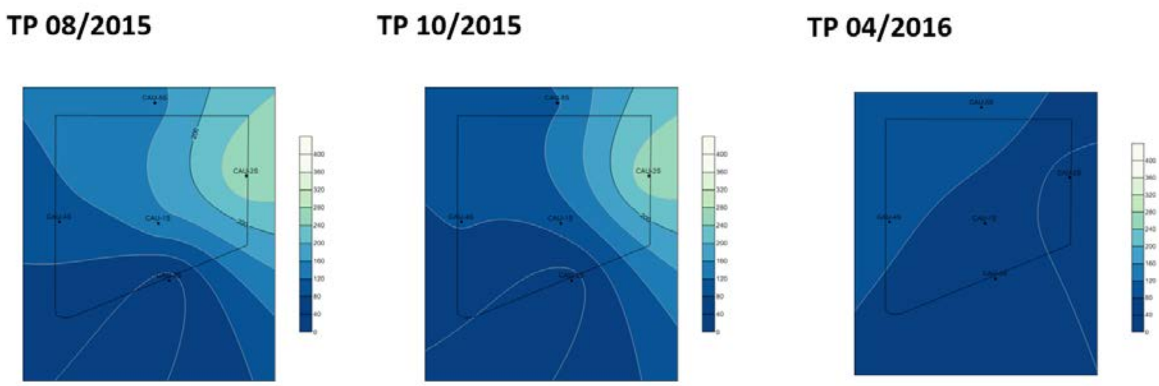


Figure B-6. Total phosphorus contour plots for shallow wells.

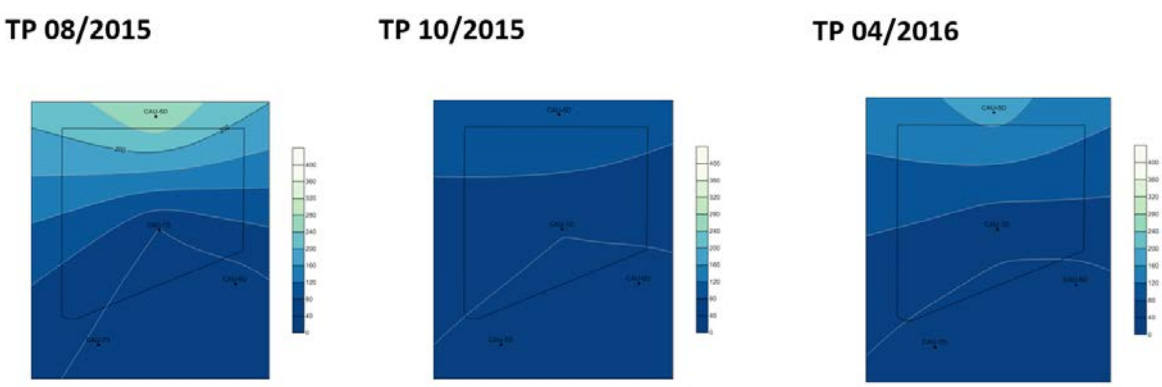


Figure B-7. Total phosphorus contour plots for deep wells.

The highest surface water TP concentration during the October 2015 sampling event was observed at CAUSG5, at the northern end of the impoundment (**Figure B-5**). By March 2016, surface water TP at this station had declined, but had increased at CAUSG2 and CAUSG4 (**Figure B-5**). Similar TP concentrations were observed in the shallow wells during the August and October 2015 events. TP decreased in CAU-2S in April 2016 (**Figure B-6**). Little change in TP concentrations was observed across the intermediate wells during the three sampling events. In contrast, a sequential decreasing trend in TP concentrations was observed in the deep zone (**Figure B-7**).

In October 2015, the highest concentration of SRP was at station CAUSG5, at the northern end of the impoundment. By March 2016, the highest SRP concentration was observed at CAUSG4, to the west. Contour plots of surface water soluble reactive phosphorus (SRP) concentrations are presented in **Figure B-8**.

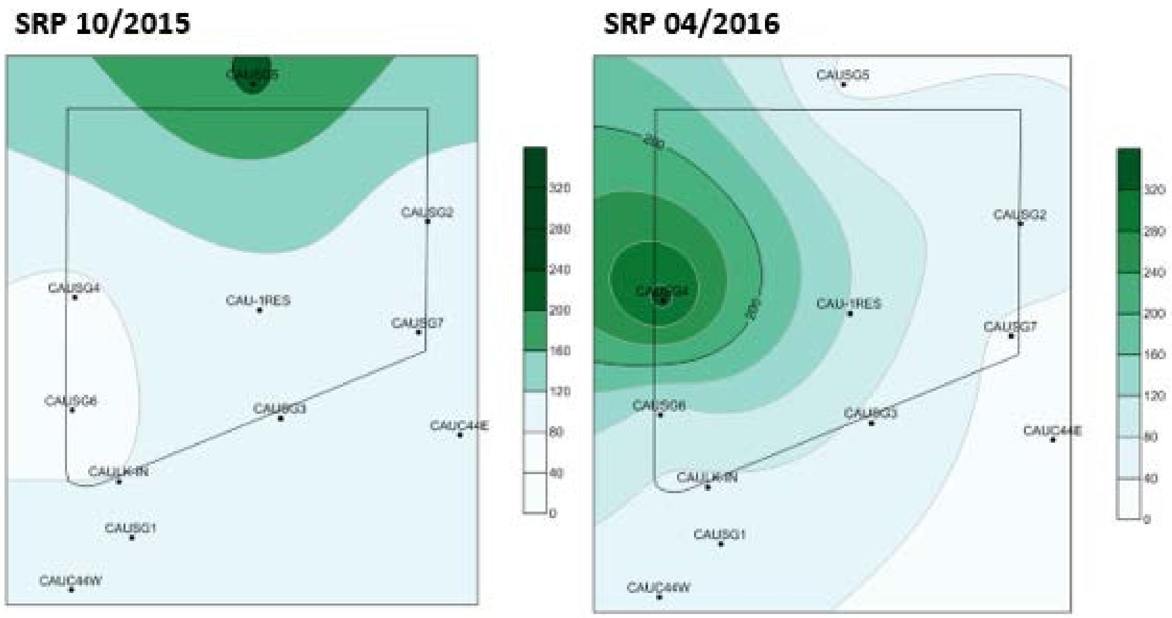


Figure B-8. Soluble reactive phosphorus contour plots for surface water stations.

The shallow zone groundwater results for August and October 2015 were similar, and SRP concentrations appeared to decline by April 2016. The intermediate wells and deep zone SRP concentrations exhibited little change between sampling events.

Total nitrogen (TN) concentrations for surface water are presented in **Figure B-9**. Surface water results indicate a spike in TN concentration at CAUSG2 in March 2016. This station is near a fertilizer storage tank; it is possible that fertilizer leaked out and was washed into the perimeter ditch during a rainfall event. TN concentrations in the shallow, intermediate, and deep wells were spatially similar in each zone for all three sampling events.

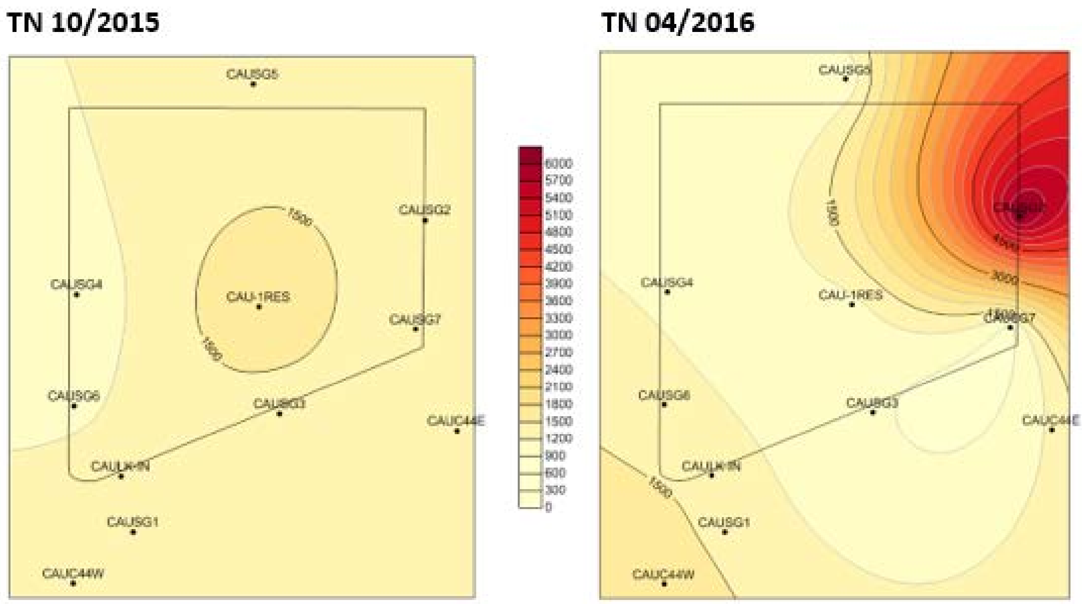


Figure B-9. Total nitrogen contour plots for surface water stations.

As with the surface water TN results, ammonium (NH_4) contour plots also show a spike at CAUSG2 in March 2016 (**Figure B-10**). Again, the shallow, intermediate, and deep zones showed little spatial variation during the three sampling events.

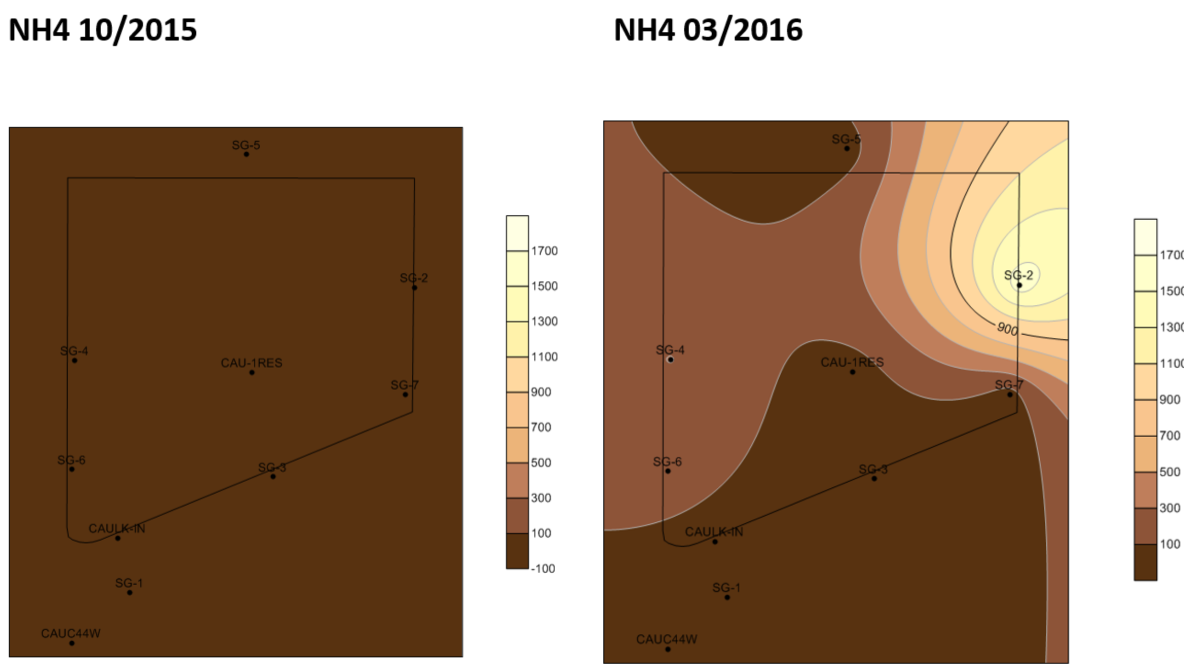


Figure B-10. Ammonium (NH_4) contour plots for surface water stations.

Other parameters include alkalinity as $CaCO_3$, bicarbonate, pH, TDS, and specific conductance. **Figure B-11** shows alkalinity as $CaCO_3$, specific conductance, pH (field), and TDS for the groundwater stations.

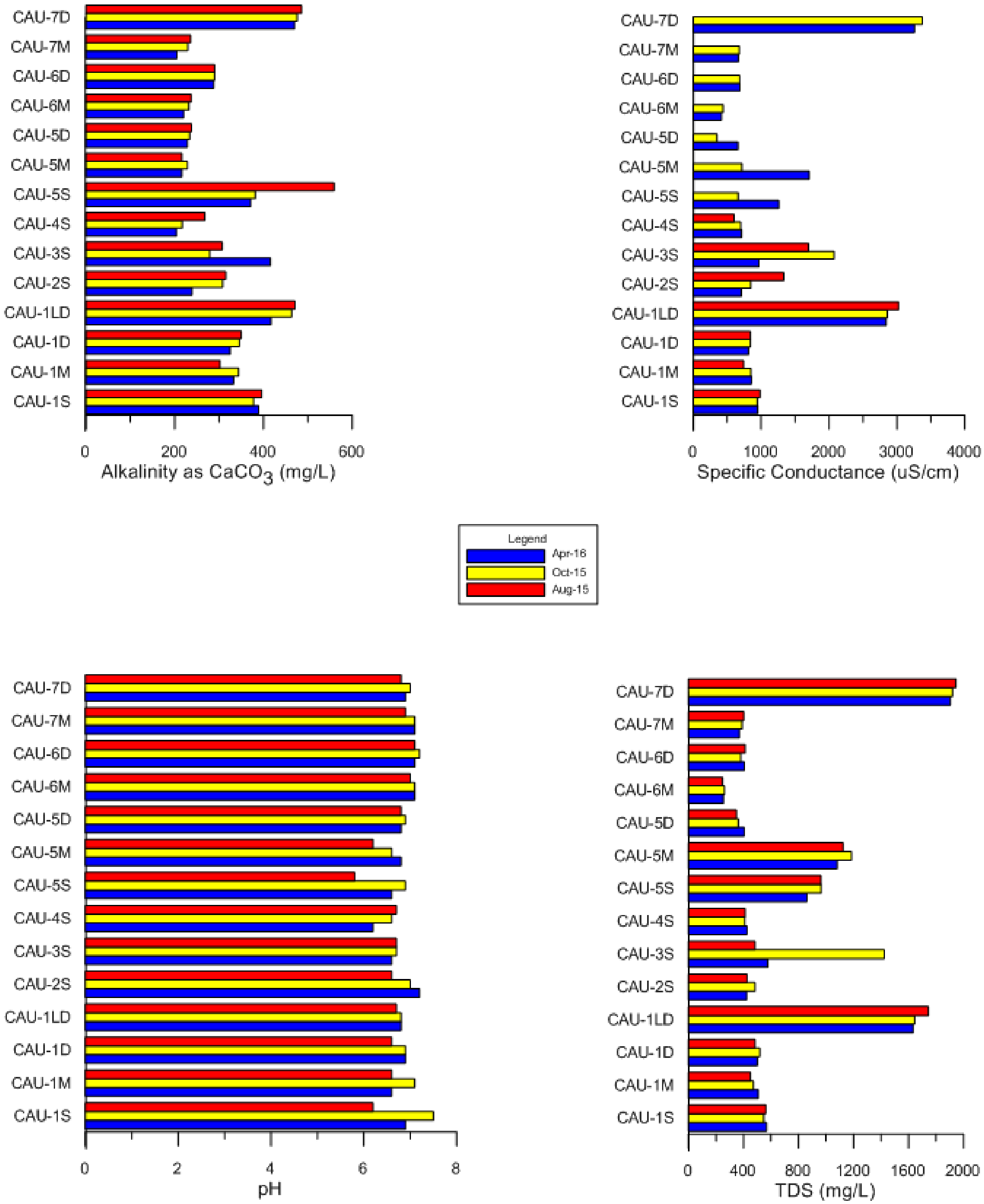


Figure B-11. Alkalinity as $CaCO_3$, specific conductance, pH (field), and total dissolved solids results for groundwater.

CAU-1LD and CAU-7D had consistently high TDS and specific conductance. CAU-5S and CAU-5M showed elevated levels of TDS, and CAU-3S spiked during the October 2015 sampling event. Alkalinity as $CaCO_3$ was highest in CAU-1LD, CAU-7D, and CAU-3S. In general, alkalinity as $CaCO_3$ concentrations were the same or higher in groundwater than in surface water, which ranged between

107 and 221 milligrams per liter (mg/L) at CAUC44W. Bicarbonate in surface water ranged between 257 mg/L and 330 mg/L at CAUC44W. Specific conductance measured at surface water stations ranged between 398 and 3,099 microsiemens per centimeter (µS/cm), with the majority of results below 800 µS/cm. Surface water pH consistently was higher than groundwater, ranging from 7.5 to 7.8.

