PUEBLO
water resources

SUMMARY OF OPERATIONS

BELTZ 8
ASR PILOT TEST PROJECT

SANTA CRUZ ASR PROJECT
PHASE 2 FEASIBILITY INVESTIGATION

Prepared for:

SANTA CRUZ WATER DEPARTMENT

MARCH 2023

PUEBLO
water resources

March 13, 2023
Project No. 15-0113

Santa Cruz Water Department
212 Locust Street, Suite C
Santa Cruz, California 95060

Attention: Ms. Leah Van Der Matten, Associate Professional Engineer

Subject: Santa Cruz ASR Project; Beltz 8 ASR Pilot Test Summary of Operations Report

Dear Leah:

We are transmitting a digital image (PDF) of the subject report documenting the operations and findings developed from the Beltz 8 ASR Pilot Test Project. A total volume of approximately 9.72 million gallons (mg) of Graham Hill Water Treatment Plant (GHWTP) product water from the Santa Cruz Water Department (SCWD) distribution system was successfully injected into the Purisima Aquifer A Unit of the Santa Cruz Mid-County Groundwater Basin (MGB) at rates ranging between approximately 300 to 315 gallons per minute (gpm). During injection testing, both active and residual well plugging rates were very low. Based on analysis of the pilot testing results and our experience with other ASR wells, a nominal ASR capacity for Beltz 8 of approximately 375 gpm injection and 565 gpm recovery pumping (equivalent to approximately 0.54 and 0.81 mgd, respectively) is recommended.

During the ASR pilot test, arsenic concentrations were observed to increase above pre-injection native groundwater concentrations as a result of geochemical interactions during aquifer storage and recovery; however, analysis of the testing results indicates that the initial high arsenic concentrations are expected to attenuate over time with successive ASR cycles and are not expected to exceed drinking water standards. The overall favorable results of the ASR pilot test program support advancing the Beltz 8 well into a long-term ASR demonstration facility to confirm the pilot testing results.

We appreciate the opportunity to provide ongoing assistance to the SCWD on this important community water-supply project. Please contact us with any questions.

Sincerely,
PUEBLO WATER RESOURCES, INC.

Robert C. Marks, P.G., C.Hg.
Principal Hydrogeologist

Copies submitted: 1 digital (PDF)

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INTRODUCTION

GENERAL STATEMENT

Presented in this report is a summary of operations and analysis of well and aquifer water-level and water-quality data developed from an Aquifer Storage and Recovery (ASR) pilot test project implemented at the Santa Cruz Water Department's (SCWD) Beltz 8 Well, located at 3701 Roland Drive in Santa Cruz, California. The location of the project site is shown on **Figure 1**. ASR pilot testing operations were conducted during the period March 3, 2020 through June 1, 2021. The project generally involved cyclic recharge, storage and subsequent recovery of treated drinking water originating from the SCWD's Graham Hill Water Treatment Plant (GHWTP) into the Purisima Aquifer system within the Santa Cruz Mid-County Groundwater Basin (MGB) via injection and extraction/pumping at the Beltz 8 well. The overall goal of the project was to verify the findings from the Phase 1 ASR Technical Feasibility Analysis and to empirically determine site-specific hydrogeologic and water-quality factors that will allow a technical and economic assessment of a permanent ASR operation at the site.

BACKGROUND

ASR is a form of managed aquifer recharge (MAR) that involves the enhanced conjunctive use of surface water and groundwater resources to "bank" water in an aquifer during times when excess surface water is available for storage (typically wet periods) and subsequent recovery of the water from the aquifer when needed (typically dry periods). ASR utilizes dual-purpose injection/recovery wells for the injection of water into aquifer storage and the subsequent recovery of the stored water by pumping. In order to feasibly implement ASR, the following five basic project components are required:

1. A supply of excess surface water for injection;
2. A system for the diversion, treatment and conveyance of water between the source and groundwater storage basin;
3. A suitable groundwater basin with available storage space;
4. Wells to inject and recover the stored water, and;
5. A system for the treatment and conveyance of recovered water from the ASR well into the distribution system.

As applied to Santa Cruz, ASR involves the diversion of "excess" winter and spring flows from SCWD's North Coast sources and the San Lorenzo River (SLR), treated to potable standards at the Graham Hill Water Treatment Plant (GHWTP), then conveyed through the existing (and/or improved) water distribution system(s) to ASR wells located in the MCB. In this context, "excess" flows are those flows that exceed SCWD demands, meet in-stream flow requirements and are within water rights.

As a consultant to the Water Supply Advisory Committee (WSAC) Technical Team, Pueblo Water Resources, Inc. (PWR) developed an implementation strategy for the ASR element of the Water Supply Augmentation Plan that consisted of three phases:

- **Phase 1 – Technical Feasibility Analyses**: Performance of detailed technical feasibility investigations, including the use of groundwater modeling, completion of site-specific injection capacity and geochemical interaction analyses, and development of a pilot ASR testing program.
- **Phase 2 – ASR Pilot Testing**: Performance of pilot ASR testing programs and assessments of probable ASR system performance, cost and schedule to complete build-out of the ASR system.
- **Phase 3 – Project Implementation**: Development of full-scale ASR project basis-of-design, construction of ASR system facilities (perhaps incrementally), establishment of ASR project operational parameters, and long-term operation of project to achieve target storage volumes.

The Phase 1 investigation was still ongoing when the Phase 2 ASR pilot testing at Beltz 8 was performed (the majority of outstanding work was in the groundwater modeling task); however, the findings developed to that point from the Phase 1 investigation had been documented in task-specific Technical Memoranda (TM)[1] presented to the SCWD, and the key Phase 1 findings related to Beltz 8 are summarized below:

- Task 1.1 – Existing Well Screening identified SCWD's Beltz 9 Well as the preferred existing well for conducting ASR pilot testing of the A Unit of the western Purisima Aquifer system of the MCB; however, SCWD decided to conduct ASR pilot testing at Beltz 8 due to system operational considerations.
- Task 1.2 – Site-Specific Injection Capacity Analysis resulted in an estimated maximum long-term injection capacity for Beltz 8 of approximately 270 gallons per minute (gpm, equivalent to approximately 0.389 million gallons per day [mgd]).
- Task 1.3 – Geochemical Interaction Analysis performed for Beltz 9 (it was the preferred well for the A Unit) indicated that there is limited potential for adverse geochemical reactions as a result of injecting treated SLR water at Beltz 9 (assuming GHWTP pH is maintained at less than 7.6); additionally, the potential for beneficial reduction of manganese concentrations in the recovered waters (relative to native groundwater) was identified and to be investigated further during the ASR pilot test program.

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[1] Pueblo Water Resources, Inc. (November 2016), *Task 1.1 Existing Wells Screening*, Technical Memorandum prepared for Santa Cruz Water Department.

Pueblo Water Resources, Inc. (May 2017), *Task 1.2 Site-Specific Injection Capacity Analysis*, Technical Memorandum prepared for Santa Cruz Water Department.

Pueblo Water Resources, Inc. (August 2017), *Geochemical Interaction Analysis (Task 1.3)*, Technical Memorandum prepared for Santa Cruz Water Department (draft).

Pueblo Water Resources, Inc. (December 2019), *Task 1.4 ASR Pilot Test Work Plan for Beltz 8*, Technical Memorandum prepared for Santa Cruz Water Department.

- Task 1.4 – Phase 2 ASR Pilot Testing Work Plan for Beltz 8 was prepared, which included detailed descriptions of the following:
    - Permitting Requirements
    - Site Preparation Details
    - ASR Pilot Test Program
    - Sampling and Analysis Plan
    - Preliminary Project Schedule

Based on the favorable results of the Phase 1 ASR technical feasibility investigation through 2019, the SCWD decided to advance the ASR investigation to Phase 2 ASR pilot testing in the A Unit of the MGB at the Beltz 8 Well while the Phase 1 groundwater modeling of full-scale ASR projects continued on a parallel track. The overall objective of the Phase 2 pilot testing is to field verify the findings developed from Phase 1 and empirically determine site-specific hydrogeologic and water-quality factors that will allow a technical and economic viability assessment of ASR technology in this area of the MGB. If feasible, the data gathered may also be used to complete CEQA documentation and permitting for a full-scale permanent ASR project.

PURPOSE AND SCOPE

The primary purpose of the Beltz 8 ASR pilot test project was to field demonstrate the potential application of ASR in the A Unit of the Purisima Aquifer system in the MGB. The data will be used to assess both the economic and logistical viability of ASR and will provide the basis for the design, environmental planning, and permitting for a long-term full-scale ASR project in the area.

The scope of work essentially consisted of implementing the ASR Pilot Test Work Plan that was developed for Beltz 8 as part of Task 4 of the Phase 1 investigation, which is presented in **Appendix A** for reference. The scope of work consisted of the following main tasks:

1. Project permitting assistance;
2. Site preparation;
3. Implementation of ASR cycle testing program;
4. Data collection, analysis and reporting, and;
5. Project management and meetings.

The findings developed from the Beltz 8 ASR pilot test project are presented in the following section.