ANALYSES

Groundwater

Six Frazee (1982) groundwater types were identified during this study: Fresh Recharge Water Types I, II, and III (FW-I, FW-II, and FW-III); Transitional Water Type I (TW-I); Transitional Connate Water (TCW); and Transitional Seawater (TRSW). The predominant groundwater types were grouped near the intersection of FW-II, FW-III, and TW-I. Waters grouped in this area predominantly consist of calcium and bicarbonate constituents, with increasing sodium, sulfate and chloride content, and are representative of infiltration through sand and clay lenses. Groundwater samples from wells CAU-1S, CAU-1M, CAU-1D, CAU-4S, CAU-5S, CAU-5D, CAU-6D, and CAU-7M fell within this grouping for each sampling event. Results for CAU-3 in August 2015 and March/April 2016, and CAU-2S in March/April 2016 also classified in the cluster area of FW-II, FW-III, and TW-1. These water types suggest that fresh recharge water mixed with water containing higher sodium and chloride percentages consistent with water from the C-44 Canal (as described below), is present from the surface to the deep wells (approximately 70 to 80 feet below land surface [bls]) beneath and adjacent to the impoundment and at the C-44 Canal near CAU-6D.

***Fresh Recharge Water Type I (FW-I)* –** Samples from one station, CAU-6M near the C-44 Canal, plotted as FW-I for each sampling event, with predominantly calcium and bicarbonate constituents characteristic of rapid infiltration through the sand column.

***Transitional Seawater (TRSW)* –** Samples from CAU-1LD and CAU7D plotted as TRSW for each sampling event. In TRSW, seawater is the dominant source water, with increasing sodium and chloride percentages and a more chloride dominated system. These results indicate that the lower deep zone of the aquifer at the CAU-1 well cluster has not been completely flushed by downward infiltration from the surface, and water at the deep level at CAU-7D may be predominately upwelling water on a path to recharge the C-44 Canal.

***Transitional Connate Water (TCW)* –** TCW was found in the medium depth well CAU-5M during three sampling events, and at CAU-3S during the October 2015 sampling event. TCW is described as sulfate beginning to dominate with increasing chloride. Because the sulfide ion may become oxidized during sampling, it cannot be satisfactorily concluded that the SO_4 results are truly representative of *in situ* concentrations at depth.

The above groundwater types are presented here in simplified cross-sections. The location of stations included in the cross-sections are shown in **Figure B-12**. The CAU-5, CAU-1, CAU-3, and CAU-6 sites (A–A’) are presented in **Figure B-13**. **Figure B-14** shows the water types for CAU-5, CAU-1, CAU-3, and CAU-7 stations (B–B’). The depth and potential flow patterns indicated by the various water types across the site are illustrated.

There is a wedge of TCW at the CAU-5M station and an upconing of TRSW towards CAU-7D. This station in proximal to the intake canal. The easternmost groundwater monitoring site (CAU-6M) plotted as fresh recharge water (FW-1) for every sampling event. No upconing of the more saline water from the lower portion of the aquifer was seen at this site.

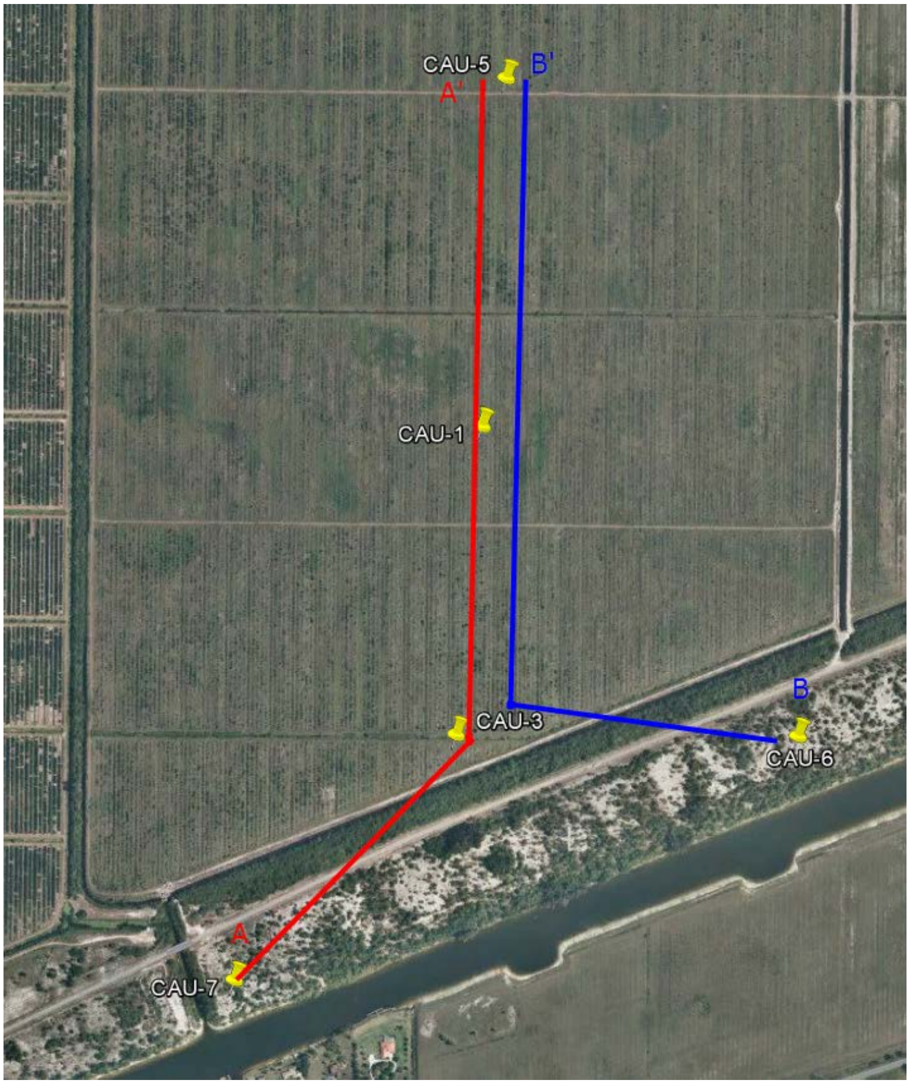


Figure B-12. Location of cross-sections.

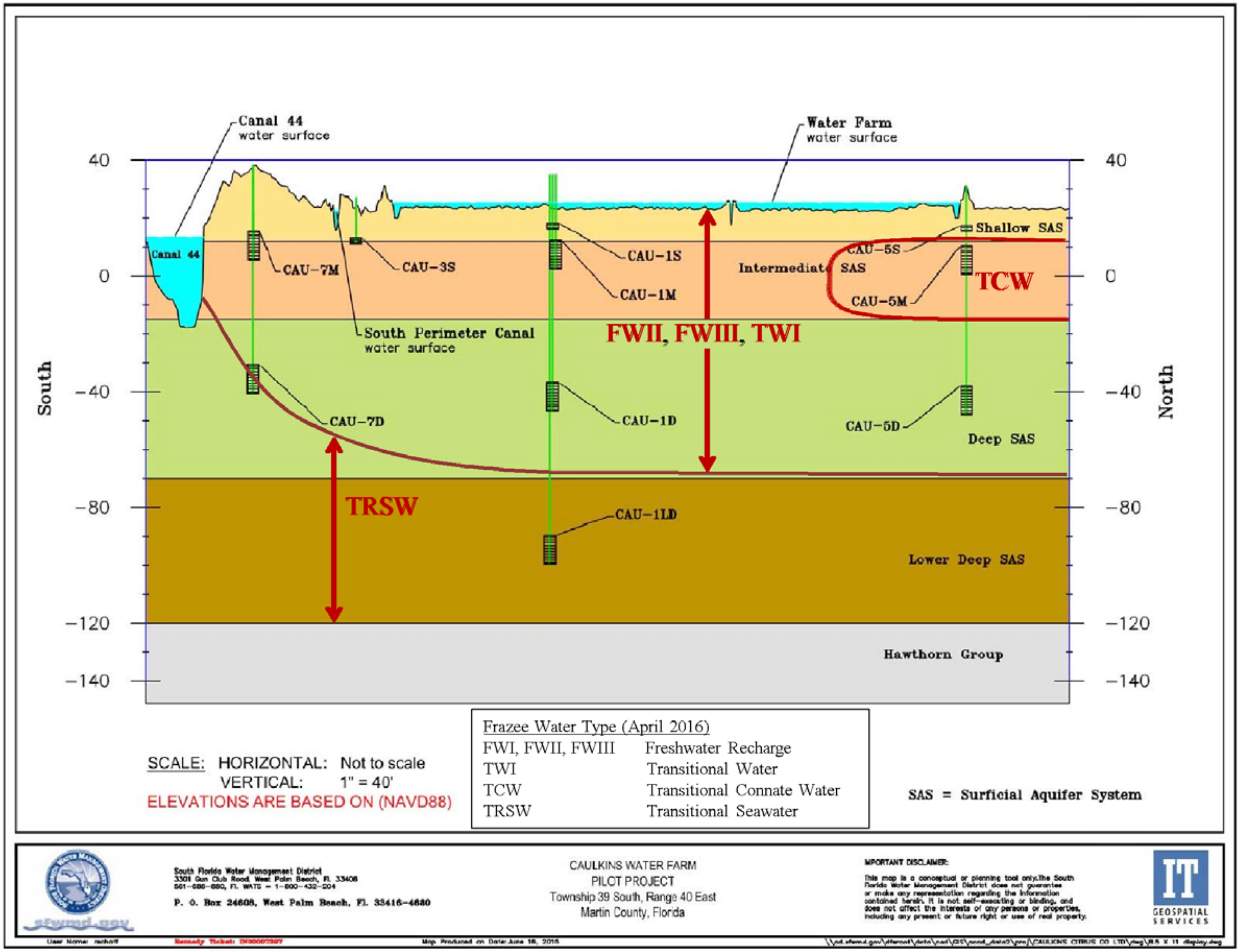


Figure B-13. Cross-section A–A' for April 2016 results.

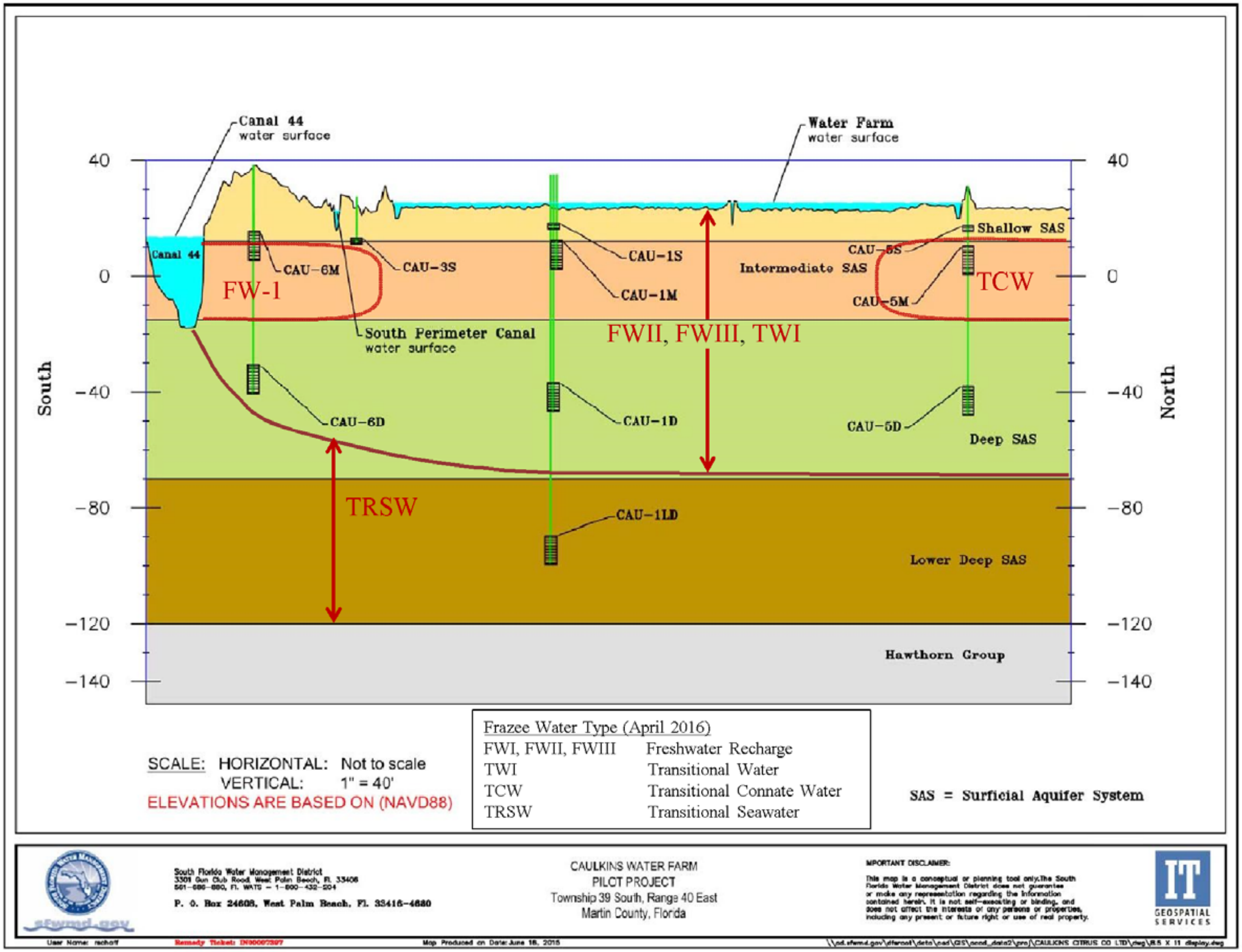


Figure B-14. Cross-section B–B’ for April 2016 results.

Surface Water

The Upchurch (1992) method for ion classification of water was used to describe surface water samples. Water samples representative of the C-44 Canal, impoundment area, and perimeter canals were classified as follows:

C-44 Canal – Surface water stations in the C-44 Canal are believed to be representative of water pumped into the impoundment. Stations representative of the C-44 Canal include CAUC44W, CAUC44E, SG-1, and S308C (at the intersection of Herbert Hoover Dike and the C-44 Canal). Eight samples were collected as part of the Caulkins sampling event at CAUC44W, CAUC44E, and SG-1 in August 2015, October 2015, and March/April 2016. Two samples were collected at S308C in August and October 2015 as part of a regional sampling program. Of 10 samples analyzed for the 3 events, each falls within the Upchurch (1992) F6 water type, which is a mixed of calcium and bicarbonate and sodium and chloride systems, or on the border between the F6 and A1 water type, which is a predominately calcium-bicarbonate water type.

Impoundment – Surface water stations in the impoundment include CAUSG5, CAUSG6, CAUSG7, and CAU-1RES. Five samples were collected in October 2015 and March/April 2016 (the impoundment was dry during the August 2015 sampling event). Each sample result falls within the F6 water type or on the border of the F6 and A1 water types, similar to the C-44 Canal water.

Perimeter Canals – Surface water stations in the east, south, and west perimeter canals (CAUSG2, CAUSG3, and CAUSG4, respectively) were sampled in October 2015 and March/April 2016. Most of the resultant water types fall within the F6 water type or on the border of the F6 and A1 water types, similar to the C-44 Canal and impoundment water. The exception to this is the March/April 2016 sample from SG-2, which is classified as E5, a predominately sodium and chloride water type. E5 waters are common in the saltwater transition zone.

The sodium to chloride ionic ratio for surface water results was 0.85 (**Figure B-15**), which is typical for rainfall in southern Florida. This suggests the surface waters are primarily sourced by precipitation. Samples with higher concentrations of calcium, bicarbonate, sodium, and chloride likely gained these ions during infiltration and residence time within the aquifer before re-emerging into surface water.

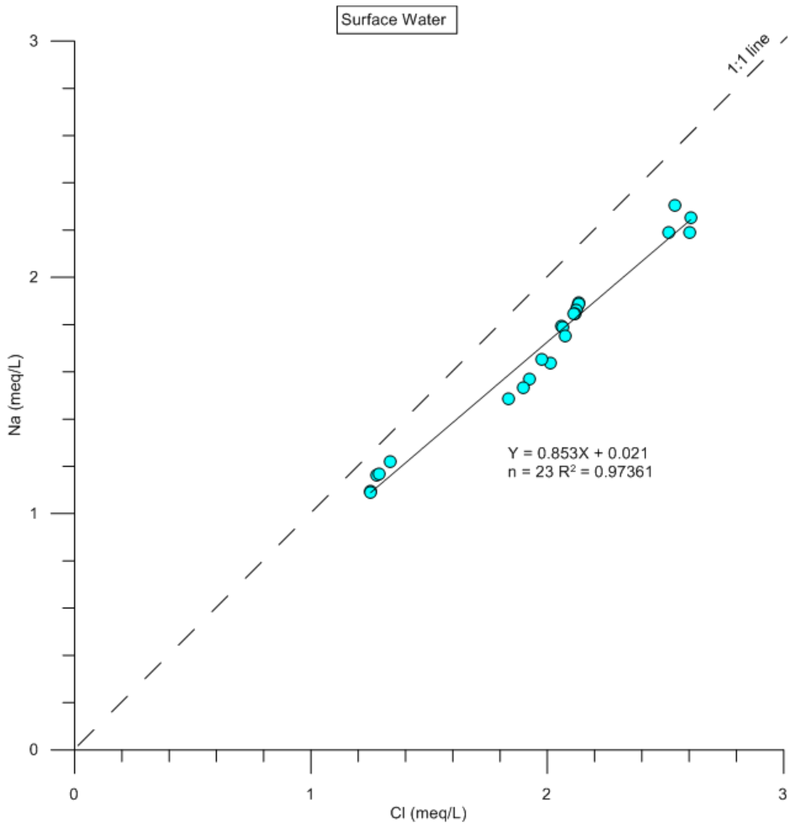


Figure B-15. Sodium (Na) to chloride (Cl) ratio for surface water results.