FINDINGS

HYDROGEOLOGIC SETTING

The Beltz 8 well site is located in the western portion of the Santa Cruz Mid-County Groundwater Basin (MGB). The Purisima Aquifer constitutes the western portion of the MGB (the eastern portion of the MGB consists of the Aromas Aquifer, which is connected to the Pajaro Valley Groundwater Basin and is not currently under consideration for an ASR project). The hydrogeology of the Purisima Aquifer has been documented in detail in reports prepared by the

United Stated Geological Survey (USGS), the California Department of Water Resources (DWR), and various individual consultants and consulting firms. These documents describe the stratigraphy, structure, and hydraulic characteristics of the regional aquifer systems. The most recent comprehensive study was prepared for the Soquel Creek Water District (SqCWD) by Johnson, et al, (2004), which synthesizes more than 35 years of previous investigations and forms the primary basis for the description presented herein.

As described, the Purisima Aquifer consists of several distinct zones within the geologic Purisima Formation (Tp). The Purisima Formation is a consolidated to semi-consolidated marine sandstone with siltstone and claystone interbeds and an uneroded thickness of approximately 2,000 feet. The Purisima Aquifer has been subdivided by Johnson (2004) into hydrostratigraphic units (from youngest to oldest, Aquifer Units F through Tu) for purposes of conceptualizing the distribution of hydrogeologic properties and pumping stresses. Underlying the Purisima Formation are older sedimentary formations, the presence of which varies depending on location. The Monterey Formation and Santa Cruz Mudstone are essentially non-water bearing; however, the Butano, Lompico and Santa Margarita Sandstones serve as productive aquifers in other areas (e.g., Scotts Valley and Seaside Groundwater Basin in Monterey) and constitute a lower extension of the Purisima Aquifer (the Tu Unit) in the Beltz wellfield area.

Site Hydrostratigraphy

The hydrostratigraphy of the Beltz 8 site is well established from the lithologic and geophysical logs for the well suggests the following stratigraphic interpretation:

Table 1. Site Hydrostratigraphy

Hydrostratigraphic Unit[1]	Depth (feet bgs)	Thickness (feet)
Terrace Deposits	0 – 25	25
A Aquifer Unit	25 – 180	155
AA Aquifer Unit	180 – 220*	40+

Notes:
1 – Designations based on Johnson (2004)
* - Total depth of borehole

Due to the dip in the formation, only remnants of the Purisima Formations lower-most strata occur within the SCWD service area, and the younger Aquifers F through B stratigraphic units are not present at the Beltz 8 well site.

As-Built Well Construction

Beltz 8 was drilled and constructed in 1998 by Maggiora Bros. Drilling under the supervision of Fugro West, Inc. An as-built schematic of the well is presented on **Figure 2** and a summary of the as-built well construction features of the well is presented below in **Table 2**:

Table 2. As-Built Well Construction Summary

Design Feature	As-Built	Comment
Total Well Depth (ft bgs)	220	
Seal Depth (ft bgs)	80	10.5-sack cement sand slurry
Casing Material	Mild Steel x Stainless Steel	14-inch Blank and Screen
Screen Interval (ft bgs)	100 - 180	Aquifer Unit A
Total Screen Length (feet)	80	
Perforation Aperture	0.035-inch slots	Stainless Steel Wire-Wrapped
Gravel Pack (gradation)	12 x 20	RMC Lonestar Lapis Lustre Sand
Cellar Section (ft bgs)	180 - 210	

PERMITTING

Injection operations during the Beltz 8 ASR pilot test project were authorized under State Water Resources Control Board (SWRCB) General Waste Discharge Requirements for Aquifer Storage and Recovery Projects that Inject Drinking Water into Groundwater (Water Quality Order 2012-0010). A Notice of Intent (NOI) package was prepared by PWR and submitted by the SCWD to the Central Coast Regional Water Quality Control Board (RWQCB) in December 2019 and the project was authorized via a Notice of Applicability (NOA) letter from the Central Coast RWQCB, dated February 24, 2020.

Discharges during the pilot test program were sent to the municipal storm drain system via an on-site storm drain inlet and were performed under the existing SWRCB Statewide NPDES Permit for Drinking Water System Discharges to Waters of the United States (Order WQ 2014-0194-DWQ, General Order No. CAG140001), which the SCWD was previously enrolled.

SITE PREPARATION

Monitoring Well

A proximate monitoring well that is located within the radius of injected water predicted to surround the subject well (i.e., within the injection “bubble”) during the ASR pilot test and that is completed in the same aquifer zone as the ASR pilot test well is needed for monitoring of both water-level responses and water-quality interactions during the ASR pilot test program. Such a monitoring well is particularly important for the following investigative issues:

- Monitoring of ion exchange and redox reactions;
- Evaluation of water-quality changes during aquifer storage and recovery pumping, and;
- Monitoring of DBPs ingrowth and degradation during aquifer storage.

The on-site monitoring well, designated as the Beltz 8 Monitoring Well (Beltz 8 MW) was drilled in January/February 2020 and is located approximately 35 feet from the Beltz 8 well as shown on **Figure 1**. The monitoring well is constructed of 2-inch-diameter Sch 40 PVC casing and is screened in the same intervals as the Belt 8 well (i.e., is a "mirror" completion). Documentation of well drilling, completion and development operations are presented in a separate report.[2]

Well Preparation

Beltz 8 was drilled in 1998. Following its construction, it displayed a 24-hour specific capacity[3] of approximately 22.8 gpm per foot of drawdown (gpm/ft) and by 2019 the performance had declined with the 24-hour specific capacity at approximately 17.4 gpm/ft. This represents an approximate 25 percent decline in performance, indicating that some plugging of the gravel pack and/or near-bore aquifer matrix was present; therefore, the well needed to undergo light rehabilitation to remove loose materials that may present in the well screen and/or gravel pack that could become lodged during injection and result in further well plugging.

Downhole well cleaning activities at Beltz 8 occurred during the period February 27 through March 18, 2020. Zim Industries, Inc. (Zim) of Fresno, California, as a subcontractor to PWR. A summary of the downhole well preparation work is presented below:

Pump Assembly Removal and Pre-Cleaning Video Survey. The contractor mobilized to the site on February 27, 2020 and began removal of the existing pump assembly. Following removal of the pump assembly, a pre-rehabilitation video survey was performed on March 2, 2020 and the report is presented in **Appendix B** for reference. The video survey revealed that the screen was relatively open with light to moderate plugging throughout.

Downhole Cleaning Activities. Following the video survey and mobilization of additional equipment and supplies, mechanical rehabilitation was initiated on March 5, 2020, with brushing of the well screen. A 14-inch-diameter nylon brush assembly was utilized, and each 20-foot section of screen was brushed for approximately 30 minutes (total brushing time was approximately 2 hours).

Dual-swab isolation zone airlift pumping of the screen was then performed to remove loose materials from the screen/gravel pack/near bore aquifer materials prior to injection testing to limit the potential for plugging. The dual-swab assembly consisted of two 14-inch-outside-diameter rubber swabs separated by approximately 5 feet on a perforated spindle. The tool was placed on the end of 5-inch diameter eductor pipe with a 1.25-inch diameter airline.

Dual-swab airlifting operations were initiated on March 9, 2020 from the top of the screen and worked progressively to bottom. Each 20-foot interval of screen was generally worked for a period of approximately 60 minutes until the discharge became relatively clear. Initial discharge from each interval was typically extremely turbid and of a brown color with abundant fine grey sand. Upon reaching bottom, a second pass was performed on a couple of intervals (131 – 136

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[2] Pueblo Water Resources, Inc., *Monitoring Well Completion Report, Beltz 8 Monitoring Well Project*, report prepared for the Santa Cruz Water Department, dated December 2020.

[3] Specific capacity is the ratio of discharge rate to drawdown, typically expressed in terms of gallons per minute per foot of drawdown (gpm/ft). The value is useful for tracking the performance of a given well over its service life and comparing performance between wells.

and 111 – 116 feet bgs) that required additional development time for the discharge to become clear.

Post-Cleaning Video Survey. A post-rehabilitation video survey was performed on March 11, 2020 by Newman Well Surveys. The clarity of the video was relatively poor due to a turbid water column; however, side-scan views of the screen were good and gravel pack material was clearly visible throughout the screen, indicating that most of the loose material present prior to cleaning had been successfully removed and no damage to the well had occurred during the process.

Site Improvements

Temporary modifications to the Beltz 8 well facility required for implementation of the ASR pilot test program were installed between March 11 and 13, 2020 by Zim, and generally consisted of the following activities:

- Fabrication of a special temporary well head seal plate to accommodate a test pump, injection drop tubes and sounding tubes.
- Installation of a 30 HP submersible test pump
- Installation of three injection drop tubes and two water-level sounding tubes.
- Installation of temporary piping, valving, metering and storage tanks to route injection supply water to the well and discharge water from well to storm drain inlet and/or the on-site 70,000 gallon reclaim storage tank.
- Removal of test pump and injection drop tubes from the well.
- Performance of post-testing downhole video survey
- Reinstallation of SCWD's existing 25 HP submersible pump assembly
- Disinfection of the well and pump assembly in accordance with State Well Standards

A 30 HP submersible test pump was installed to a depth of approximately 191 feet below top of casing (btoc), with the pump assembly placed within the cellar section equipped with a PVC motor cooling shroud. Three 2-inch-diameter schedule 40 PVC injection drop tubes were installed to depths of approximately 80 ft btoc. The bottom of each injection tube was fitted with a fixed-orifice end cap of a specific size (orifice sizes were 0.75-, 1.25- and 1.50-inch-diameter), which allowed positive pressures to be maintained within the piping system and drop tubes at all times during injection testing at variable rates to prevent water cascading in the well (which can lead to gas-binding and plugging of the well screen).

Zim furnished and installed temporary PVC injection and discharge water piping from the wellhead, a flow meter, several valves, pressure gages, and other appurtenances. The 2-inch-diameter injection drop tubes were connected to a 4-inch-diameter PVC manifold that was connected to two 2-inch-diameter reduced pressure (RP) backflow preventers supplied by the SCWD, which were connected to the SCWD municipal water supply via an on-site fire hydrant. Pressure gages were installed at the wellhead on each injection tube and at various points in the temporary piping system. Zim also installed a temporary 6-inch-diameter BFP and PVC discharge piping from the wellhead to the on-site storm drain inlet.

ASR PILOT TEST SUMMARY OF OPERATIONS

ASR operations generally consist of three steps:

1. Injection of potable-quality drinking water into the aquifer;
2. Storage of the injected/recharged water within the aquifer until needed, and;
3. Recovery of the stored water.

The structure of the ASR pilot test program at Beltz 8 included incremental steps of ASR operations to provide multiple checkpoints in the event that pilot operations deviate significantly from the predicted responses. The test program generally involved three repeated ASR cycles of operations and monitoring, each of larger volume and duration than the preceding cycle, so that if adverse conditions were encountered at any point, the program could be adjusted.

The primary purpose of the ASR pilot testing was to demonstrate injection well hydraulics and operational performance characteristics of Beltz 8 and to monitor the local aquifer hydraulic and geochemical responses to recharge and recovery operations. These data can then be used to both assess the economic and logistical viability of ASR and as a basis for environmental planning and permitting documentation for a long-term, full-scale ASR project.

The primary issues investigated can be generally categorized into two areas of investigation:

1. Well and Aquifer Hydraulics:
    - Determination of injection well efficiency and specific capacity.
    - Evaluation of injection well plugging rates (both active and residual).
    - Determination of optimal rates, frequency, and duration of backflushing in order to maintain long-term injection capacity.
    - Determination of long-term sustainable injection rates.
    - Determination of local aquifer response to injection at the Beltz 8 site.
2. Water Quality:
    - Monitor geochemical reaction mechanisms.
    - Evaluate water quality changes during storage.
    - Monitor recovery efficiency.
    - Monitor injected water quality stability and equalization in the aquifer.
    - Monitor THM and HAA fate.
    - Quantify aquifer mixing/dispersion parameters.
    - Monitor recovered water ‘post extraction’ for re-chlorination and THM/HAA reformation.

Summary of ASR Cycles

The ASR pilot test program generally consists of a pre-ASR baseline pumping performance test, a 1-day hydraulic “pre-test” to establish injection system hydraulics, followed by three (3) repeated cycles of injection-storage-recovery, with each cycle of greater duration and volume. A robust dataset of aquifer response and water quality information has been developed, while minimizing the risk of adverse effects to the well or aquifer system. It is noted that ASR Cycles 1 and 2 included recovery volumes that were approximately 150 percent of the injection volumes in order to recover a sufficient volume to assess the degree of mixing between the injected water and native groundwater in the recovered water.

As discussed in the ASR Pilot Test Work Plan for Beltz 8[4], under current conditions and incorporating an assumed improvement in well performance from rehabilitation, a nominal injection rate of approximately 400 gallons per minute (gpm) was assumed for planning purpose. The testing program was designed around this rate; however, in the field the 2-in-diameter backflow preventers (BFPs) supplied by the SCWD on the injection supply system became unacceptably noisy (the site in located in a residential neighborhood) at rates exceeding approximately 300 gpm; therefore, the pilot test program was redesigned around this injection rate and is summarized in **Table 3** below:

Table 3. ASR Pilot Test Program Summary

ASR	ASR	Dates / Times		Duration	Total Volume		Avg Rate	
Cycle	Phase	Start	End	(days)	(gals)	(af)	(gpm)	(mgd)
System Pre-Test	Injection	3/13/20 14:15	3/13/20 14:40	0.02	3,614	0.01	145	0.21
1	Injection	3/20/20 9:30	3/21/20 9:30	1.00	452,992	1.39	315	0.45
	Storage	3/21/20 9:30	3/23/20 10:00	2.02	--	--	--	--
	Recovery	3/23/20 10:00	3/24/20 10:00	1.00	797,000	2.45	553	0.80
2	Injection	3/25/20 10:00	4/1/20 10:00	7.0	3,153,899	9.68	313	0.45
	Storage	4/1/20 10:00	4/15/20 11:00	14.0	--	--	--	--
	Recovery	4/15/20 11:00	4/21/20 11:00	6.0	4,768,000	14.63	552	0.79
3	Injection	4/6/21 10:20	4/20/21 10:20	14.0	6,115,070	18.77	303	0.44
	Storage	4/20/21 10:20	5/18/21 10:00	28.0	--	--	--	--
	Recovery	5/18/21 10:00	6/1/21 10:00	14.0	9,094,000	27.91	451	0.65

Total Injection Duration (days):	22.02
Total Extraction Duration (days):	21.00
Cummulative Total Injection Volume (af):	29.85
Cummulative Total Extraction Volume (af):	44.99
Cummulative Total Net Volume (af):	-15.14
Cummulative Total Injection Volume (mg):	9.72
Cummulative Total Extraction Volume (mg):	14.66
Cummulative Total Net Volume (mg):	-4.94

In addition, the well was thoroughly backflushed following each of the injection tests to limit residual plugging of the well due to injection and assess the efficacy of well backflushing (discussed in a following section).

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[4] Pueblo Water Resources, Inc. (December 2019), *Santa Cruz ASR Project – Phase 1 Feasibility Investigation; Task 1.4 ASR Pilot Test Work Plan for Beltz 8 Site-Specific Injection Capacity Analysis*, Technical Memorandum prepared for Santa Cruz Water Department.

The primary test objectives for each ASR Cycle are summarized below:

ASR Cycle 1

- Establish short-term injection hydraulics
- Monitor short-term ion exchange reactions

ASR Cycle 2

- Measure well plugging rates (active and residual)
- Evaluate backflushing efficacy
- Monitor longer-term ion exchange reactions
- Monitor redox reactions
- Evaluate water chemistry changes during storage
- Monitor recovery efficiency (the percentage of recharged water that is recovered during each cycle)
- Monitor Disinfection Byproducts (DBP's) during recovery
- Define volume of potential "buffer zone" around ASR well

ASR Cycle 3

- Evaluate longer-term well performance and plugging rates
- Monitor injected water quality stability during storage
- Monitor DBP ingrowth/degradation during storage and recovery
- Monitor recovery efficiency (the percentage of recharged water that is recovered during each cycle)

Procedures and Monitoring Program

Injection feed water was potable water provided from the SCWD distribution system. Injection rates were controlled by several butterfly valves on the temporary piping system and ball valves on the injection drop tubes. Injection flow rates and total injected volumes were measured with a totalizing meter. Injection operations were performed through three 2-inch-diameter Schedule 40 PVC drop tubes fitted with fixed orifice caps at the bottom of each tube. Positive pressures were maintained within the piping system and drop tubes during injection testing to prevent water cascading and cavitation in the well. Field data sheets collected during the course of the testing program are presented in **Appendix C**.

Water levels in Beltz 8, the on-site monitoring well, and several offsite monitoring wells owned by both the SCWD and SqCWD were measured during the testing program with pressure transducer data loggers and were periodically verified with a manual electric sounder. The locations of the project wells are shown on **Figure 3**. A summary of the construction details of the test program wells is presented in **Table 4** below:

Table 4. Project Well Construction Summary

Well	Distance from Beltz 8 (ft)	Elev. (ft msl)	Depth (ft bgs)	Dia (in)	Screen Intervals (ft bgs)	Tp Unit(s) Completed
Beltz 8	--	47.8	210	14	100 - 180	A
Beltz 8 MW	38	46.3	190	2	100 - 180	A
Beltz 4 MW	945	60.1				
shallow			90	2	50 - 80	A (upper?)
deep			135	2	115 - 125	A (lower?)
Beltz 10	1010	58.0	362	8	100 - 357	AA
Beltz 9	2120	43.1	230	14	110 - 200	A
30th Ave	2385	75.1				
shallow			240	2	200 - 240	A
medium			410	2	370 - 410	AA
deep			800	2.5	720 - 800	Tu
Pleasure Pt	2565	45.3				
shallow			140	2	110 - 130	A (upper)
medium			240	2	210 - 230	A (lower)
deep			355	2	325 - 345	AA (upper)
Corcoran Lagoon	2740	26.1				
shallow			40	2	30 - 40	A (upper)
medium			100	2	80 - 100	A (lower)
deep			195	2	175 - 195	AA (upper)
SC-1A*	3670	77.3	320	2.5	113 - 320	A
SC-22 *	3675	75.3				
shallow			240	2	150 - 230	A
medium			500	2	460 - 490	AA
deep			705	2	640 - 700	Tu
SC-13*	3745	82.5	820	2	760 - 770	Tu
Moran Lake	4025	27.3				
shallow			170	2	130 - 170	A (upper)
medium			225	2	205 - 225	A (lower)
deep			295	2	255 - 295	AA (upper)
Soquel Pt	4190	31.2				
SP-3			130	2	110 - 130	A (upper)
SP-2			270	2	250 - 270	AA (lower)
SP-1			330	2	310 - 330	AA (upper)

Notes:

Tp - Purisima Formation

* - SqCWD monitoring w ell

Water-level data collected from the project wells during the course of ASR pilot test Cycles 1 and 2 are shown on **Figures 4 through 15** and during Cycle 3 are shown on **Figures 16 through 27**. Water-level data collected during each phase of the test program are presented and discussed in more detail in following sections.