Nutrients

Nutrients were sampled in surface water and groundwater stations to measure concentrations of TP, SRP, TN, and NH_4, also in addition to qualitatively comparing potential surface water recharge sources to groundwater. Potential surface water sources included water from the C-44 Canal, inflow pump (from the south perimeter canal into the impoundment), impoundment, and perimeter canals. Other than the C-44 Canal, surface water samples were collected only in October 2015 and March 2016 because the impoundment and perimeter canals were dry during the non-pumping period of August 2015. For purposes of nutrient analysis, three stations within the C-44 Canal (CAUC44W, CAUC44E, and CAUSG1) were averaged for each event to represent source water concentrations. Four stations within the impoundment (CAUSG5, CAUSG6, CAUSG7, and CAU-1RES) were averaged for each event to represent surface water in the impoundment.

Phosphorus

TP and SRP concentrations for groundwater are shown in **Figure B-16**, and surface water concentrations are plotted in **Figure B-17**. The highest TP concentrations in surface waters were found in the west and east perimeter canals during the March 2016 sampling event, with concentrations of 0.36 mg/L (SG-4) and 0.27 mg/L (SG-2), respectively. The highest TP concentrations in groundwater were found at CAU-2S and CAU-5D, east and north of the impoundment, during the August 2015 sampling event, with concentrations of 0.28 mg/L and 0.27 mg/L, respectively. These concentrations are higher than potential source water in the C-44 Canal and impoundment, which averaged 0.17 mg/L and 0.15 mg/L, respectively.

The median TP concentration of monitor wells CAU-6M, CAU-6D, CAU-7M, and CAU-7D near the C-44 Canal was 0.04 mg/L, approximately 25 percent of the C-44 Canal. These well clusters are located approximately 300 and 170 feet north of the C-44 Canal, respectively, and are believed to be representative of groundwater discharged to the C-44 Canal.

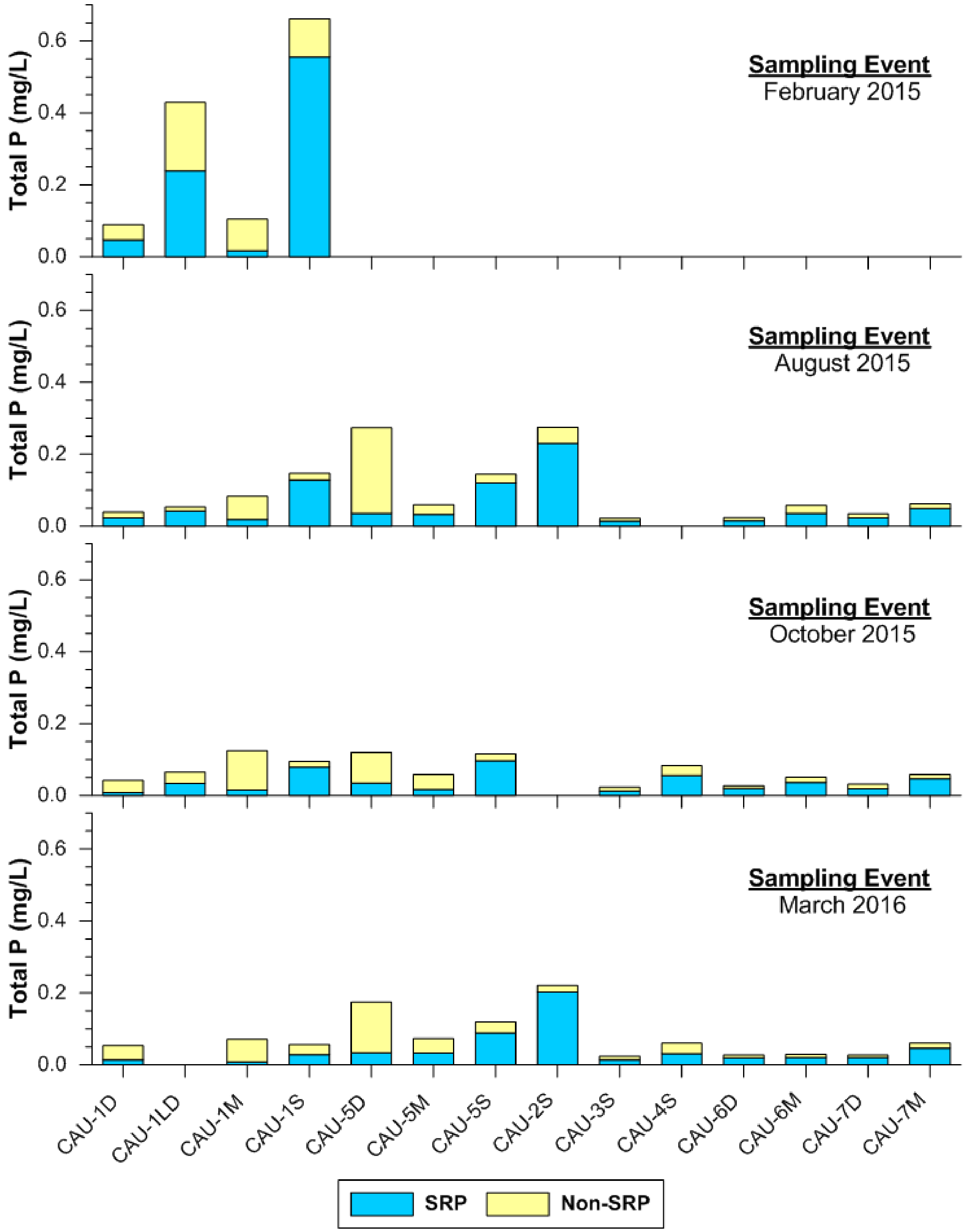


Figure B-16. Total phosphorus and soluble reactive phosphorus concentrations in groundwater sampling events.

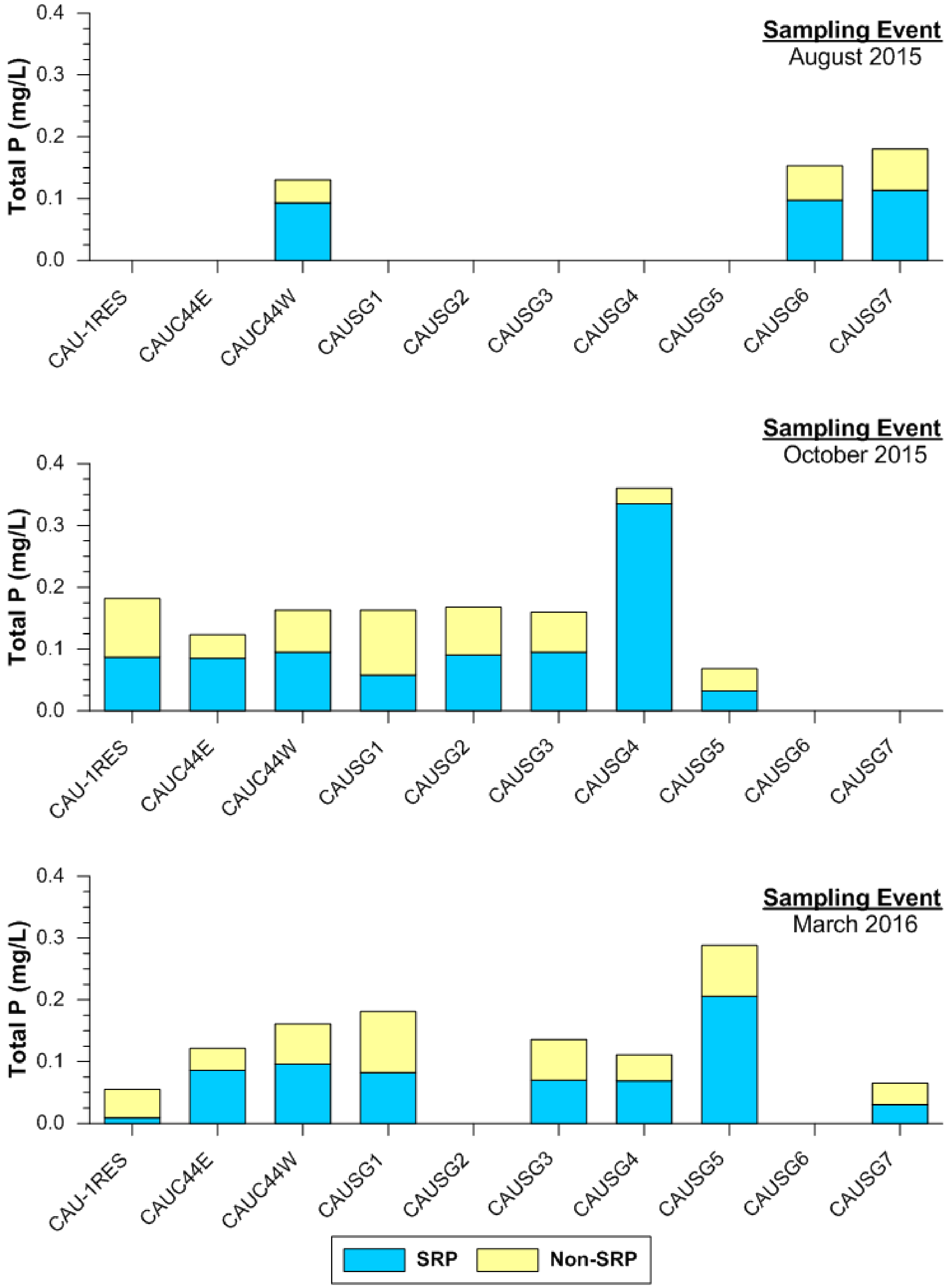


Figure B-17. Total phosphorus and soluble reactive phosphorus concentrations in surface water sampling events.

Median TP concentrations for surface water and groundwater at various depth intervals and locations are shown in **Table B-4**. In general, TP concentrations were higher in surface water than in groundwater, and higher in shallow wells compared to deeper wells. The median TP concentration in surface water was 0.16 mg/L, followed by shallow wells at 0.12 mg/L, and intermediate, deep, and lower deep wells, which ranged from 0.04 to 0.08 mg/L. Within the impoundment, surface water was approximately 12 percent less than the source water of the C-44 Canal. Median TP concentrations at CAU-1S and CAU-1M were 0.10 and 0.08 mg/L, respectively; well above the concentrations in the deep (0.04 mg/L) and lower deep (0.06 mg/L) wells. Water in the shallow, intermediate, and deep wells were 59, 47, and 24 percent, respectively, of the concentration of water in the C-44 Canal. This suggests a trend towards reduction of TP within the upper approximately 70 feet of the surficial aquifer system (SAS), the depth of the deep well within the impoundment.

Table B-4. Total phosphorous in surface water and groundwater (mg/L).

Sample Location	August 2015	October 2015	March/April 2016	Median Avg.	Std.	Percent of Surface Water
Surface Water	0.12	0.16	0.20	0.16	0.04	100
Shallow Wells	0.14	0.12	0.10	0.12	0.02	72
Intermediate Wells	0.07	0.07	0.06	0.07	0.01	43
Deep Wells	0.09	0.06	0.07	0.07	0.02	43
Lower Deep Well	0.05	0.07	ND	0.06	0.01	37
						Percent of C-44
C-44 Canal	0.12	0.17	0.21	.017	0.05	100
Impoundment	--	0.22	0.08	.015	0.10	88
CAU-1S	0.15	0.09	0.06	0.10	0.05	56
CAU-1M	0.08	0.12	0.07	0.08	0.03	47
CAU-1D	0.04	0.04	0.05	0.04	0.01	24
CAU-1LD	0.05	0.07	ND	0.06	0.01	35

-- No sample was collected because the impoundment was dry.
ND = no data available.

Nitrogen

TN and NH_4 concentrations are presented for each groundwater sampling event in **Figure B-18**, and each surface water sampling event in **Figure B-19**. The highest TN concentration in surface water was found in the east perimeter canal (CAUSG2) during the March/April 2016 sampling event; at 6.10 mg/L, the concentration was almost four times higher than the next highest surface water result and almost two times higher than the highest groundwater result. The highest TN concentrations in groundwater were found at the CAU-5 well cluster north of the impoundment, with a median of 3.11 mg/L in the shallow well and 1.75 mg/L in the intermediate well. The shallow well adjacent to the east perimeter canal (CAU-2S) also had high TN concentrations, with a median of 1.50 mg/L. TN concentrations at CAUSG2 during March/April 2016 and at CAU-5S and CAU-5M during all three sampling events were higher than potential source water in the C-44 Canal and impoundment, with medians of 1.37 mg/L and 1.17 mg/L, respectively. The median concentrations for monitor wells CAU-6M, CAU-6D, CAU-7M, and CAU-7D near the C-44 Canal were 0.75 mg/L TN, approximately 73 percent of the average concentrations of the C-44 Canal.

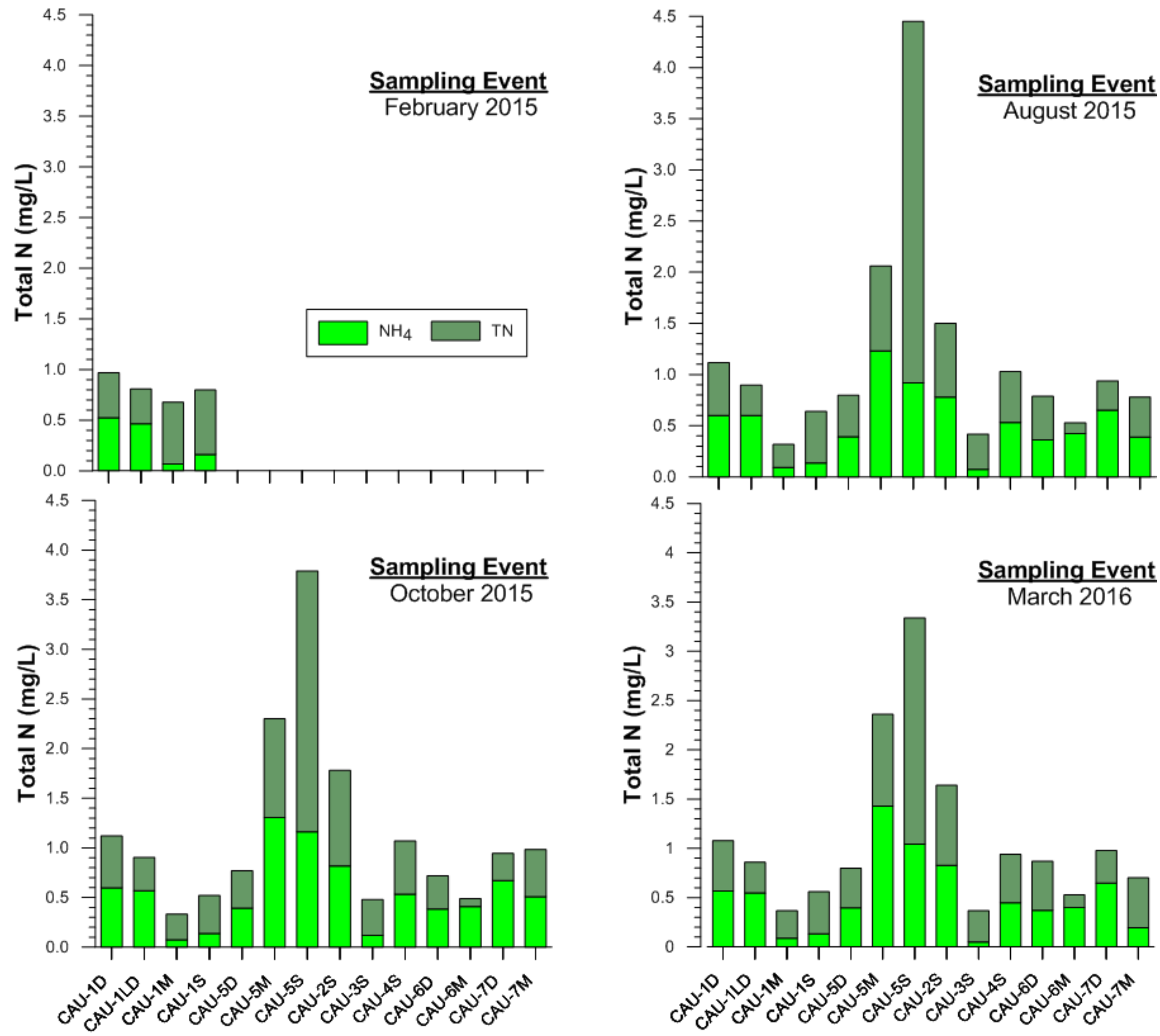


Figure B-18. TN and NH_4 concentrations in groundwater sampling events.