Pre-Injection Pumping Performance Test

A post-rehabilitation pumping performance test was conducted on March 18, 2020 to establish baseline pre-injection well performance. The performance test consisted of a 100-minute constant rate discharge test. A 100-minute duration test (approximately three measurable log-cycles) was performed because the long-term response of a well is a logarithmic function, and a pumping test of this duration is sufficient to document well performance (i.e., specific capacity).

Throughout the test, water levels in the pumping well were measured and recorded using the transducer and data logger, and the discharge rate was measured using the totalizing flow meter. The static water level in the well prior to pumping was approximately 34.1 feet below top of casing (btoc). The discharge was maintained at an average rate of approximately 315 gpm during the test. The pumping level after 100-minutes was approximately 49.9 feet btoc, corresponding to a drawdown of 15.8 feet, and a 100-minute baseline specific capacity of 19.9 gpm/ft.

Injection Hydraulics Pre-Test

An injection hydraulics pre-test was performed on March 13, 2020. The purpose of the pre-test was to establish well and injection system hydraulic relationships prior to initiating the formal ASR pilot test program. The pre-test generally consisted of initiating injection with each of the three injection tubes for periods of 5 to 10 minutes each over a range of flow rates and drop tube head pressures. The resulting hydraulic relationships are summarized in **Table 5** below:

Table 5. Injection Hydraulics Pre-Test Summary

Drop Tube Orifice (in dia)	Rate (gpm) vs. Pressure	
	10 psi	25 psi
0.75	60	70
1.25	120	150
1.50	150	180

As shown, injection rates for each tube ranged between approximately 60 to 180 gpm over drop tube pressures of 10 to 25 pounds per square inch (psi) on each.

ASR Cycle 1 Injection

The ASR Cycle 1 injection test was initiated on March 20, 2020. This phase of testing consisted of a continuous rate injection test performed at an average injection rate of approximately 315 gpm for a period of 24-hours, with a total volume of approximately 0.453 million gallons (1.39 acre-feet) injected. Water-level data for ASR Cycle 1 Injection Test are graphically presented on **Figure 28**. As shown, the static water level in the well prior to injection was 34.4 feet btoc. During injection, total drawup in the well was approximately 19.3 feet, corresponding to a 24-hr specific injectivity of 16.3 gpm/ft.

ASR Cycle 1 Recovery

Following a two-day aquifer storage period, the ASR Cycle 1 recovery test was initiated on March 23, 2020. The discharge rate was maintained at an average rate of approximately 553 gpm for a period of 24 hours and a total volume of 0.797 million gallons (2.45 acre-feet) was extracted, equivalent to approximately 175 percent of the previously injected volume. Water-level data for the ASR Cycle 1 recovery test are graphically presented on **Figure 29**.

As shown, the static water level prior to pumping was approximately 33.8 feet bgs. The pumping level recorded after 100 minutes was approximately 62.7 feet, corresponding to a drawdown of 28.9 feet and a 100-minute specific capacity of approximately 19.1 gpm/ft. This 100-minute specific capacity value is slightly less (4 percent) than the pre-injection 100-minute specific capacity of 19.9 gpm/ft, suggesting that some amount of residual plugging may have occurred as a result of the ASR Cycle 1 injection test; however, it is noted that the pre-injection performance test was performed at a lower pumping rate (315 gpm vs 553 gpm), which results in lower entrance velocities and higher well hydraulic efficiency.

The pumping level recorded after 24-hours was approximately 65.4 feet, corresponding to a drawdown of 31.6 feet and a 24-hour specific capacity of 17.5 gpm/ft, comparable to the pre-injection 24-hour specific capacity of 17.4 gpm/ft.

ASR Cycle 2 Injection

Following termination of the ASR Cycle 1 recovery test and a period of water-level recovery, the ASR Cycle 2 injection test was initiated on March 25, 2020 and continued until April 1, 2020. This phase of testing consisted of a continuous rate injection test performed at an average injection rate of approximately 313 gpm for a period of 7 days, with a total volume of approximately 3.15 million gallons (9.68 acre-feet) injected.

Water-level data for the ASR Cycle 2 injection test are graphically presented on **Figure 30**. As shown, the static water level in the well prior to injection was 35.6 feet btoc. During injection, drawup in the well was approximately 19.6 and 22.8 feet after 24 hours and 7 days of injection, respectively, corresponding to specific injectivities of 16.0 and 13.7 gpm/ft, respectively. The 24-hr value is comparable to the specific injectivity observed during the Cycle 1 injection test, indicating that backflushing of the well was effective and little to no residual plugging of the well occurred following ASR Cycle 1.

ASR Cycle 2 Recovery

Following a 14-day aquifer storage period, the ASR Cycle 2 recovery test was initiated on April 15 and continued until April 21, 2020. The discharge rate was maintained at an average rate of approximately 552 gpm during the test and a total volume of 4.77 million gallons (14.6 acre-feet) was extracted, equivalent to approximately 150 percent of the Cycle 2 injected volume.

Water-level data for the ASR Cycle 2 recovery test are graphically presented on **Figure 31**. As shown, the static water level prior to pumping was approximately 33.5 feet btoc. The pumping level recorded after 24-hours was approximately 65.9 feet, corresponding to a drawdown of 32.4 feet and a 24-hour specific capacity of 17.0 gpm/ft. This 24-hr specific capacity value is very slightly lower (approximately 3 percent) than the Cycle 1 recovery test 24-hour specific capacity of 17.5 gpm/ft, indicating that little residual plugging (discussed in more detail in a later section) of the well had occurred as result of the Cycle 2 injection test. The final pumping level at the end of the approximate 6-day test was approximately 68.7 feet btoc.

ASR Cycle 3 Injection

Following termination of the ASR Cycle 2 recovery test, the project was temporarily suspended while a geochemical interaction evaluation of the ASR Cycle 1 and 2 results was performed (discussed in a later section). The ASR Cycle 3 injection test was subsequently initiated on April 6 and continued until April 20, 2021. This phase of testing consisted of a continuous rate injection test performed at an average injection rate of approximately 303 gpm, with a total volume of approximately 6.11 million gallons (18.8 acre-feet) injected. During the 14-day test, injection operations were briefly interrupted after approximately 1 week of injection for backflushing in order to limit plugging and maintain well performance.

Water-level data for the ASR Cycle 3 injection test are graphically presented on **Figure 32**. As shown, the static water level in the well prior to injection was 35.8 feet btoc. During injection, drawup in the well was approximately 17.2, 20.1 and 21.4 feet after 24 hours, 7 days and 14 days of injection, respectively, corresponding to specific injectivities of approximately 17.6, 15.1 and 14.2 gpm/ft, respectively. These 24-hr and 7-day specific injectivity values are approximately 10 percent greater than those observed during the Cycle 2 injection test, indicating that the wells performance improved slightly as a result of rigorous backflushing performed following Cycle 2 and during the Cycle 3 injection test.

ASR Cycle 3 Recovery

Prior to initiating the ASR Cycle 3 recovery test, the test pump was removed from the well and the SCWD permanent pump assembly was reinstalled on May 11, 2021, and then the well was disinfected with sodium hypochlorite solution in accordance with State Well Standards. The chlorine was flushed from the well on May 12, 2021, and a sample subsequently collected later that day, which tested non-detect (absent) for both Total and Fecal Coliform.

Following a 28-day period of aquifer storage, the ASR Cycle 3 recovery test was initiated on May 18 and continued until June 31, 2021. It is noted that the ASR Cycle 3 recovery pumping was originally planned for delivery of the recovered water into the distribution system following treatment at the Beltz Treatment Plant; however, as discussed in a later section, due to concerns regarding the concentration of arsenic in the recovered water, recovered water from ASR Cycle 3 was not turned into the system as planned, and instead of all of the ASR Cycle 3 recovered water was directed to the storm drain system. The discharge rate was maintained at an average rate of 451 gpm during the test as planned, and a total volume of approximately 9.09 million gallons (27.9 acre-feet) was extracted, equivalent to approximately 150 percent of the Cycle 3 injected volume.

Water-level data for ASR Cycle 3 Recovery Test are graphically presented on **Figure 33**. As shown, the static water level in Beltz 12 prior to pumping was approximately 34.7 feet btoc. The pumping level recorded after 24-hours was approximately 60.9 feet, corresponding to a drawdown of 26.2 feet and a 24-hour specific capacity of 17.2 gpm/ft. This 24-hr specific capacity value is comparable to the Cycle 2 recovery test 24-hour specific capacity of 17.0 gpm/ft, indicating that no residual plugging of the well occurred as result of the Cycle 3 injection test. The final pumping level at the end of the 14-day test was 65.7 feet bgs.