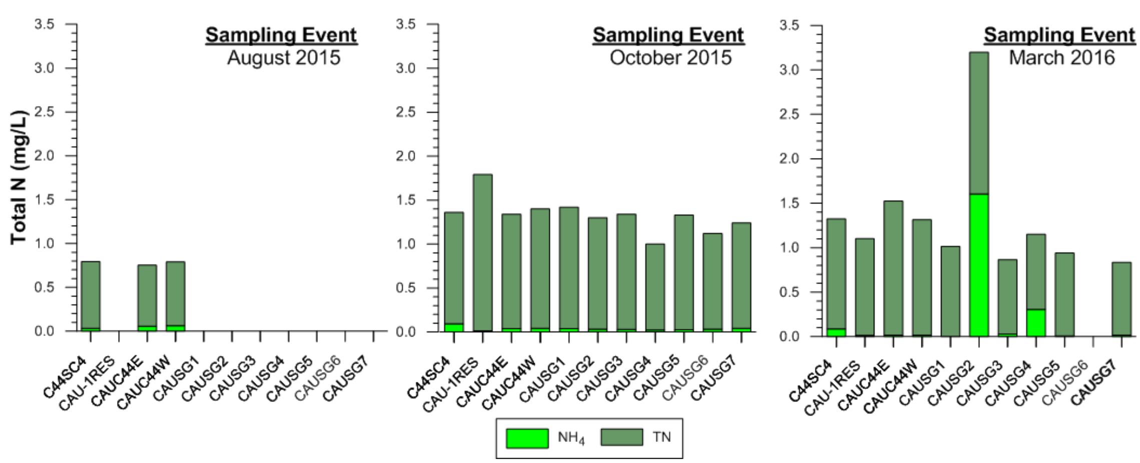


Figure B-19. Total nitrogen and ammonium (NH_4) concentrations in surface water sampling events.

NH_4 concentrations were much higher in groundwater compared to surface water, and nitrate + nitrite (NO_3+NO_2) concentrations were higher in surface water compared to groundwater, as would be expected based on oxygenated conditions in surface water.

Median TN concentrations for surface water and groundwater at various depth intervals and locations are shown in **Table B-5**. In general, TN concentrations were higher in surface water and shallow aquifer wells compared to deeper wells. The median TN concentrations in all surface water was 1.28 mg/L, and 1.17 mg/L for surface water in the impoundment. The median TN concentration for all shallow wells was 1.30 mg/L, well above median concentrations of 0.88 mg/L, 0.90 mg/L, and 0.90 mg/L for intermediate, deep, and lower deep wells, respectively. Within the impoundment, surface water TN concentrations were approximately 15 percent less than the source water of the C-44 Canal. Average TN concentrations at CAU-1S and CAU-1M were 0.56 mg/L and 0.33 mg/L, respectively, 41 and 24 percent of concentrations in the C-44 Canal. This suggests a trend towards reduction of TN within the upper approximately 23 feet of the SAS, the depth of the intermediate well within the impoundment.

Table B-5. Total nitrogen in surface water and groundwater (mg/L).

Sample Location	August 2015	October 2015	March/April 2016	Median	Std.	Percent of Surface water
Groundwater						
Surface Water	0.79	1.28	2.11	1.28	0.67	100%
Shallow Wells	1.45	1.30	1.26	1.30	0.10	102%
Intermediate wells	0.79	0.89	0.94	0.88	0.07	69%
Deep Wells	0.91	0.90	0.92	0.90	0.02	70%
Lower Deep	0.91	0.91	0.84	0.90	0.04	70%
Surface Water						Percent of C-44
C-44 Canal	0.79	1.37	1.69	1.37	0.46	100%
Impoundment	N/A	1.37	0.96	1.17	0.29	85%
CAU-1S	0.60	0.52	0.57	0.56	0.03	41%
CAU-1M	0.29	0.33	0.37	0.33	0.04	24%
CAU-1D	1.12	1.12	1.11	1.12	0.01	82%
CAU-1LD	0.91	0.91	0.84	0.91	0.04	66%

SUMMARY

Ion and nutrient data were examined to characterize groundwater recharge and flow patterns within the SAS at the Caulkins WFPP. Analysis of ionic data based on Frazee (1982) water types, Upchurch (1992) water classification, and stiff plots indicated little change in ionic makeup of surface water and groundwater during project monitoring. The C-44 Canal, which flows from Lake Okeechobee and is the main source of surface water pumped into the impoundment, also serves as a source to the perimeter canals. All surface water samples exhibited similar ionic compositions, except sample SG-2 collected from the east perimeter canal in March/April 2016. Surface waters in the project area appeared to consist of predominately a calcium and bicarbonate source and, to a lesser extent, sodium-chloride. Therefore, these surface waters can be classified as TW-1 water (Frazee, 1982). These waters are believed to be sourced primarily by seepage of fresh recharge water (FW-II or FW-III) and upward seepage of transitional sodium and chloride groundwater (TRSW), similar to what was found in the groundwater at the Caulkins water farm.

The ionic composition of samples from the shallow, intermediate, and deep wells beneath the impoundment were consistent and generally near the boundary between fresh recharge water (FW-II and FW-III) and transitional water (TW-I). Fresh recharge waters (FW-II and FW-III) are believed to be representative of infiltration through sand and clay lenses, which are present beneath the impoundment. There has been little change in the relative ionic contribution in the well cluster at the impoundment since it was first sampled in February 2015 (approximately 1 year after pumping began), which indicates that either pumping into the impoundment has not influenced the ionic makeup of the SAS, or if it has, the changes occurred before the February 2015 sampling event. The presence of water classified as TRSW at CAU-1LD beneath the impoundment suggests that the lower deep zone of the aquifer has not been affected by downward infiltration from the surface. The only other well in which TRSW water was found was CAU-7D, near the C-44 Canal. The presence of this water at a shallower interval adjacent to the canal, in addition to an upward gradient observed in the lower deep zone, suggests that water from the lower deep interval flows upward towards the C-44 Canal.

Two additional water types found in three wells varied from predominate types discussed earlier. Samples from station CAU-6M near the C-44 Canal plotted as FW-I for every sampling event, predominantly composed of calcium and bicarbonate constituents with little sulfate or chloride. These waters are described as sourced by rapid recharge through sands and high concentrations of calcium bicarbonate. The water in CAU-6M may be influenced by the lack of the upper clay-rich layer found beneath the impoundment at this well location and rapid recharge through the sandy soil above the screen interval. The fact that CAU-6D was consistently classified as FW-II, may be an indicator of an alternate source, presumably flow from the north.

TCW was found in one shallow well, CAU-3S, adjacent to the south perimeter canal in the October 2015 event (dry), and in the deep well CAU-5M north of the impoundment during all three events. TCW is described as sulfate beginning to dominate with increasing chloride, and is suggestive of TW-1 water mixing with TCW water. An explanation for the presence of connate water in these wells is not evident. However, the presence of higher sulfate water in the intermediate zone is consistent with Domenico's (1972) description for water in the intermediate zone.

The agricultural history of the site and surrounding land includes fertilizer application that likely affected nutrient concentrations in surface water and groundwater. In addition to the C-44 Canal, the highest surface water TP concentrations were found in perimeter canals east and west of the impoundment, and in the northern station within the impoundment. The highest surface water TN concentrations were found in the perimeter canal to the east. The east perimeter canal is approximately 1,100 feet downgradient (north) from a former fertigation station adjacent to the canal (MilCor Group, 2013), and the west perimeter canal is the return canal from the former grove's irrigation system. Concentrations in groundwater were highest in wells north (TN) and east (TP) of the impoundment, which are downgradient based on regional flow towards the south, of the former grove, and exceeded concentrations in the C-44 Canal, suggesting historical farming practices as a source.

Nutrient sampling showed that TP and TN concentrations were lower in the SAS beneath the impoundment, and farther south near the C-44 Canal, compared to both surface water and upgradient groundwater sources as shown at CAU-5. Below the upper sand, silt, and clay layer beneath the impoundment, average concentrations of TP and TN were 27 and 26 percent, respectively, of the C-44 Canal within the upper 70 feet of the aquifer. TP and TN concentrations in monitor wells to the south, near subsurface discharge to the C-44 Canal, averaged approximately 25 and 59 percent, respectively, of concentrations in the C-44 Canal. This suggests reduction of nutrients via vertical flow from the impoundment into the SAS, and lateral flow from north of the impoundment towards the C-44 Canal. The processes responsible for reduction are not well understood based on the limited scope of sampling to date.

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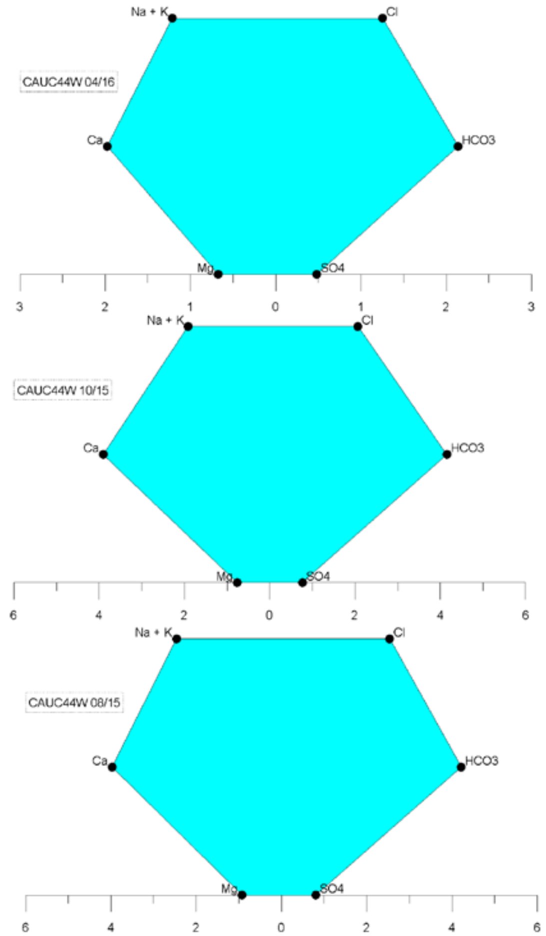
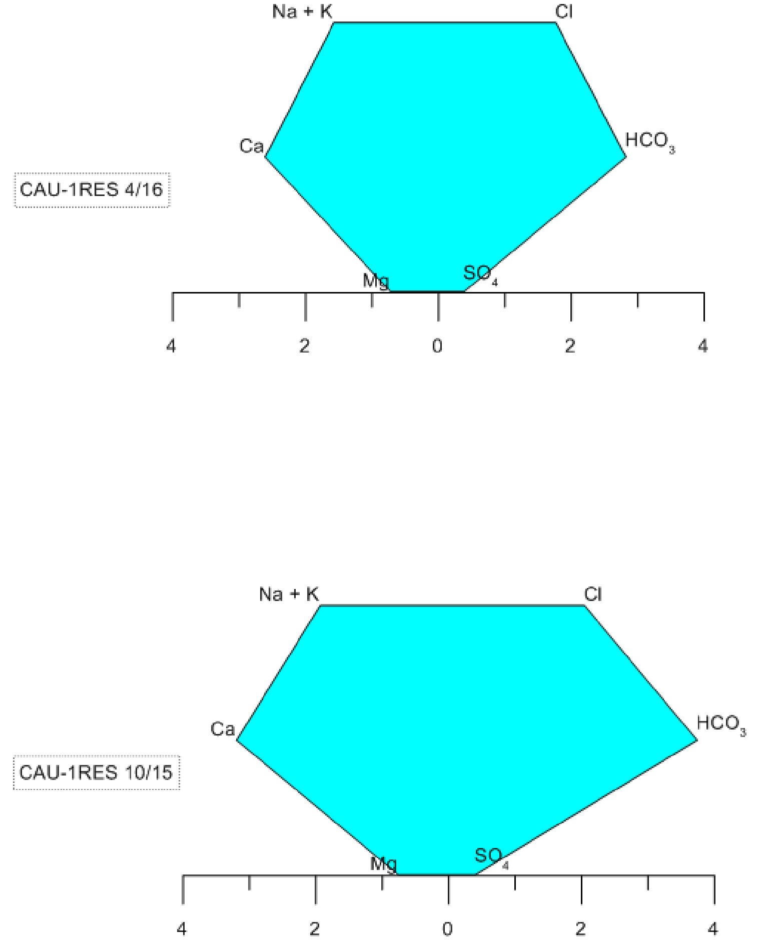
ATTACHMENTS

ATTACHMENT 1
STIFF PLOTS

SURFACE WATER

CAUC44W (C-44 Canal water)	CAU-1RES (Surface water inside Caulkins Water Farm)
	

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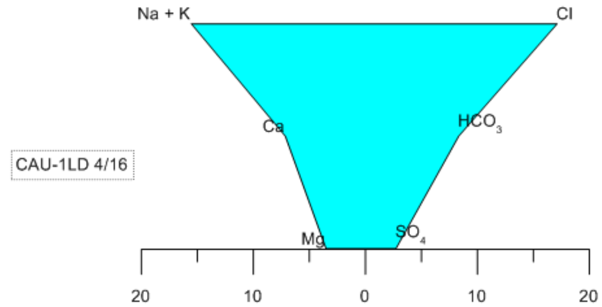

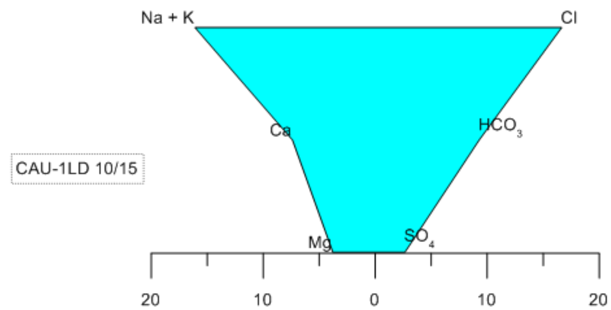

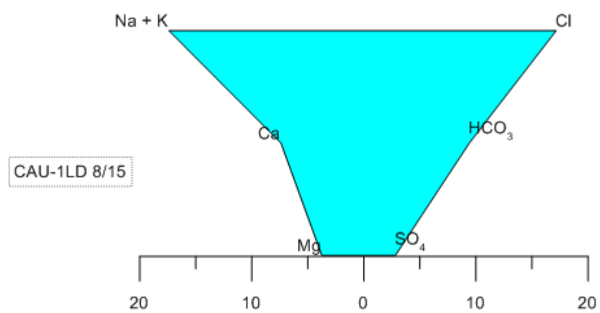

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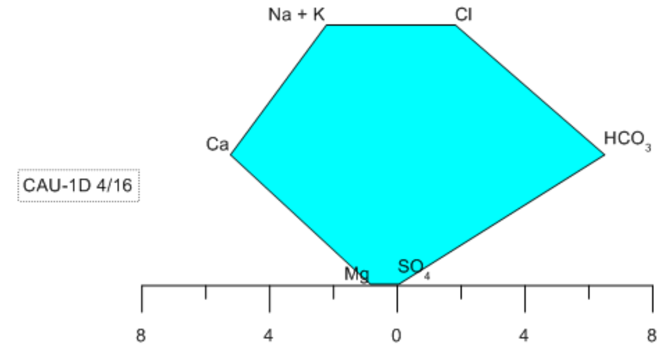
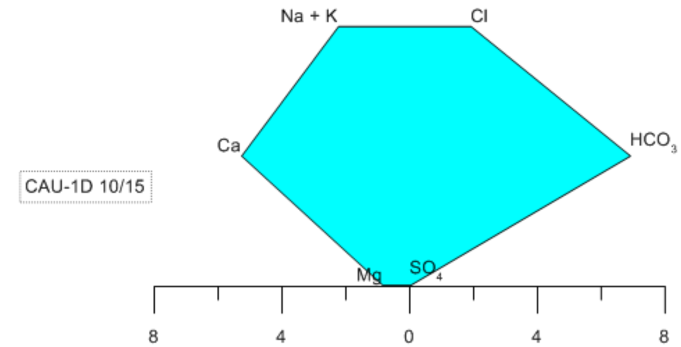
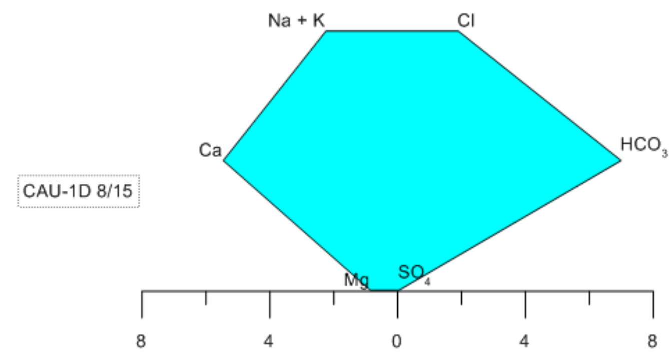
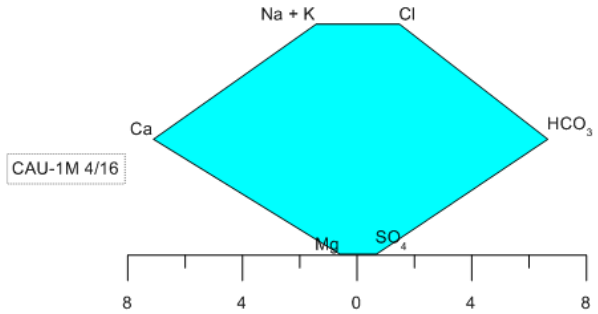


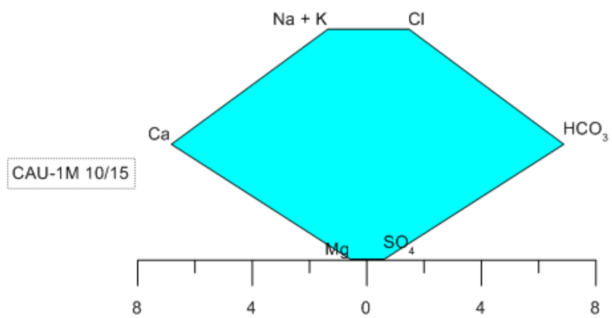


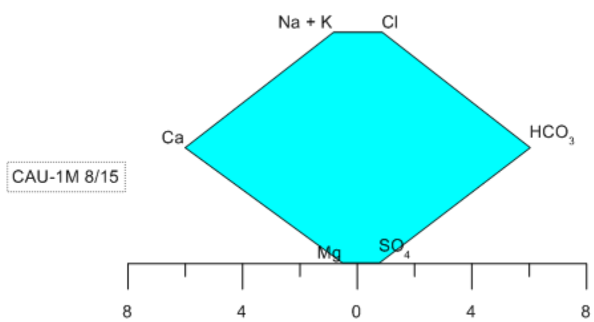


CAU-1M	CAU-1S

CAU-1M







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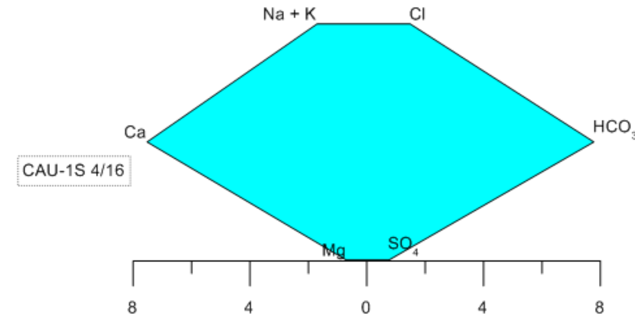

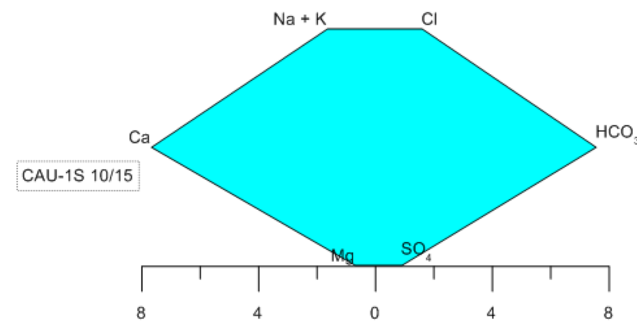

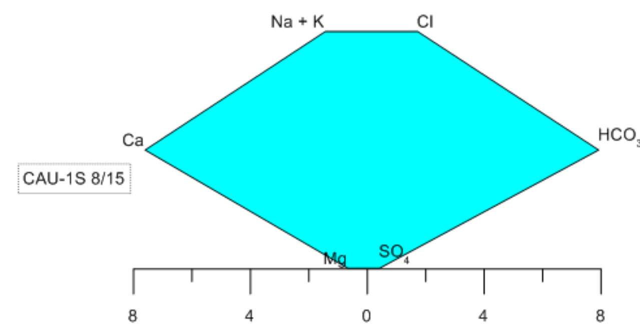

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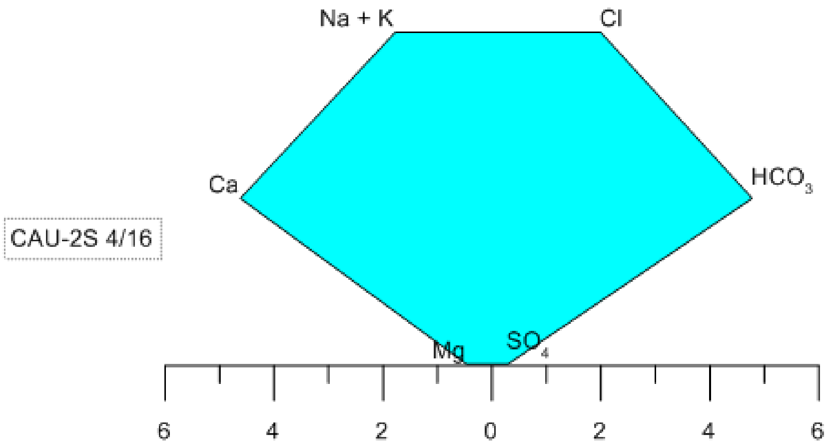

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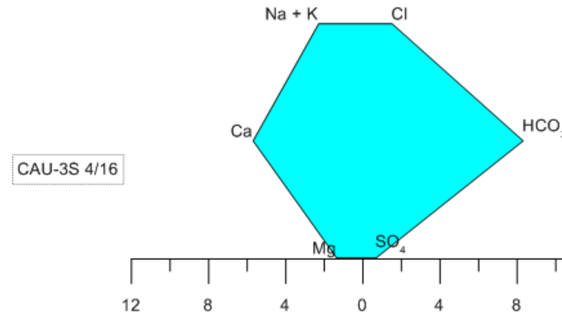

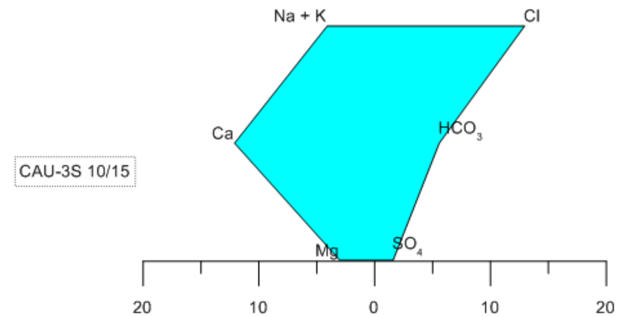

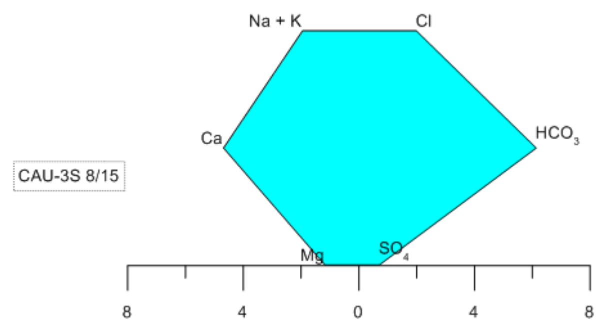

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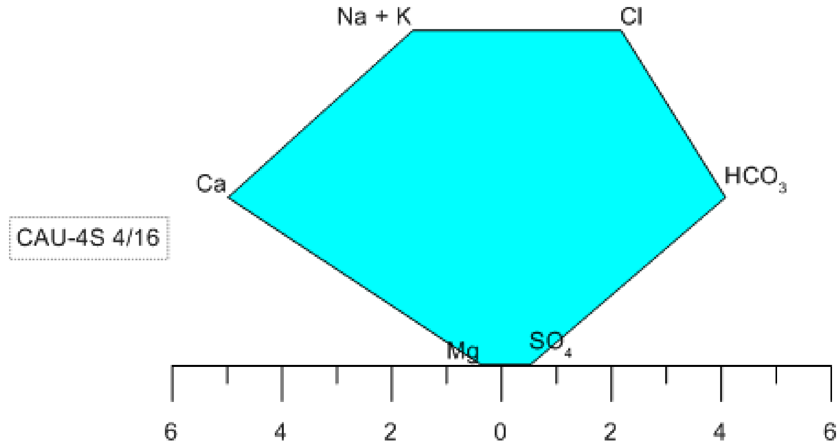	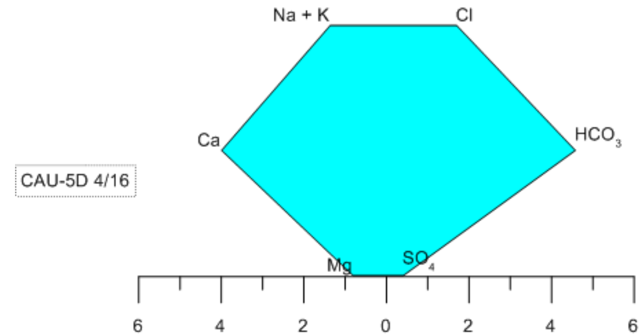
	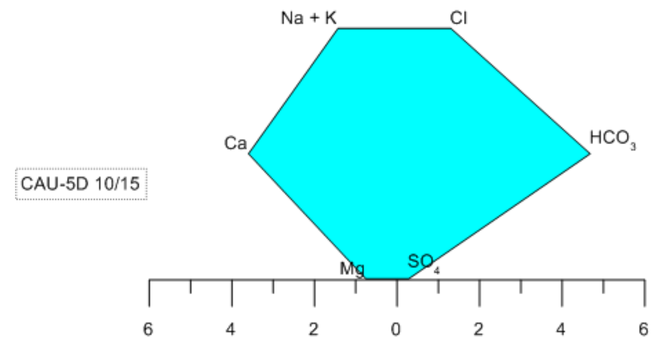
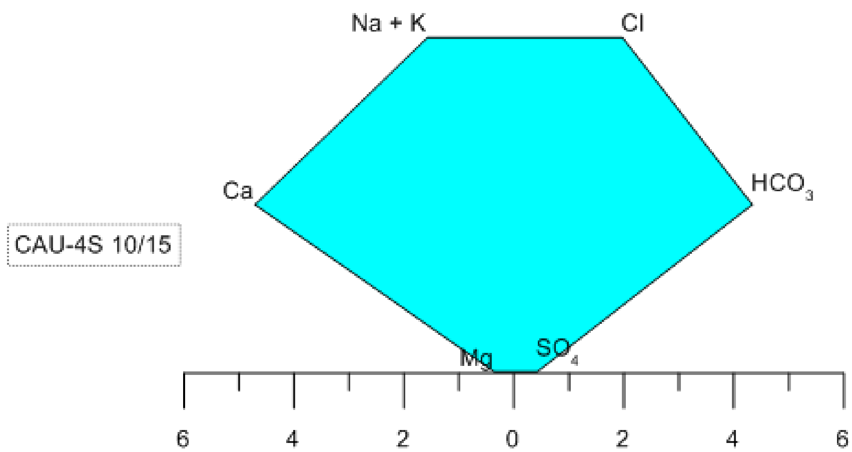	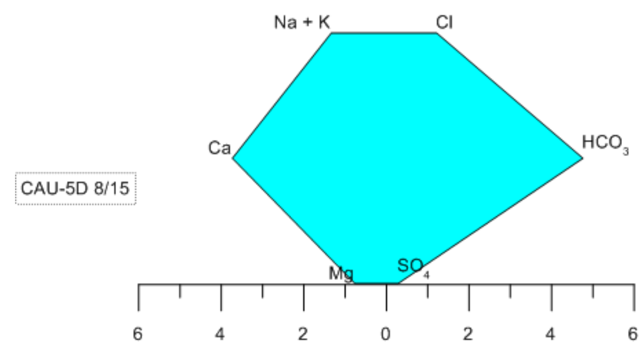

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Mg
SO_4
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HCO_3
Mg
SO_4
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HCO_3
Mg
SO_4
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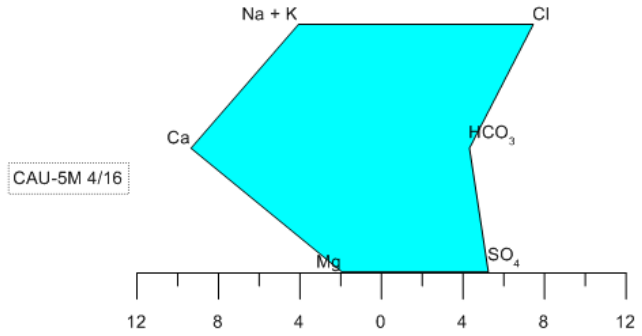
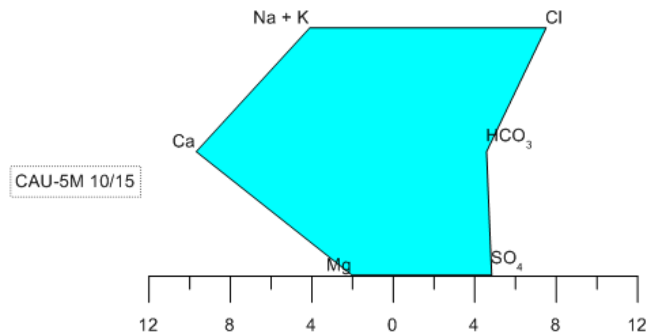
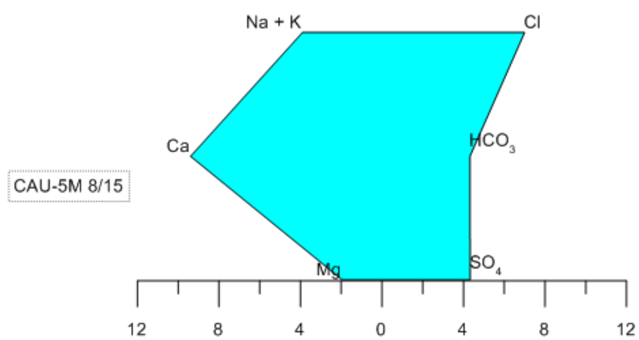
CAU-5M







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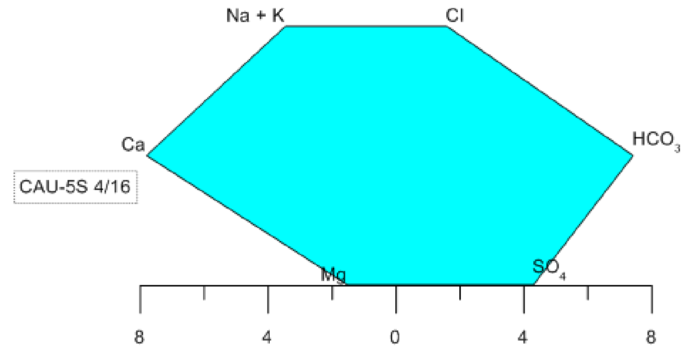

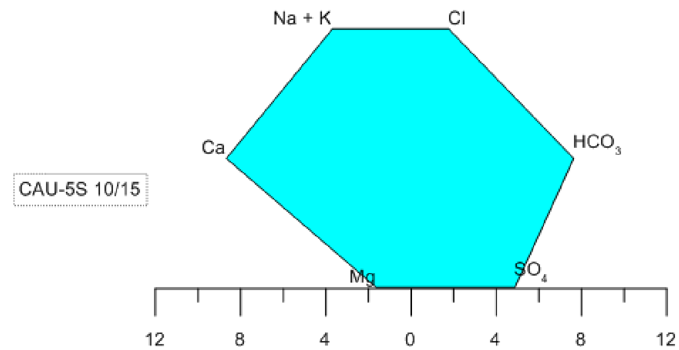

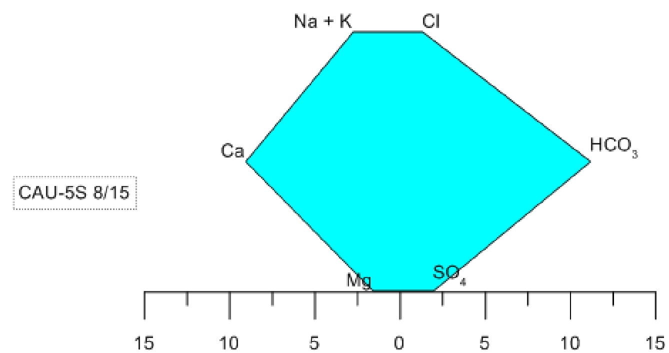

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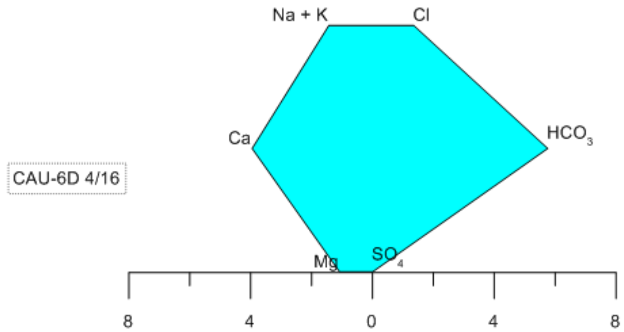

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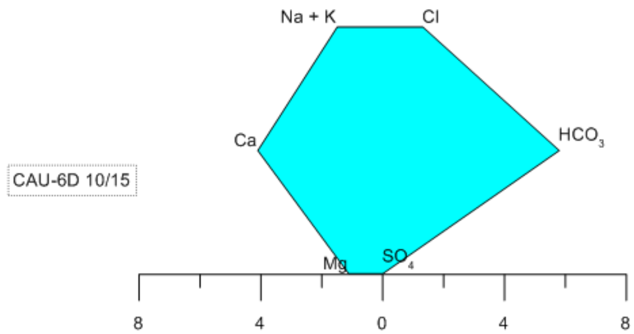