Injection vs. Extraction Specific Capacity Ratios

Most injection wells display a difference in injection and extraction specific capacities, with the injection specific capacity (aka specific injectivity) usually being lower than the extraction specific capacity, even when plugging is taken into account. Typically, injection wells display injection specific capacities that are 25 to 80 percent of the extraction specific capacities (Huisman and Olsthoorn, 1983, and Pyne, 1994). 24-hour injection and extraction specific capacities observed during the Beltz 8 ASR pilot test program are summarized in **Table 6** below:

Table 6. Injection vs. Extraction Specific Capacity Ratio Summary

ASR Cycle	Injection					Extraction					Q/s Ratio
	Rate (gpm)	SWL (ft btoc)	IWL (ft btoc)	DUP (ft)	Q/s (gpm/ft	Rate (gpm)	SWL (ft btoc)	PWL (ft btoc)	DDN (ft)	Q/s (gpm/ft	
1	315	34.4	15.1	19.3	16.3	553	33.8	65.4	31.6	17.5	**0.931**
2	313	35.6	16.0	19.6	16.0	552	33.5	65.9	32.4	17.0	**0.937**
3	303	35.8	18.6	17.2	17.6	451	34.7	60.9	26.2	17.2	**1.02**

Notes:
SWL - Static Water Level
IWL - Injection Water Level
DUP - Draw up
PWL - Pumping Water Level
DDN - Draw down
Q/s - Specific Capacity/Injectivity

As shown, the injection to extraction specific capacity ratios displayed by Beltz 8 are at the high end of the typical range (i.e., approximately 80 to 90 percent) and consistent with the ratios observed during the Beltz 12 ASR pilot test, which were in the range of approximately 0.823 to 0.912.

The reason(s) for the difference in injection vs. extraction specific capacities has been the subject of considerable discussion in the ASR community. Some of the reasons for the difference that have been advanced include:

- Particle rearrangement,
- Differential hydraulic well losses, and
- Differential aquifer response.

The reason(s) for the slight differences in injection vs. extraction specific capacities observed at Beltz 8 (and Beltz 12) are not precisely known and are likely due to some combination of the above-listed factors; nonetheless, the testing results are at the high end of typical values and demonstrate that well performance conditions at the Beltz 8 site are favorable for ASR.

Backflushing

Following each injection test, backflushing was performed on the well. In addition, backflushing was performed during the ASR Cycle 3 injection test on a weekly basis. Backflushing operations generally consisted of pumping the well to the on-site 70,000 gallon reclaim tanks at rates ranging between approximately 600 and 700 gpm for a period of 15 minutes. The pump was then shut off and the water contained in the pump column pipe allowed to surge back into the well, followed by a 15-minute idle period. The pump was then restarted and pumped to waste for another 15 minutes, resulting in a double-backflush procedure. During each backflushing pumping event, the well discharge was initially turbid (approximately 10 to 140 NTU) and of dark brown color for the first 2 minutes or so, followed by a significant decrease in turbidity for the remaining backflushing cycle. Discharge water during the subsequent backflushing cycles was essentially clear (typically less than 5 NTU in the first 2 minutes), indicating that the majority of particulates were removed from the well during the initial 15 minutes of backflushing.

Following each backflushing event, controlled 10-minute specific capacity tests were performed to track well performance and the efficacy of backflushing. Additional 10-minute specific capacity data were developed during the storage period water-quality sampling events. Declining specific capacities would indicate the presence of residual plugging occurring following backflushing. The 10-minute specific capacity results are summarized in **Table 7** below and presented graphically on **Figure 34**. As shown, the well displayed a pre-injection 10-minute specific capacity of 21.9 gpm/ft. During the course of the testing program, the 10-minute specific capacity ranged between 21.1 and 22.4 gpm/ft (within approximately -4 to +3 percent of baseline) and did not display a clear declining trend. The average value was 21.8 gpm/ft, essentially equivalent to the pre-injection value. These results indicate that weekly backflushing was largely effective at removing particulates introduced into the well during injection and maintaining well performance.

Plugging Rate Analysis

Experience at injection sites around the world shows that all injection wells are subject to some amount of plugging because no water source is completely free of particulates. During injection, trace amounts of suspended solids are continually being deposited in the gravel pack and aquifer pore spaces, much as a media filter captures particulates in the filter bed. The effect of plugging is that it impedes the flow of water from the injection well into the aquifer, causing increased injection heads in the well to maintain a given injection rate, or reduced injection rates at a given head level. Well plugging reduces injection and extraction capacity, and consequently, well life.

Plugging can occur due to water quality issues, improper system operation, or poor well design practices. In general, plugging issues fall into four general categories: physical plugging (by particulate matter), chemical reaction (between the injectate and native waters or aquifer minerals), biofouling (the proliferation of bacteria in the gravel pack or aquifer), and gas binding (the vapor locking of the aquifer by entrained or evolved gasses in the injectate). **Figure 35** shows the characteristic plugging mechanisms from suspended solids, biological growth, and air entrainment and the increased resistance to flow over time.

Table 7. 10-Minute Specific Capacity Summary

Date	SWL (ft btoc)	PWL (ft btoc)	DDN (ft)	Q (gpm)	Q/s (gpm/ft)	% Change*	Comments
3/18/20	34.1	48.5	14.4	315	21.9	--	Pre-Injection Performance Test
3/21/20	33.1	60.5	27.4	600	21.9	0.10	Following Cycle 1 injection test
4/1/20	31.0	58.6	27.6	600	21.7	-0.62	Following Cycle 2 injection test
4/8/20	33.4	60.6	27.2	600	22.1	0.84	Cycle 2 Storage sampling
4/29/20	35.2	66.4	31.2	700	22.4	2.56	Following Cycle 2 recovery test
4/1/21	36.2	66.9	30.7	675	22.0	0.51	Prior to Cycle 3 injection test
4/13/21	32.1	59.7	27.6	596	21.6	-1.28	During Cycle 3 injection test
4/20/21	31.9	58.7	26.8	580	21.6	-1.07	Cycle 3 Storage sampling
5/18/21	34.7	56.0	21.3	450	21.1	-3.42	Start of Cycle 3 recovery test

Notes:

SWL - Static Water Level
ft btoc - feet below top of casing
PWL - Pumping Water Level
DDN - Drawdown
Q - Discharge Rate
gpm - gallons per minute
Q/s - Specific Capacity
* - compared to pre-injection baseline

Silt Density Index Testing. Relative measurements of the particulate matter in the injectate (and hence the potential for physical plugging) were made through silt density index (SDI) testing during injection. The SDI was originally developed to quantitatively assess particulate concentrations in reverse osmosis feed waters. The SDI test involves pressure filtration of source water through a 0.45-micron membrane, and observation of the decrease in flow over time; the resulting value of SDI is dimensionless and used as a comparative value for tracking relative well plugging rates versus water quality or other parameters. SDI test results are summarized in **Table 8** below.

As shown, during pre-injection pipeline flushing, SDI values started out relatively high (up to 5.8 initially) gradually declining to less than 3.0 (unitless) as particulates were purged from the distribution system piping prior to initiating injection. SDI values during injection testing were very consistent, ranging between approximately 1.8 and 3.5 (unitless). SDI values less than 3.0 (dimensionless) are generally representative of source waters with relatively low amounts of particulates and, therefore, favorable for injection.

Active Plugging Rates. Active plugging rates during injection testing of Beltz 8 were estimated utilizing the Graphical Observed vs. Theoretical Drawup Method (Pyne, 1994). Water level rise in an injection well is a combination of both aquifer response and well losses. Theoretically, at any given constant injection rate, well losses should remain constant; therefore, in the absence of plugging, any water level rise in the well would be due only to aquifer response. The difference between the theoretical water level and the observed water can be presumed to be caused by plugging.

Table 8. Silt Density Index (SDI) Test Results

Date / Time	t_0 (secs)	t_{15} (secs)	SDI (unitless)	Comments
3/19/20 11:35	43	127	4.41	Pre-Injection line flushing
3/19/20 13:50	41	91	3.66	Pre-Injection line flushing
3/19/20 14:45	45	89	3.30	Pre-Injection line flushing
3/19/20 15:20	47	93	3.30	Pre-Injection line flushing
3/19/20 16:25	42	85	3.37	Pre-Injection line flushing
3/20/20 8:40	46	63	1.80	Pre-Injection line flushing
3/20/20 11:10	44	60	1.78	Cycle 1 Injection
3/20/20 15:30	43	80	3.08	Cycle 1 Injection
3/21/20 8:45	41	67	2.59	Cycle 1 Injection
3/25/20 9:15	35	63	2.96	Pre-Injection line flushing
3/25/20 11:30	40	69	2.80	Cycle 2 Injection
3/26/20 10:00	42	75	2.93	Cycle 2 Injection
3/27/20 10:00	43	73	2.74	Cycle 2 Injection
3/28/20 9:50	43	80	3.08	Cycle 2 Injection
3/29/20 10:00	43	72	2.69	Cycle 2 Injection
3/30/20 9:00	41	70	2.76	Cycle 2 Injection
3/31/20 9:00	41	66	2.53	Cycle 2 Injection
4/1/20 9:00	40	65	2.56	Cycle 2 Injection
4/5/21 13:45	26	203	5.81	Pre-Injection line flushing
4/5/21 14:30	26	140	5.43	Pre-Injection line flushing
4/5/21 15:30	26	113	5.13	Pre-Injection line flushing
4/5/21 16:00	25	71	4.32	Pre-Injection line flushing
4/6/21 8:55	26	36	1.85	Pre-Injection line flushing
4/6/21 9:20	24	40	2.67	Pre-Injection line flushing
4/6/21 9:40	24	39	2.56	Pre-Injection line flushing
4/6/21 11:20	24	41	2.76	Cycle 3 Injection
4/6/21 13:20	24	41	2.76	Cycle 3 Injection
4/6/21 16:20	24	40	2.67	Cycle 3 Injection
4/7/21 7:20	25	40	2.50	Cycle 3 Injection
4/7/21 17:35	24	38	2.46	Cycle 3 Injection
4/8/21 9:20	24	36	2.22	Cycle 3 Injection
4/9/21 9:40	25	37	2.16	Cycle 3 Injection
4/9/21 16:40	24	40	2.67	Cycle 3 Injection
4/10/21 10:20	24	35	2.10	Cycle 3 Injection
4/11/21 10:20	24	37	2.34	Cycle 3 Injection
4/12/21 10:20	25	53	3.52	Cycle 3 Injection
4/12/21 16:20	24	39	2.56	Cycle 3 Injection
4/13/21 10:20	25	37	2.16	Cycle 3 Injection
4/14/21 9:00	24	35	2.10	Cycle 3 Injection
4/15/21 9:00	24	36	2.22	Cycle 3 Injection
4/16/21 9:00	24	38	2.46	Cycle 3 Injection
4/17/21 10:00	24	37	2.34	Cycle 3 Injection
4/18/21 10:00	24	37	2.34	Cycle 3 Injection
4/19/21 10:00	25	39	2.39	Cycle 3 Injection
4/20/21 10:00	24	36	2.22	Cycle 3 Injection