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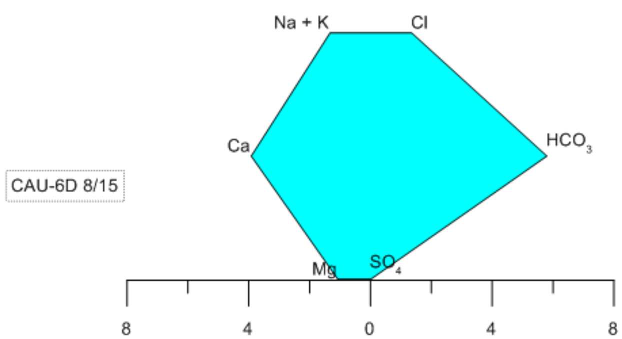

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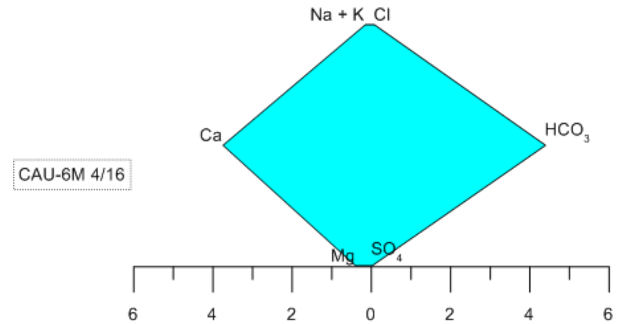
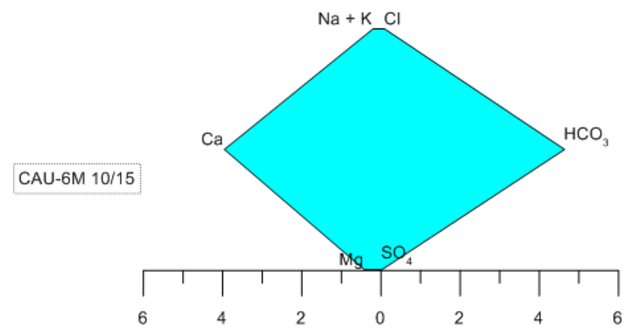


CAU-6M 4/16
Na + K
Cl
Ca
HCO3
Mg
SO4
6
4
2
0
2
4
6



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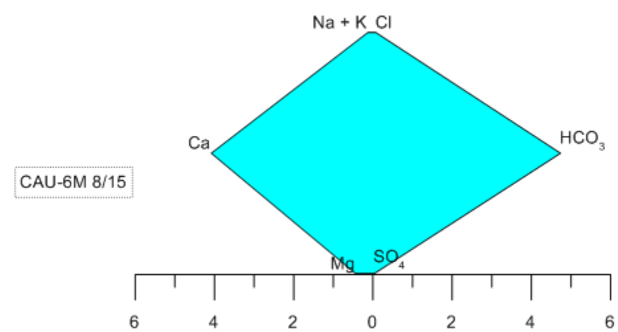
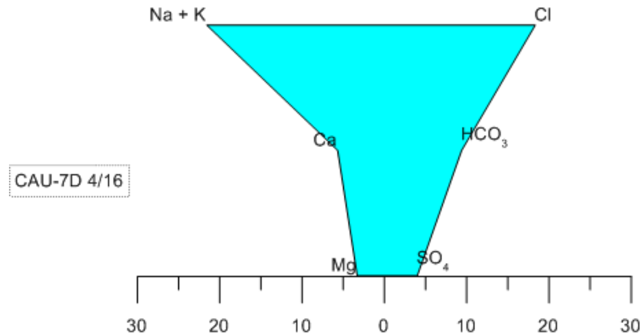
Na + K
Cl
Ca
HCO3
Mg
SO4
6
4
2
0
2
4
6

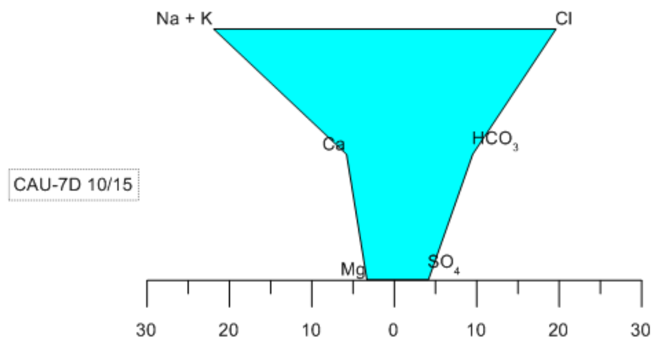


CAU-6M 8/15
Na + K
Cl
Ca
HCO3
Mg
SO4
6
4
2
0
2
4
6

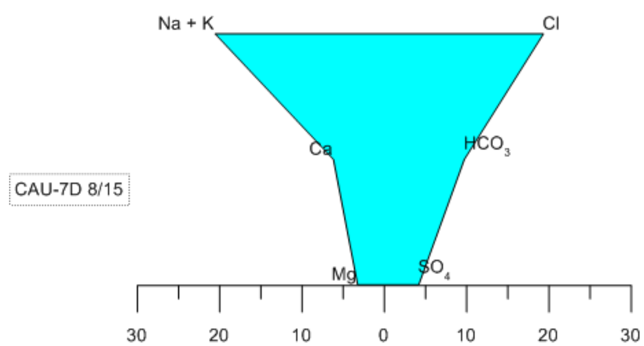
CAU-7D



Na + K
Cl
Ca
HCO$_3$
Mg
SO$_4$
CAU-7D 4/16
30 20 10 0 10 20 30

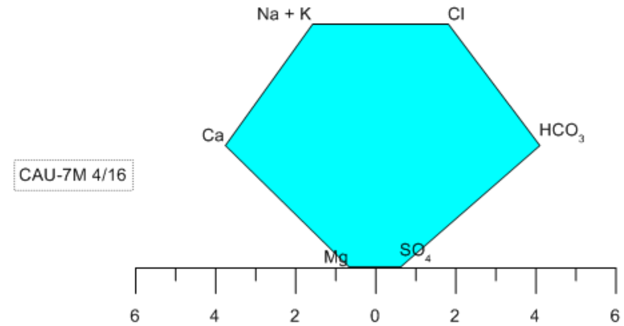


Na + K
Cl
Ca
HCO$_3$
Mg
SO$_4$
CAU-7D 10/15
30 20 10 0 10 20 30

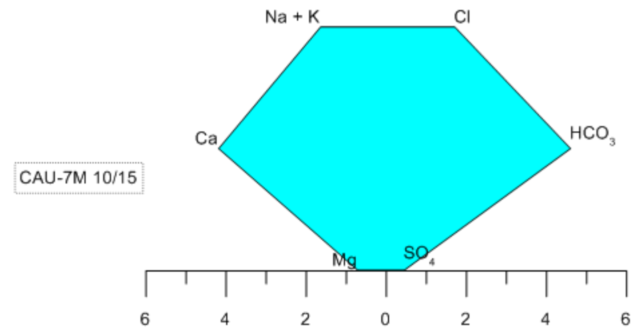


Na + K
Cl
Ca
HCO$_3$
Mg
SO$_4$
CAU-7D 8/15
30 20 10 0 10 20 30

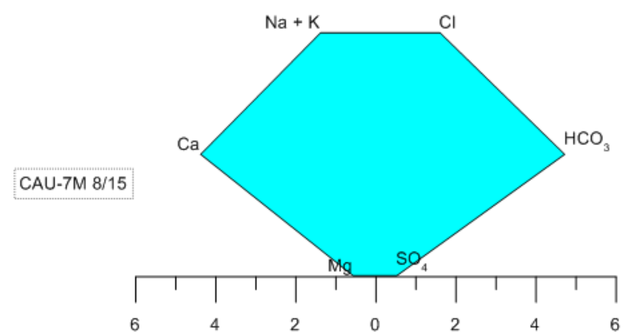
CAU-7M



Na + K
Cl
Ca
HCO$_3$
Mg
SO$_4$
CAU-7M 4/16
6 4 2 0 2 4 6

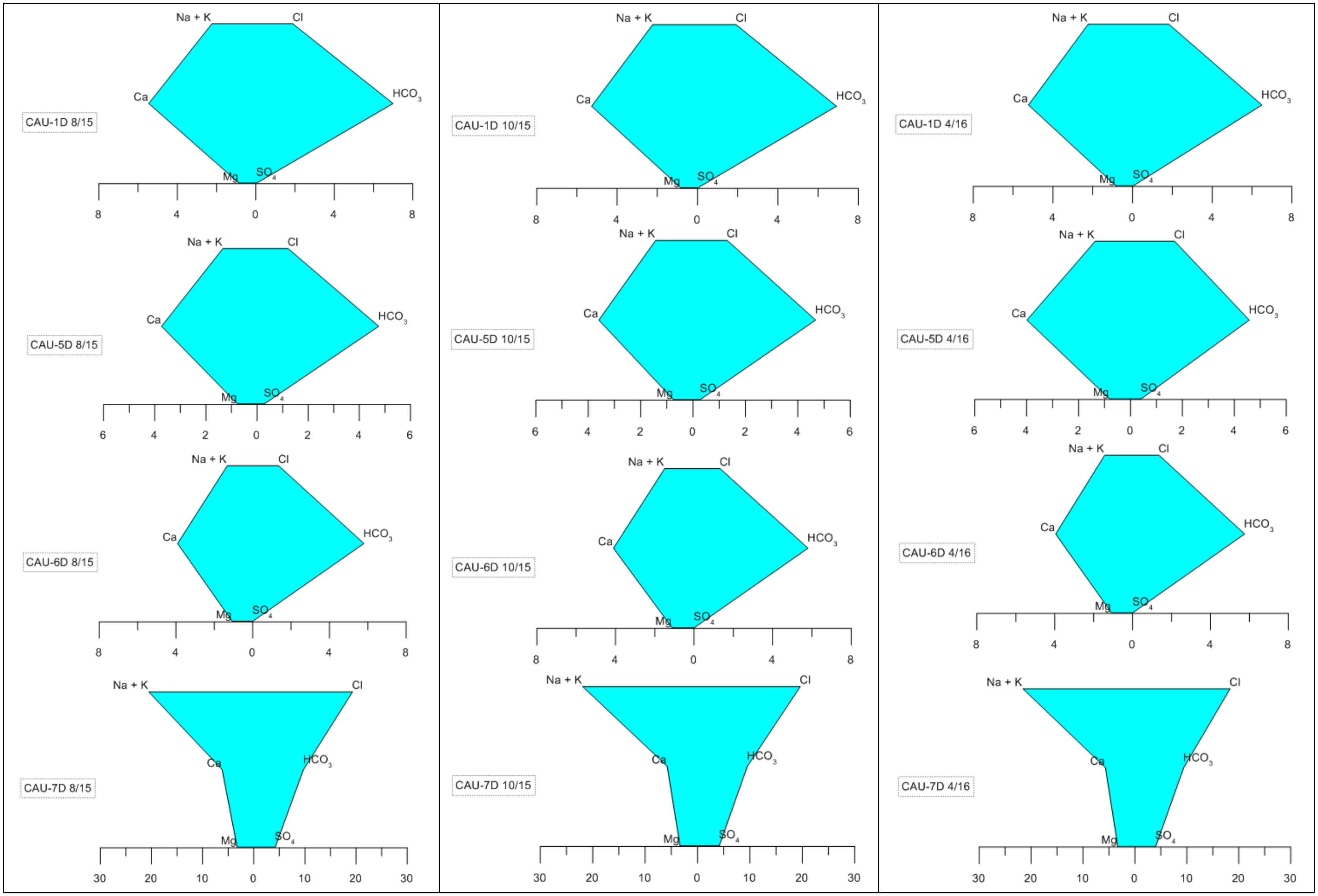


Na + K
Cl
Ca
HCO$_3$
Mg
SO$_4$
CAU-7M 10/15
6 4 2 0 2 4 6

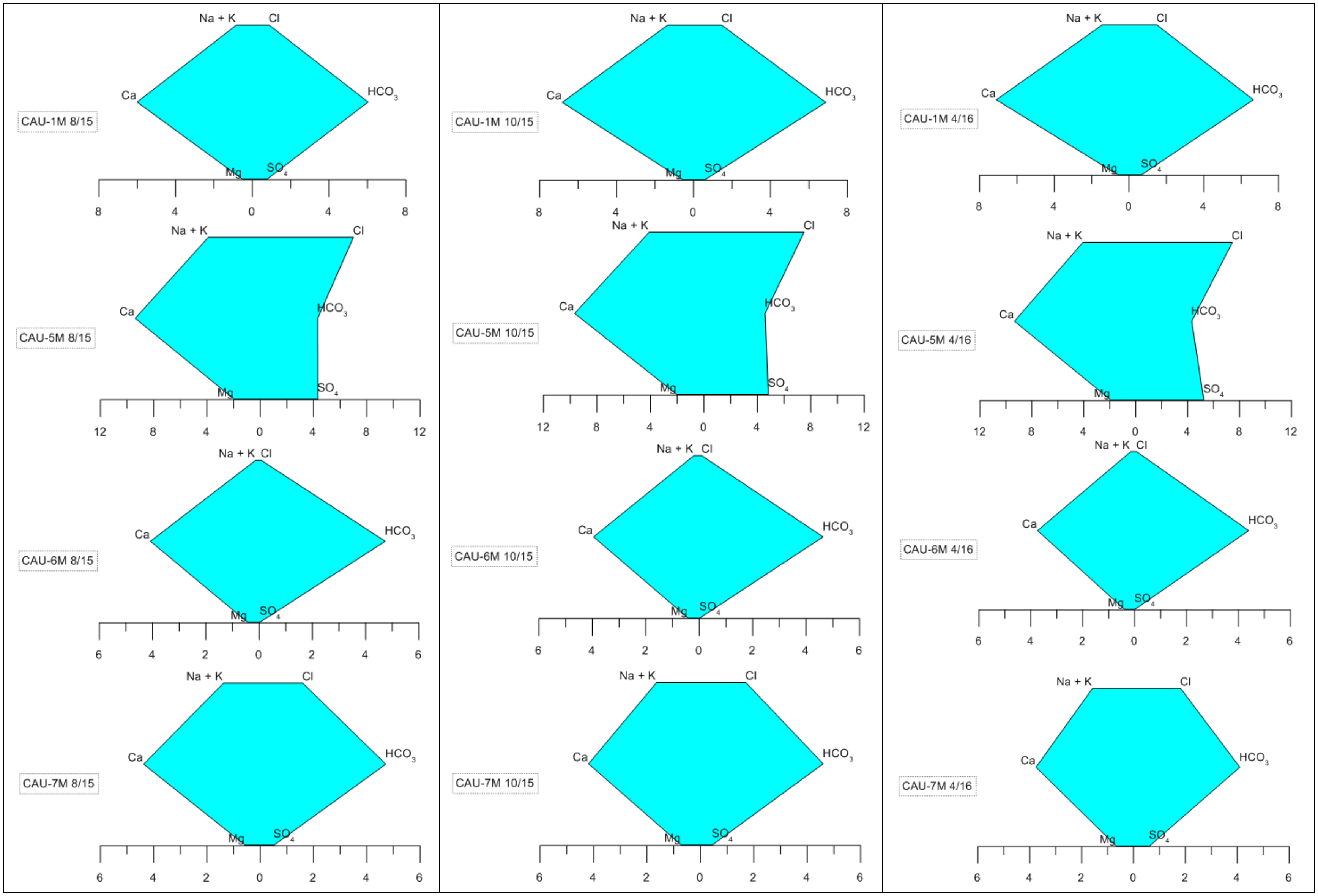


Na + K
Cl
Ca
HCO$_3$
Mg
SO$_4$
CAU-7M 8/15
6 4 2 0 2 4 6

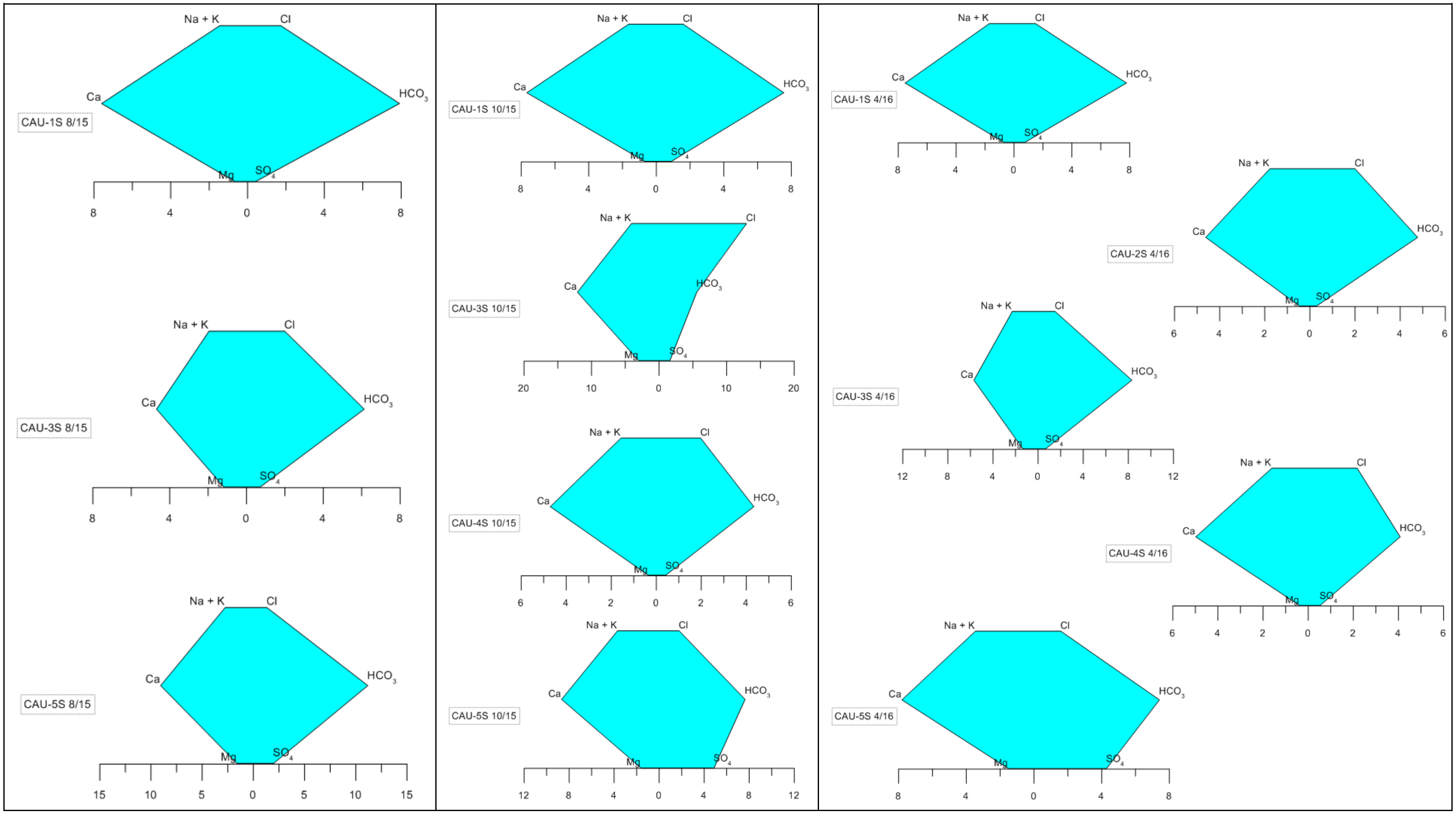
GROUNDWATER – DEEP



GROUNDWATER – MEDIUM



GROUNDWATER – SHALLOW



ATTACHMENT 2
FLAGGED DATA

Station	Collection Date	Parameter	Value	Units	Reason for Flagging Data
CAU-3S	8/21/2015	SC	832	µmhos/cm	Precision or accuracy criteria not met
CAU-2S			818		
CAU-4S			764		
CAU-7D			3,351		
CAU-7M			671		
CAU-6M			448		
CAU-6D			678		
CAU-2S		Ca	111.7	mg/L	Matrix Interference
CAU-2S		Mg	6		
CAU-2S		Na	40.1		
CAU-2S		K	7.8		
CAU-4S		Ca	106		
CAU-4S		Na	38.2		
CAU-2S	10/28/2015	Ca	123.1		
CAU-1LD	4/1/2016	SRP	0.054		Possible Matrix Interference
CAU-1LD			0.053		
CAU-1LD			0.058		

Ca = calcium; K = potassium; Mg = magnesium; Na = sodium; SC = specific conductance; SRP = soluble reactive phosphorus.

ATTACHMENT 3
NUTRIENT DATA

TOTAL PHOSPHORUS (TP)

Groundwater

Station	August 2015	October 2015	April 2016	Median
CAU-1D	0.04	0.04	0.05	0.04
CAU-1LD	0.05	0.07	ND	0.06
CAU-1M	0.08	0.12	0.07	0.08
CAU-1S	0.15	0.09	0.06	0.09
CAU-2S	0.28	0.27	0.22	0.27
CAU-3S	0.02	0.02	0.02	0.02
CAU-4S	0.11	0.08	0.06	0.08
CAU-5D	0.27	0.12	0.17	0.17
CAU-5M	0.06	0.06	0.07	0.06
CAU-5S	0.14	0.12	0.12	0.12
CAU-6D	0.02	0.03	0.03	0.03
CAU-6M	0.06	0.05	0.03	0.05
CAU-7D	0.04	0.03	0.03	0.03
CAU-7M	0.06	0.06	0.06	0.06

ND = no data.
Note: all values are in parts per million (ppm).

Surface Water

Site	August 2015	October 2015	April 2016	Median
CAUSG2	ND	0.17	0.27	0.22
CAUSG3	ND	0.16	0.14	0.15
CAUSG4	ND	0.11	0.36	0.24
CAULK-IN	ND	0.15	0.13	0.14
RESERVOIR	ND	0.22	0.09	0.16
C-44 CANAL	0.12	0.17	0.21	0.17
BACKGROUND	0.11	0.12	0.21	0.12

ND = no data.
Note: all values are in parts per million (ppm).

SOLUBLE REACTIVE PHOSPHORUS (SRP)

Groundwater

Station	August 2015	October 2015	April 2016	Median
CAU-1D	0.02	0.01	0.01	0.01
CAU-1LD	0.04	0.03	ND	0.04
CAU-1M	0.02	0.02	0.01	0.02
CAU-1S	0.13	0.08	0.03	0.08
CAU-2S	0.23	0.22	0.20	0.22
CAU-3S	0.01	0.01	0.01	0.01
CAU-4S	0.09	0.06	0.03	0.06
CAU-5D	0.04	0.03	0.03	0.03
CAU-5M	0.03	0.02	0.03	0.03
CAU-5S	0.12	0.10	0.09	0.10
CAU-6D	0.02	0.02	0.02	0.02
CAU-6M	0.04	0.04	0.02	0.04
CAU-7D	0.02	0.02	0.02	0.02
CAU-7M	0.05	0.05	0.05	0.05

ND = no data.
Note: all values are in mg/L.

Surface Water

Site	August 2015	October 2015	April 2016	Median
CAUSG2	ND	0.09	0.07	0.08
CAUSG3	ND	0.10	0.07	0.09
CAUSG4	ND	0.07	0.34	0.21
CAULK-IN	ND	ND	ND	ND
RESERVOIR	ND	0.14	0.04	0.09
C-44 CANAL	0.08	0.10	0.08	0.08
BACKGROUND	0.04	0.06	0.06	0.06

ND = no data.
Note: all values are in mg/L.

TOTAL NITROGEN (TN)

Groundwater

Station	August 2015	October 2015	April 2016	Median
CAU-1S	0.60	0.52	0.57	0.57
CAU-1M	0.29	0.33	0.37	0.33
CAU-1D	1.12	1.12	1.11	1.12
CAU-1LD	0.91	0.91	0.84	0.91
CAU-2S	1.48	1.57	1.50	1.50
CAU-3S	0.44	0.41	0.34	0.41
CAU-4S	0.89	0.88	0.87	0.88
CAU-5S	3.85	3.11	3.03	3.11
CAU-5M	1.59	1.75	2.21	1.75
CAU-5D	0.78	0.81	0.80	0.80
CAU-6M	0.51	0.49	0.51	0.51
CAU-6D	0.79	0.72	0.81	0.79
CAU-7M	0.78	0.98	0.67	0.78
CAU-7D	0.93	0.94	0.96	0.94

Note: all values are in mg/L.

Surface Water

Site	August 2015	October 2015	April 2016	Median
CAUSG2	ND	1.30	6.10	3.70
CAUSG3	ND	1.34	0.97	1.16
CAUSG4	ND	1.00	1.15	1.08
CAULK-IN	ND	1.39	1.41	1.40
RESERVOIR	ND	1.37	0.96	1.17
C-44 CANAL	0.80	1.37	1.69	1.37
BACKGROUND	ND	ND	ND	ND

ND = no data.
Note: all values are in mg/L.

NITRATES + NITRITES ($NO_2 + NO_3$)

Groundwater

Station	August 2015	October 2015	April 2016	Median
CAU-1S	0.01	ND	0.02	0.02
CAU-1LD	ND	ND	0.02	0.02
CAU-2S	0.01	0.01	0.01	0.01
CAU-3S	ND	0.01	ND	0.01
CAU-4S	0.02	0.02	0.01	0.02
CAU-5S	0.01	0.01	0.03	0.01
CAU-5M	0.01	0.01	0.01	0.01
CAU-6M	0.01	ND	ND	0.01
CAU-7M	0.01	ND	0.01	0.01

ND = no data.
Note: all values are in mg/L.

Surface Water

Site	August 2015	October 2015	April 2016	Median
CAUSG2	ND	ND	2.90	2.90
CAUSG3	ND	ND	0.07	0.07
CAUSG4	ND	ND	ND	ND
CAULK-IN	ND	0.48	0.27	0.38
RESERVOIR	ND	ND	0.38	0.38
C-44 CANAL	0.02	ND	0.30	0.16
BACKGROUND	ND	ND	ND	ND

ND = no data.
Note: all values are in mg/L.

AMMONIUM (NH_4)

Groundwater

Station	August 2015	October 2015	April 2016	Median
CAU-1S	0.14	0.14	0.13	0.14
CAU-1M	0.09	0.07	0.09	0.09
CAU-1D	0.60	0.60	0.57	0.60
CAU-1LD	0.60	0.57	0.55	0.57
CAU-2S	0.78	0.82	0.83	0.82
CAU-3S	0.08	0.12	0.05	0.08
CAU-4S	0.53	0.53	0.45	0.53
CAU-5S	0.92	1.16	1.04	1.04
CAU-5M	1.23	1.31	1.43	1.31
CAU-5D	0.39	0.39	0.40	0.39
CAU-6M	0.42	0.41	0.40	0.41
CAU-6D	0.36	0.38	0.37	0.37
CAU-7M	0.39	0.51	0.20	0.39
CAU-7D	0.65	0.67	0.65	0.65

Note: all values are in mg/L.

Surface Water

Site	August 2015	October 2015	April 2016	Median
CAUSG2	ND	0.03	1.60	0.82
CAUSG3	ND	0.03	0.03	0.03
CAUSG4	ND	0.02	0.31	0.17
CAULK-IN	ND	ND	ND	ND
RESERVOIR	ND	0.03	0.01	0.02
C-44 CANAL	51	0.05	0.04	0.05
BACKGROUND	ND	ND	ND	ND

ND = no data.
Note: all values are in mg/L.

TOTAL KJELDAHL NITROGEN (TKN)

Groundwater

Station	August 2015	October 2015	April 2016	Median
CAU-1S	0.64	ND	0.56	0.60
CAU-1M	0.32	ND	0.37	0.35
CAU-1D	1.12	ND	1.08	1.10
CAU-1LD	0.90	ND	0.86	0.88
CAU-2S	1.50	1.78	1.64	1.64
CAU-3S	0.42	0.48	0.37	0.42
CAU-4S	1.03	1.07	0.94	1.03
CAU-5S	4.45	3.79	3.34	3.79
CAU-5M	2.06	2.30	2.36	2.30
CAU-5D	0.80	0.77	0.80	0.80
CAU-6M	0.53	ND	0.53	0.53
CAU-6D	0.79	ND	0.87	0.83
CAU-7M	0.78	ND	0.70	0.74
CAU-7D	0.94	ND	0.98	0.96

ND = no data.
Note: all values are in mg/L.

Surface Water

Site	August 2015	October 2015	April 2016	Median
CAUSG2	ND	ND	ND	ND
CAUSG3	ND	ND	ND	ND
CAUSG4	ND	ND	ND	ND
CAULK-IN	ND	ND	ND	ND
RESERVOIR	ND	ND	ND	ND
C-44 CANAL	0.82	ND	ND	0.82
BACKGROUND	ND	ND	ND	ND

ND = no data.
Note: all values are in mg/L.

APPENDIX C

Aquifer Performance Tests

INTRODUCTION

Two aquifer performance tests (APTs) were performed on the central well cluster (site CAU-1) in the Caulkins Water Farm Pilot Project (WFPP) impoundment on November 4, 2015. The reservoir stage was 28.21 ft NGVD29. No water was pumped into the Caulkins WFPP on that date. This additional testing was recommended and undertaken to help define the range of estimated seepage at the impoundment.

METHODS

South Florida Water Management District (SFWMD or District) staff performed APTs on two wells (CAU-1M and CAU-1S) in the impoundment. The tests were completed on November 4, 2015. Insitu troll™ data loggers were installed in each well and water level data were collected continuously for the duration of both tests and the recovery periods. Manual water level measurements were taken before the start of each test. Data were recorded until each well recovered to background conditions after pumping. The pump then was moved to the next well, progressing from the deepest to shallowest. The first well pumped was CAU-1M, at a rate of 3 gallons per minute (gpm). The pump then was moved to CAU-1S and pumped at a rate of 1 gpm.

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 (HydroSOLVE Inc., 2007) for analysis. There was significant "noise" in the derivative data for each APT. The derivative curve is useful when combined with the drawdown curve to select 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 seconds was used for smoothing to minimize distortion of the derivative data (Horne, 1995). After the smoothed derivative curves were plotted together with their associated drawdown, the diagnostic plots were used to select appropriate solutions for analysis.

The APTs were analyzed assuming a hydraulic conductivity anisotropy ratio of 0.15 for CAU-1S in the shallow interval. This is the average of field permeability tests for depths from 0 to 12 ft below land surface (bls) (Ardaman & Associates, 2003). For CAU-1M, which was finished in a deeper interval, the assumed hydraulic conductivity anisotropy ratio was 0.03. This is the average from APTs for depths 40 to 80 ft bls (CDM, Inc., 2004). Both ratios were from field testing completed at the C-44 reservoir and were consistent with the analyses completed in the first annual report (Janzen et al., 2015).

RESULTS

Figures C-1 and **C-2** show the drawdown of the pumped well and the observation well for each APT. They are presented in the order they were executed in the field – the deepest well being pumped first.

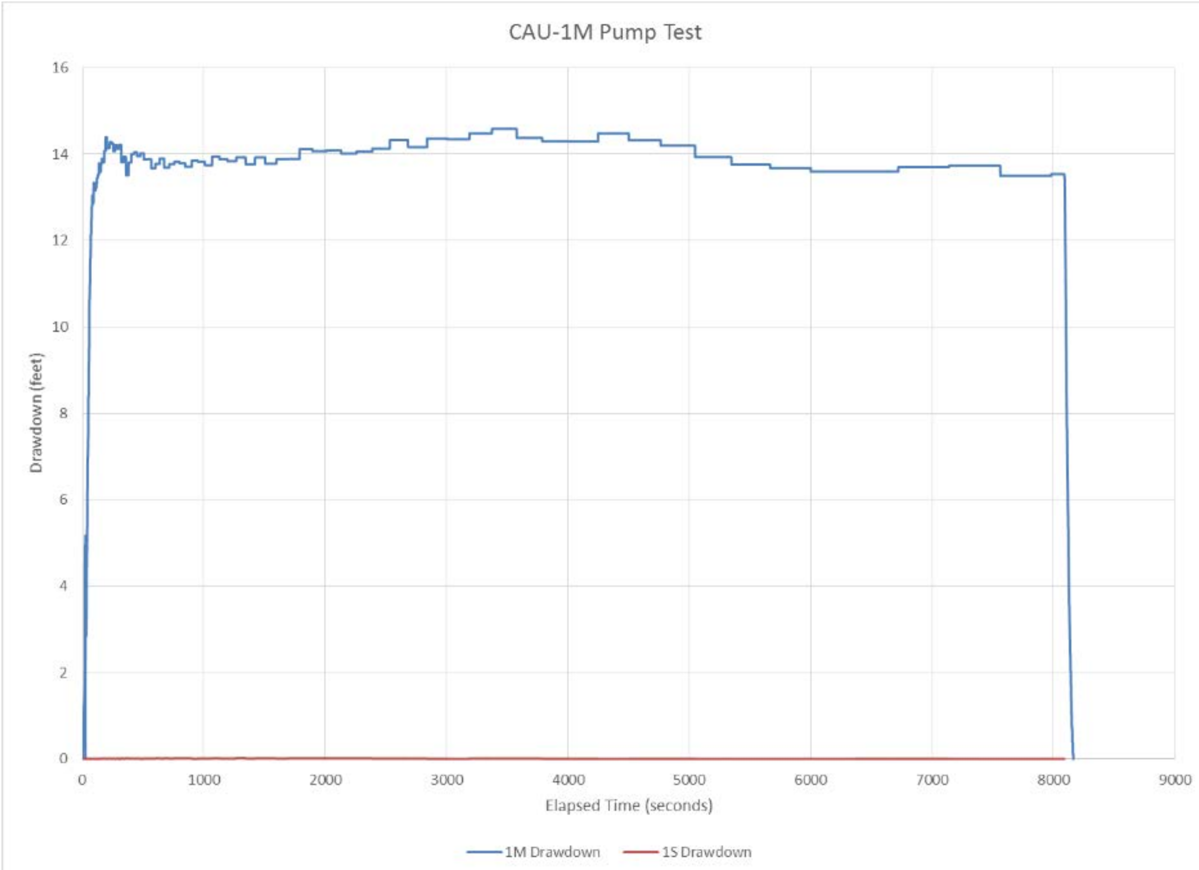


Figure C-1. Drawdown and observation well responses to aquifer performance tests at CAU-1M.