Notes:

t_0 - elapsed time 0 minutes

t_{15} - elapsed time 15 minutes

secs - seconds

SDI - Silt Density Index

It is important to note that the theoretical water level rise corresponds to the water level that would occur if well losses were negligible. In order to account for well efficiency losses, the graphical method involves drawing a straight line through moderate elapsed time data points (100 to 1000 minutes). Assuming no plugging is occurring, the theoretical water level rise during injection would plot along a straight line on a semi-log plot. The variance from the straight line is assumed to be indicative of the amount of plugging.

The amount of plugging, in feet of water level rise, was calculated for the ASR Cycles 2 and 3 constant-rate injection tests[5]. The plugging rate analyses for these long-term constant rate injection tests are presented graphically on **Figures 36 and 37**. As shown on **Figure 36**, at the end of ASR Cycle 2 Injection, the observed water level rise was 23.7 feet. The theoretical water level rise was estimated to be approximately 22.3 feet. Total water level rise due to plugging was, therefore, approximately 1.4 feet, yielding an average plugging rate of approximately 0.206 feet per day (ft/day) for the ASR Cycle 2 injection test. As shown on **Figure 37**, calculated plugging rate for the ASR Cycle 3 injection test was a comparable value of 0.223 ft/day.

Normalized Plugging Rates. Normalizing plugging rates to a reference velocity at the well screen of 3 feet per hour and a water temperature of 20 degrees allows for comparison of data from wells that have different constructions, injection rates, and water temperatures. The observed plugging rate is normalized by the following equation (Olsthoorn, 1982):

$$PR_{norm} = PR_{obs} (Vs/V)^2 (n_{20}/n) \qquad \text{(Eq.2)}$$

Where:

PR_{norm} = plugging rate in feet/day normalized to 20 degrees Celsius and a borehole velocity of 3 ft/hr

PR_{obs} = calculated observed plugging rate in ft/day

Vs = standard velocity at borehole wall of 3 ft/hr

V = calculated velocity at borehole wall in ft/hr

n_{20} = viscosity (in centipose) at standard temperature of 20 degrees Celsius

n = viscosity (in centipose) at measured temperature

A summary of the normalized plugging rate calculations is presented in **Table 9** below:

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[5] ASR Cycle 1 Injection Test was limited to 1 day of injection, which is too short for a meaningful plugging rate analysis. Only the first week of continuous injection of ASR Cycle 3 Injection Test was analyzed, as the well was backflushed on a weekly basis for the remainder of the 14-day test period (i.e., was non-continuous after the first week).

Table 9. Summary of Pugging Rate Calculations

ASR Cycle Injection Test	Injectate Temp (^{0}C)	Injection Rate (gpm)	Duration of Injection (days)	Flux at B.H. Wall (ft/hr)	Obs. Plug Rate (ft/day)	Norm. Plug Rate (ft/day)
2	17.1	313	7	4.99	0.206	0.069
3	16.8	303	7	4.83	0.223	0.080

As shown, the observed plugging rates during ASR Cycles 2 and 3 Injection Tests ranged between 0.206 and 0.223 ft/d, averaging approximately 0.215 ft/d. Normalization of these observed plugging rates yields plugging rates of approximately 0.069 and 0.080 ft/d. Both the observed active and normalized plugging rates are considered very low and compare favorably with other ASR well sites PWR has studied in California.

It is noted that these observed and normalized plugging rates at Beltz 8 are approximately an order of magnitude lower than the plugging rates at Beltz 12 during the ASR pilot test at that well in 2019. Plugging due to particulates is largely a function of the flux of particulates at the borehole wall (i.e., particulate loading rate) and the hydraulic conductivity of the aquifer materials. The injectate quality during the ASR pilot tests was very similar (as measured by SDI) and the borehole wall fluxes were within the same order of magnitude; therefore, the fundamental reason for the very different plugging rates at these two wells is the differences in the hydraulic conductivity of the aquifer materials that each well is completed in, where the average hydraulic conductivity of the AA – Tu Aquifer Units that Beltz 12 is screened in is approximately 5.89 feet per day (ft/d), whereas the hydraulic conductivity of the A Aquifer Unit that Beltz 8 is screened in is approximately 76.9 ft/d (i.e., the hydraulic conductivity of the A Aquifer Unit is approximately an order of magnitude greater than the AA – Tu Aquifer Units).

Residual Plugging. As discussed previously, following backflushing operations controlled 10-minute specific-capacity tests were performed to track well pumping performance. Residual plugging is the plugging that remains following backflush pumping. Residual plugging increases drawdown during pumping and drawup during injection and is manifested as declining specific capacity / injectivity. The presence of residual plugging is indicative of incomplete removal of plugging particulates during backflushing and has the cumulative effect of reducing well performance and capacity over time. Presented in **Table 10** below is a summary of the residual plugging calculations for the Beltz 8 ASR pilot test program.

As shown, there was an insignificant amount of approximately 0.3 feet of residual plugging observed over the course of the pilot test program; in other words, no significant residual plugging of Beltz 8 occurred as a result of the ASR pilot testing, indicating that the weekly schedule of a double-backflush operation was successful at maintaining well performance.

Table 10. Residual Plugging Summary

Date	Pumping Rate (gpm)	10-min Drawdown (ft)	10-min Q/s[1] (gpm/ft)	Normalization Ratio[2]	Normalized Drawdown[2] (ft)	Residual Plugging (ft)
3/18/20	315	14.4	21.9	1.90	27.4	--
3/21/20	600	27.4	21.9	1.00	27.4	0.0
4/1/20	600	27.6	21.7	1.00	27.6	0.2
4/8/20	600	27.2	22.1	1.00	27.2	-0.2
4/29/20	700	31.2	22.4	0.86	26.7	-0.7
4/1/21	675	30.8	21.9	0.89	27.4	-0.1
4/13/21	596	27.6	21.6	1.01	27.8	0.4
4/20/21	580	26.8	21.6	1.03	27.7	0.3

Notes:

1 - Specific Capacity. Ratio of pumping rate to drawdown.

2 - Normalized based on ratio of 600 gpm to actual test pumping rate.

AQUIFER RESPONSE TO INJECTION AND RECOVERY

The response of the regional aquifer system to ASR testing at Beltz 8 was monitored throughout the pilot test program. The locations of the project wells are shown on **Figure 3** and summary of the construction details of the test program wells was presented in **Table 4** above. Water-level data collected from the project monitoring wells during the course of the ASR pilot test program are shown on **Figures 5 through 15 and 17 through 27**. In addition, water-level data collected from the onsite Beltz 8 monitoring well during each injection test are shown on **Figures 4 and 16**.

Aquifer Response to ASR Operations

Summaries of the aquifer water-level response observations during the ASR pilot test program injection tests are presented and discussed below:

Beltz 8 MW (Figures 4 and 16). The on-site monitoring well displayed a strong response to the ASR operations at Beltz 8, with water-level increases of 9.0 and 11.9 feet at the end of the ASR Cycles 1 and 2 injection tests, respectively. At the end of the ASR Cycle 1 and 2 recovery tests, the well displayed water-level decreases of 15.6 and 19.3 feet, respectively, in response to pumping at Beltz 8.

The well also displayed a strong response to the ASR Cycle 3 operations at Beltz 8, with a water-level increase of 11.4 feet at the end of the injection test. At the end of the ASR Cycle 3 recovery test, the well displayed a water-level decrease of 17.1 feet in response to pumping at Beltz 8.