Well CAU-1M was pumped at a rate of 3 gpm for approximately 135 minutes, during which time there was no noticeable change in water level at the CAU-1S observation well. The step function failed at the commencement of recovery, so no logarithmic data are available for recovery analysis. The well took less than 3 minutes to recover to background conditions. The recovery data were linear. Drawdown pump test data analysis was appropriate with these results.

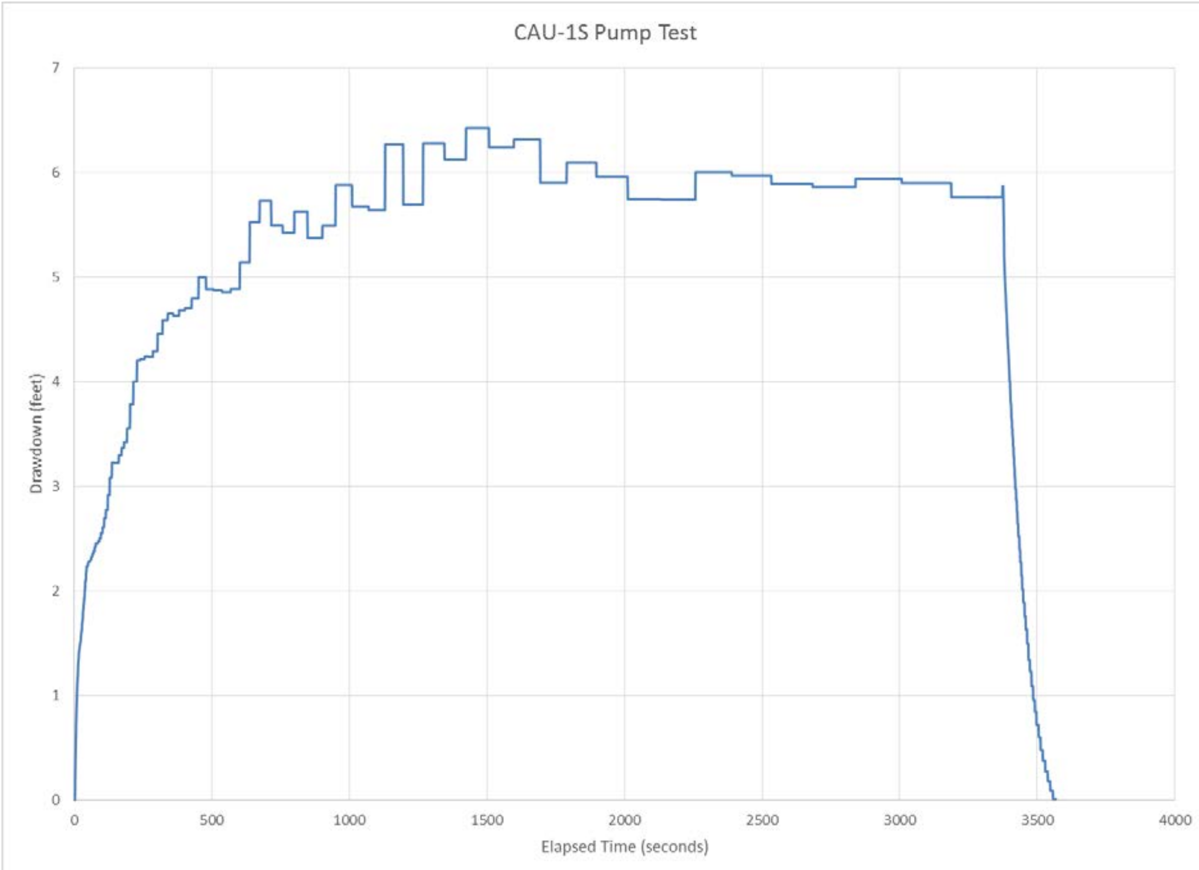


Figure C-2. Drawdown and observation well responses to aquifer performance tests at CAU-1S.

Approximately 11 minutes into the CAU-1S pump test, there was a significant drop in water level at the CAU-1M observation well (approximately 20 ft). Because of this, drawdown and recovery data in CAU-1S were used for analysis as the observation data were questionable beyond the first 11 minutes. The pumping phase lasted approximately 56 minutes, and the well recovered to background conditions in less than 4 minutes.

Figure C-3 shows the drawdown and its derivative for the pump test at CAU-1M, with and without derivative curve smoothing. The Bourdet (2002) derivative curve smoothing method was applied to the derivative data for each APT. This approach produces a better diagnostic plot for analysis. The log linear plot of displacement versus the elapsed time for the APT at CAU-1M without smoothing is on the right, and with smoothing (0.5 log time) is on the left. The displacement is depicted in blue squares, and the corresponding derivatives are red crosses.

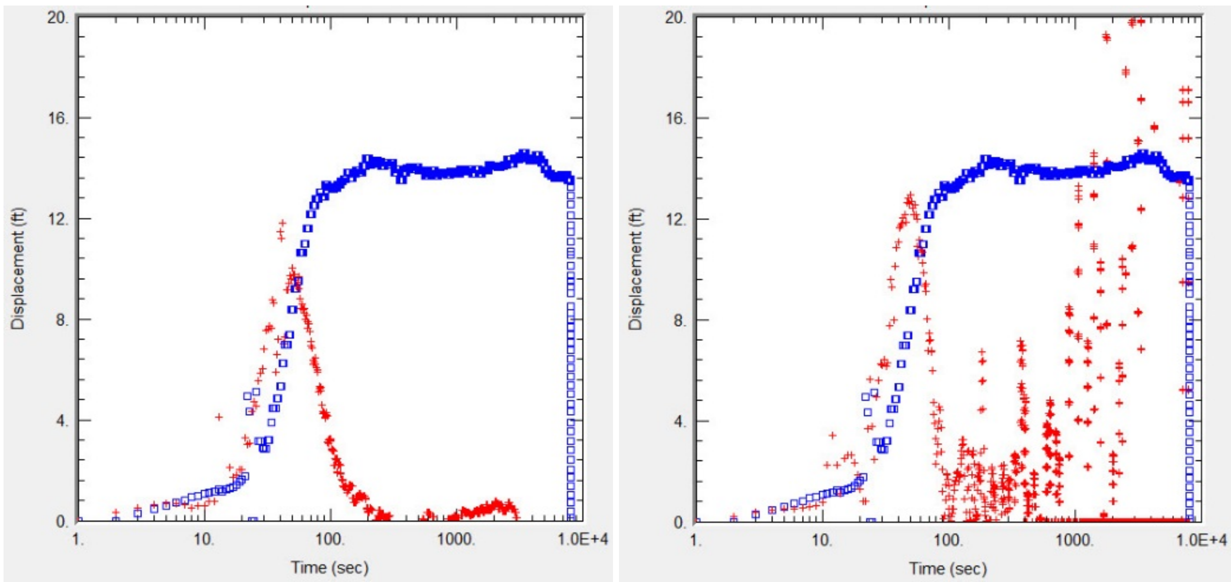


Figure C-3. Plot of test CAU-1M displacement versus time with (left) and without (right) derivative smoothing.

The displacement versus time graphs for the APT at CAU-1M plots like a confined aquifer. Solutions for confined aquifers giving an approximate curve match include Dougherty and Babu (1984) and Papadopulos and Cooper (1967). **Table C-1** documents the results using these solutions for CAU-1M.

Table C-1. Aquifer performance test results at CAU-1M.

Solution	Hydraulic Conductivity (ft/day)	Notes
Dougherty and Babu (1984)	3.1	Fair match
Papadopulos and Cooper (1967)	3.5	Fair match
Average	3.3	

The APT at CAU-1S was treated as a leaky confined aquifer for analysis. The bottom of the casing is beneath a thin clay layer and on top of a second clay layer. The saturated thickness of the aquifer is assumed to be 2 ft. Hantush and Jacob (1955) and Moench (1985) solutions were used in analyses for these tests. The only solution that yielded results remotely close to CAU-5S curves was Moench (1985). The results are presented in **Table C-2**.

Table C-2. Aquifer performance test results at CAU-1S.

Solution	Hydraulic Conductivity (ft/day)	Notes
Hantush and Jacob (1955)	2.8	Fair match
Moench (1985)	10.4	Fair match
Average	6.6	

Figure C-4 shows the solution and data curve match using the Papadopulos and Cooper (1967) solution for CAU-1M. The blue squares represent the displacement data in the pumped well, the red crosses are the smoothed derivative data, and the blue lines are the lines that data are expected to fall on with the solution applied. **Figure C-5** presents the matching results for the APT at CAU-1S using the Moench (1985) solution.

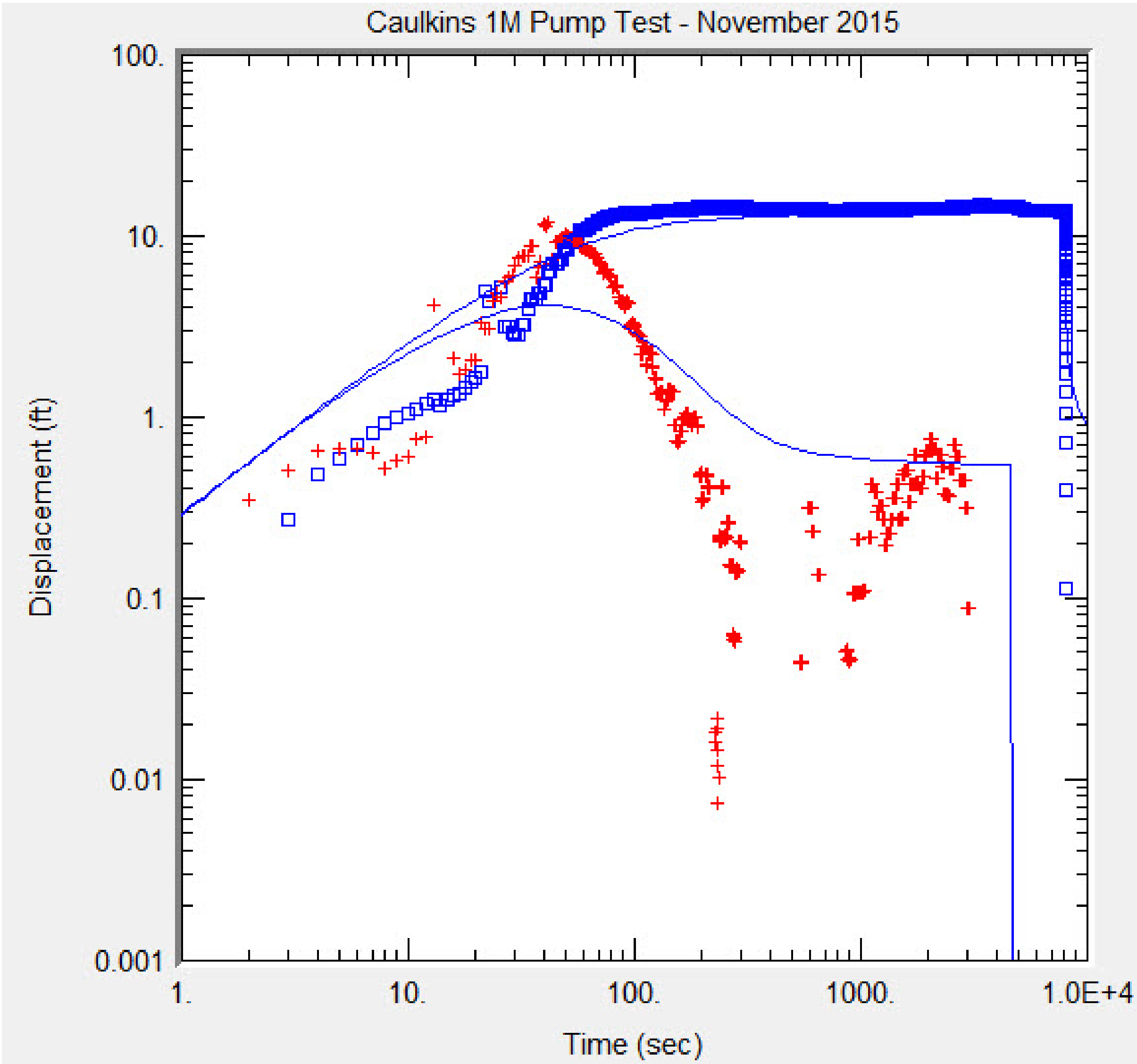


Figure C-4. Matching results for the aquifer performance test at CAU-1M using the Papadopulos and Cooper (1967) solution.

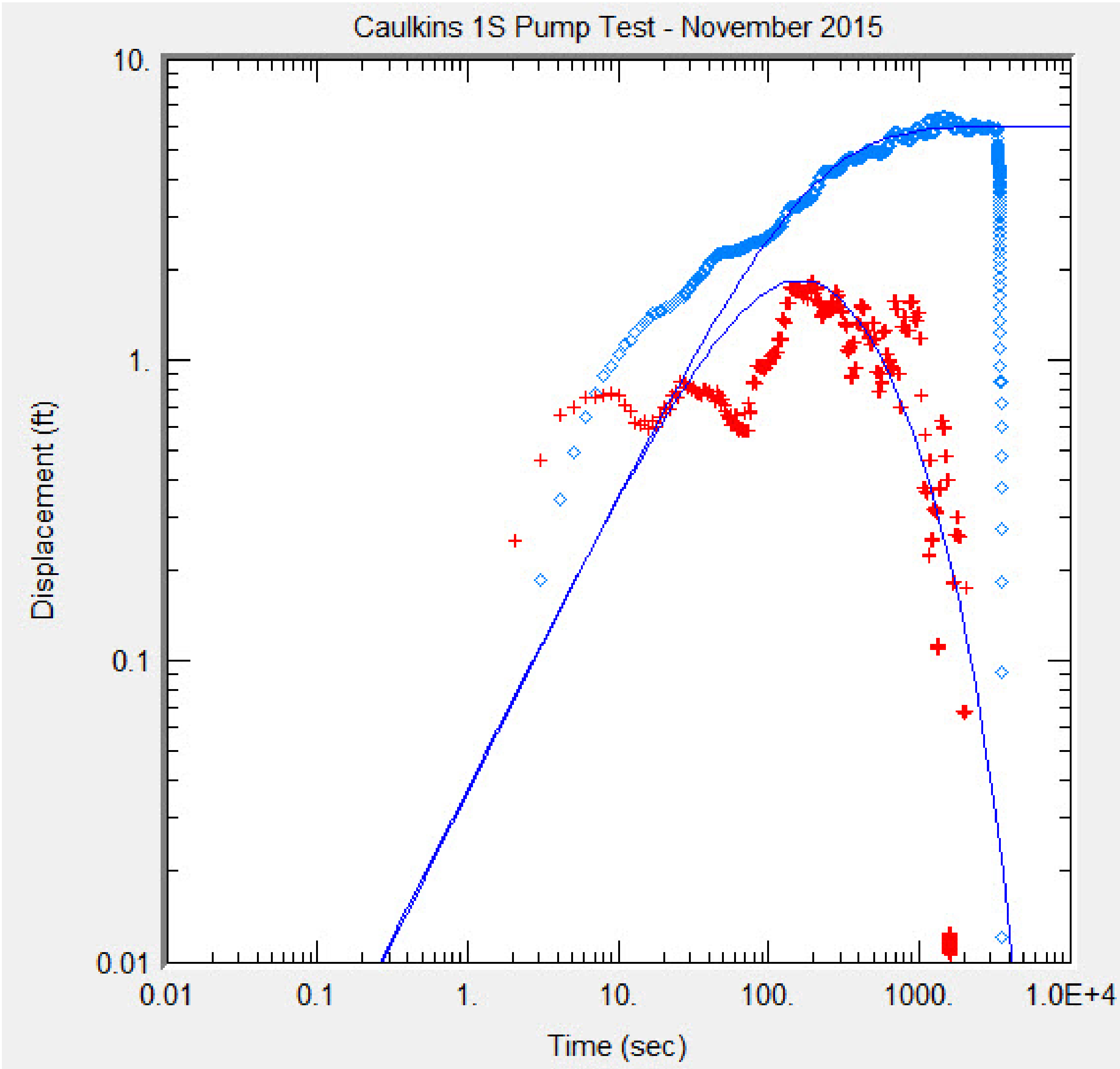


Figure C-5. Matching results for the aquifer performance test at CAU-1S using the Moench (1985) solution.

ANALYSIS

Table C-3 summarizes the results for the APTs. The results are consistent with March 2015 tests (Janzen, et al., 2015) where the average hydraulic conductivity values for CAU-1M and CAU-1S were 11 ft/day and 10 ft/day, respectively. The impoundment stage in March 2015 was 28.83 ft NGVD29, and in November 2015, the stage was 28.21 ft NGVD29. On both occasions the impoundment was nearly full.

Table C-3. Summary results for November 2015 aquifer performance tests.

Well	Average Hydraulic Conductivity (ft/day)
CAU-1M	3.3
CAU-1S	6.6

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