Beltz 4 (Figures 5 and 17). The Beltz 4 shallow and deep monitoring wells, believed to be completed in the upper and lower portions of the A Aquifer Unit, respectively, did not display a discernable response to ASR Cycle 1 operations at Beltz 8. The wells did appear to display a delayed response to the ASR Cycle 2 injection test, with approximately 0.3 to 0.5 feet of water-level increase, respectively. Water levels remained relatively stable during the storage period, then declined by approximately 0.57 and 0.79 feet, respectively, in response to the ASR Cycle 2 recovery test.

The wells displayed comparable responses to the ASR Cycle 3 injection test, with approximately 0.9 feet of water-level increase. Water levels remained relatively stable during the storage period, then declined by approximately 1.0 feet in response to the ASR Cycle 3 recovery test.

Beltz 10 (Figures 6 and 18). The Beltz 10 production well, completed in the upper AA Aquifer Unit, did not display a discernable response to ASR operations at Beltz 8. These results are not entirely unexpected, as this well is not completed in the same target aquifer (A Unit) as Beltz 8.

Beltz 9 (Figures 7 and 19). The Beltz 9 production well, completed in the A Unit, did not display a response to ASR operations at Beltz 8 that could be reasonably discerned from the background fluctuations in water levels at this well. These results are somewhat unexpected, as this well is completed in the same target aquifer (A Unit) as Beltz 8 and are discussed further in the following section.

30th Ave (Figures 8 and 20). The 30th Ave wells did not display discernable responses to the relatively short-term ASR Cycle 1 operations at Beltz. The 30th Ave shallow and medium monitoring wells, completed in the A and AA Aquifer Units, respectively, did display comparable responses[6] to the ASR Cycle 2 injection test, with approximately 0.30 and 0.22 feet of water-level increase, respectively. Water levels remained relatively stable during the storage period, then declined by approximately 0.41 and 0.31 feet, respectively, in response to the ASR Cycle 2 recovery test.

These wells also displayed comparable responses to the ASR Cycle 3 injection test, with 0.4 feet of water-level increase. Water levels remained relatively stable during the Cycle 3 storage period, then declined by approximately 0.5 feet in response to the ASR Cycle 3 recovery test. The deep monitoring well, completed in the underlying Tu Aquifer Unit, did not display a response to ASR operations at Beltz 8.

Pleasure Pt (Figures 9 and 21). The Pleasure Point monitoring wells are located at the coast (refer to **Figure 3**) and screened in the upper and lower A Aquifer Unit and the upper AA Aquifer Unit. As shown, all three wells display similar responses to diurnal tidal fluctuations, with the levels fluctuating as much as approximately 1 to 2 feet, depending on the magnitude of tidal variation. All three wells also displayed similar responses to ASR operations at Beltz 8. The responses to the short-duration ASR Cycle 1 were somewhat muted and difficult to discern; however, the responses to the ASR Cycle 2 injection test were discernable and of similar magnitudes, with approximately 1.4 to 1.5 feet of overall water-level increase. During the Cycle

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[6] It is noted that these two monitoring wells are completed within a single borehole (i.e., “nested” monitoring wells) and that the seal intended to isolate the wells may not completely hydraulically isolate the two wells (i.e., the seal may leak, which is common for nested monitoring wells). If so, they would exhibit similar water levels, as observed. In other words, just because the AA Unit monitoring well mimics the response of the A Unit monitoring well at this particular location does not necessarily mean the Beltz 8 well is actually affecting water levels in the AA Unit.

2 storage period, the water levels began declining (reverting back to static) and then responded to the ASR Cycle 2 recovery test, with approximately 1.4 to 1.8 feet of overall water-level decline.

The responses to the ASR Cycle 3 injection test were of similar magnitudes, with approximately 4.3 to 6.5 feet of overall water-level increase. During the storage period, the water levels began declining (reverting back to static) and then responded to the ASR Cycle 3 recovery test, with approximately 4.5 feet of overall water-level decline at all three wells. It is also noted that water levels at all three monitoring wells remained approximately 7 to 9 feet above sea level at the end of the ASR Cycle 3 recovery pumping period.

Corcoran Lagoon (Figures 10 and 22). The Corcoran Lagoon monitoring wells are screened in the upper and lower A Aquifer Unit and the upper AA Aquifer Unit. As shown, none of the three wells displayed a discernable response to ASR operations at Beltz 8. Although two of these are completed in the A Aquifer Unit, these results are not entirely unexpected given the distance from Beltz 8 and the proximity to the lagoon, which represents potential head boundary that likely dominates and dampens the water level responses to operations at Beltz 8 at this location.

SC-1A (Figures 11 and 23). The SC-1A monitoring well is screened in the entire A Aquifer Unit and is located on the coast (refer to **Figure 3**). As shown, similar to the other coastal monitoring wells, SC-1A displays a similar response to diurnal tidal fluctuations, with the levels fluctuating as much as approximately 4.5, depending on the magnitude of tidal variation. Also as shown, SC-1A did not displayed a discernable response to ASR operations at Beltz 8.

SC-22 (Figures 12 and 24). The SC-22 medium and deep monitoring wells, completed in the AA and Tu Units, respectively, did not display a discernable response to ASR operations at Beltz 8. These results are not entirely unexpected, as these wells are not completed in the same target aquifer (A Unit) as Beltz 8. Unfortunately, the data logger installed in SC-22 A (completed in the A Unit) malfunctioned and no data are available for the period of ASR operations at Beltz 8.

SC-13 (Figures 13 and 25). The SC-13 monitoring well is completed in the Tu Aquifer Unit, and as shown, did not display a response to ASR operations at Beltz 8.

Moran Lake (Figures 14 and 26). The Moran Lake monitoring wells are located near the coast (refer to **Figure 3**) and screened in the upper and lower A Unit and the upper AA Unit. As shown, all three wells display similar responses to diurnal tidal fluctuations, with the levels fluctuating as much as approximately 0.5 to 2.0 feet, depending on the magnitude of tidal variation. Also as shown, none of the three wells displayed a discernable response to ASR operations at Beltz 8.

Soquel Point (Figures 15 and 27). Similar to the Pleasure Point wells, the Soquel Point monitoring wells are located at the coast (refer to **Figure 3**) and screened in the upper and lower A Unit and the upper AA Unit. As shown, all three wells display similar responses to diurnal tidal fluctuations, with the levels fluctuating as much as approximately 1 to 3 feet, depending on the magnitude of tidal variation. Also as shown, none of the three wells displayed a discernable response to ASR operations at Beltz 8.

Observed vs. Predicted Responses

As part of the ASR pilot test NOI Technical Report, PWR estimated the area of hydrologic influence affected hydraulically (i.e., water-level changes) by the injection tests utilizing the Theis Non-Equilibrium Equation and the following assumptions:

Table 11. Theis Equation Calculations Assumptions

Parameter	Value
Injection Rate (Q) (gpm)	400
Transmissivity (T) (gpd/ft)	46,000
Storativity (S) (dimensionless)	3.0×10^{-3}
Time (t) (days)	1, 7 & 30

The above hydrogeologic parameters were developed from the pumping test program conducted at Beltz 8 following its construction in 1998. The Theis-predicted theoretical drawup vs. distance calculations specifically estimated the amount of predicted water-level drawup within the aquifer system at the nearest test program monitoring well (Beltz 8 MW) and at the nearest offsite production well that is completed in the target Aquifer A (Beltz 9 Well). A summary comparison of the observed vs. predicted responses to the ASR injection tests at these two wells is presented in **Table 12** below:

Table 12. Observed vs Predicted Responses to Injection

Injection Test	Rate (gpm)	Duration (days)	Observed Response (ft)		Predicted Response (ft)	
			Beltz 8 MW	Beltz 9	Beltz 8 MW	Beltz 9
1	315	1	9.0	Undiscernable	6.3	0.4
2	313	7	11.9	Undiscernable	7.8	1.6
3	303	14	11.4	Undiscernable	8.1	2.0

As shown in **Table 12**, the water-level data for the Beltz 8 monitoring well showed an actual drawup response of approximately 9.0 to 11.9 feet to the injection test compared to the Theis-predicted responses of approximately 6.3 to 8.1 feet. As also shown in **Table 12** and discussed previously, the water levels at Beltz 9 did not show a discernable response to injection at Beltz 8; however, the amount of predicted response only ranges between approximately 0.4 to 2.0 feet, which is relatively low.

The greater-than-predicted response of the local aquifer system to injection at Beltz 8 (approximately 30 percent greater) suggests that the site-specific aquifer parameters at Beltz 8 may not be representative of the broader regional aquifer system and/or there are boundary condition effects (e.g., the western basin boundary and the Pacific Ocean) not accounted for by the relatively simplistic Theis-based analytical calculations[7] that are affecting the aquifer system

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[7] The Theis Equation assumes that the aquifer is homogenous and infinite in areal extent.

response to injection. These results should be investigated further with the calibrated groundwater flow model of the MGB as part of a future investigation.

WATER QUALITY

A critical aspect of the Beltz 8 ASR pilot test program was the empirical assessment of water-quality issues through the repeated Injection-Storage-Recovery (ISR) cycles of ASR operations. For the SCWD ASR program, potable Title-22 compliant water produced from the GHWTP and conveyed to the site via the SCWD distribution system was used for injection into the aquifer. The ASR pilot program was designed to monitor and verify that potability was maintained throughout the ASR cycle sequence of injection, aquifer storage, and recovery operations.

The principal focus of the water-quality investigation was on parameters associated with potability; however, additional water-quality parameters were monitored that are known to affect well and aquifer performance vis-à-vis well screen and/or aquifer plugging. Such adverse reactions can occur between the injection source water (from GHWTP) and the native groundwater (NGW); the injected water and the geologic matrix of the aquifer; or both. Beneficial reactions may also occur and are discussed in a later section.

The potential reactions between injected waters, native groundwaters, and aquifer matrix minerals can be classified into the following general categories:

- **Precipitation reactions** result from aqueous reactions which create oversaturated mineral conditions and produce precipitates of minerals in order to balance geochemical equilibrium. Such reactions can occur as a result of chemical mixing between disparate waters, or via temperature or pressure changes that may occur during ASR operations. The result on ASR operations is the same; a reduction in well performance due to well screen or aquifer porosity plugging and/or water-quality degradation via color or turbidity increases from the formation of colloidal or suspended solids.

- **Ion Exchange reactions** can occur when recharge waters interact with aquifer minerals facilitating a substitution of cations (or anions) based on their relative affinity for geochemical equilibrium in the aquifer mineral matrix. The most common ion exchange reactions in ASR operations are cationic exchanges between Na and Ca ions and are especially problematic in the presence of smectite or montmorillonite clays; if high-sodium recharge waters displace native groundwaters in a high-clay content matrix, swelling can occur and result in lower aquifer permeability.

- **Redox reactions** occur when significant differentials in oxidation states are present in the injected water, native groundwater, and aquifer minerals. Redox reactions can demerit water quality, cause decreases in aquifer permeability, release soluble contaminants, or mobilize otherwise stable elements present in aquifer minerals.

- **Solubilization reactions** can also leach undesirable elements from aquifer minerals and contaminate stored waters in the aquifer. Leaching processes can occur when injected waters are significantly undersaturated and/or unbuffered with respect to various minerals. Common leaching processes that adversely affect stored water quality include Fe, Mn, As, or Hg; major cations such as Ca, Mg, or K, while also susceptible to leaching, generally do not render waters non-potable.

- **Biochemical reactions** can be significant and especially detrimental to ASR operations. Microbial populations, whether indigenous within the aquifer or introduced via ASR operations, can proliferate under certain environmental and nutritional conditions; this can result in mineral precipitation, taste and/or odor creation, corrosion of well screens and piping, and formation of slimes and biomass that can significantly plug well screens and/or near-well aquifer matrices.

It is common for many of these mechanisms to occur simultaneously in natural waters; however, the identification of reaction processes is useful in assessing and mitigating potential water-quality issues that could adversely affect ASR operations.

Previous Studies

PWR performed a preliminary geochemical assessment of the SCWD's proposed ASR program as part of the Phase 1 Technical Feasibility Investigation[8] based on water-quality sampling of Beltz 9 native groundwater and the GHWTP injection source water. At that time, Beltz 9 had been identified as the preferred candidate existing well for ASR pilot testing in the A Aquifer Unit; however, due to operational considerations the SCWD later decided to perform an ASR pilot test at Beltz 8. The investigation included assessment of the geochemical stability of these waters individually, and in various mixtures to assess the geochemical reactions that could potentially occur during aquifer storage. The principal findings of the geochemical modeling assessment included the following:

- The treated GHWTP water is an excellent source of ASR injection water and would have an overall diluting effect in the aquifer.
- There is potential for calcite precipitation (which can lead to well plugging); however, this potential is very dependent on the actual pH of the injected water, where at a pH of 7.6 and TDS of 300 mg/L or less, the potential for calcite precipitation is essentially eliminated.
- Dissolved manganese in all of the NGWs exceeds drinking water standards; however, none of the dissolved constituents (including manganese) in recovered waters are estimated to be higher than their original concentrations in the NGW.
- A potential ancillary benefit of aquifer recharge with treated GHWTP water may be the reduction of manganese in the stored and recovered waters, perhaps persisting for some time after 100 percent of the previously injected water has been recovered; however, as recovery pumping progresses, the manganese concentrations will likely eventually tend to approach NGW levels over time.
- Overall, the modeling predicted that the potential for significant adverse geochemical reactions during ASR operations were unlikely except as noted

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[8] Pueblo Water Resources, Inc. (August 2017), *Geochemical Interaction Analysis (Task 1.3)*, Technical Memorandum prepared for Santa Cruz Water Department (draft).

above, and no geochemical interaction-related “fatal flaws” for the ASR project were identified.

It is noted that the geochemical investigation did not assess the fate of DBP’s, as DBP equilibrium data are not included in the geochemical database. Similarly, microbially mediated reactions were not assessed in the geochemical modeling. These processes are necessarily assessed empirically during actual ASR operations.

ASR Pilot Test Program Results

Numerous samples were collected during the Beltz 8 ASR pilot test program in accordance with the project Sampling and Analysis Plan (SAP) developed as part of the project Work Plan (refer to **Appendix A**). Samples were collected at Beltz 8 and the onsite monitoring well that is screened in the same aquifer zone as Beltz 8. Laboratory analyses were provided by a State Certified Laboratory (Eurofins Eaton Analytical, LLC.), which included a variety of constituent groups: general parameters, major anions and cations, nutrients, metals, miscellaneous, and DBPs. Some samples were analyzed for the complete list of constituents while other samples were analyzed for a partial list (e.g., DBPs), depending on the timing of an ASR period, as summarized in **Table 13** below:

Table 13. Water-Quality Sampling Schedule

Cycle 1						
Analyte Group	**Injection**		**Storage**		**Recovery**	
	Injectate	**MW**	**Beltz 8**	**MW**	**Beltz 8**	**MW**
F-1	Once	–	@end	--	@ 25, 50, 75, 100, 125 & 150%	--
G-1	Once	–	@end	--	@ 50 and 100%	--
DBP	Once	–	@end	--	@ 100%	--
S-1	--	–	–	--	@ 25, 75, 125, & 150%	--
Cycle 2						
Analyte Group	**Injection**		**Storage**		**Recovery**	
	Injectate	**MW**	**Beltz 8**	**MW**	**Beltz 8**	**MW**
F-1	Once	–	Weekly	@end	@ 0, 25, 50, 75, 100, 125 & 150%	@end
G-1	Once	–	Weekly	@end	@ 0, 50 and 100%	@end
DBP	Once	–	Weekly	@end	@ 0 & 100%	@end
S-1	--	–	–	--	@ 25, 75, 125, & 150%	--
Cycle 3						
Analyte Group	**Injection**		**Storage**		**Recovery**	
	Injectate	**MW**	**Beltz 8**	**MW**	**Beltz 8**	**MW**
F-1	Weekly	Weekly	Weekly	Weekly	@0, 25, 50, 75, & 100%	Weekly
G-1	Once	Once	Once	Once	@ 0, 50 and 100%	@ 0, 50 and 100%
DBP	Weekly	Weekly	Weekly	Weekly	@0, 25, 50, 75, & 100%	Weekly
S-1	Weekly	Weekly	Weekly	Weekly	@ 25 & 75%	Weekly

Laboratory reports are provided in **Appendix D**. **Tables 14, 15, and 16** summarize the respective laboratory results for Beltz 8 from ASR Cycles 1, 2 and 3, respectively. **Table 17** summarizes laboratory results for samples collected from the onsite monitoring well.

Table 14. Beltz 8 ASR Cycle 1 Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date							
Group ID						3/18/20	3/19/20	3/23/20	3/23/20	3/23/20	3/23/20	3/24/20	3/24/20
Field Parameters						Pre-Injection	Injection	Recovery					
Temperature	on-site	SM 2550	°C	0.5		19.4	16.7	16.9	16.8	17.0	17.9	19.2	18.6
EC	on-site	EPA 120.1	umho/cm	10		625	428	461	443	446	476	548	577
pH	on-site	EPA 150.1	Std Units	0.01		6.98	7.20	7.11	7.30	7.32	7.27	7.12	7.10
ORP	on-site	USGS	mV	10		53.4	615.1	82.6	7.6	2.6	0.1	10.4	14.2
Cl Residual	on-site	Hach	mg/L	0.05		0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00
Diss O2	on-site	Hach	mg/L	0.2		0.00	9.06	0.02	0.00	0.00	0.00	0.00	0.00
Turbidity	on-site	Hach 2100Q	NTU	0.1		--	1.66	0.00	0.00	0.00	0.00	--	--
SDI	on-site		Std Units	0.01		NA	1.78	NA	NA	NA	NA	NA	NA
General Mineral Analysis													
Alkalinity (Total)	Lab	SM2320B	mg/L	5		140	110	120	120	120	120	140	140
Ca	Lab	EPA 200.7	mg/L	0.03		73	53	54	52	54	52	73	80
Cl	Lab	EPA 300.0	mg/L	0.5	250	55	21	25	25	25	28	54	56
EC	Lab	EPA 120.1	umho/cm	10	900	680	430	460	460	460	490	680	680
F	Lab	EPA 300.0	mg/L	0.1	2	0.052	0.16	0.12				0.073	
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	ND	ND	ND	ND	0.024	ND	ND
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	0.18	ND	0.13	0.062	0.057	0.051	0.066	0.068
K	Lab	EPA 200.8	mg/L	1		6.1	1.9	2.1	2.3	3.4	4.7	6.9	7.3
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	ND				ND	
Mg	Lab	EPA 200.8	mg/L	0.5		19	9.4	10	9.4	10	11	18	19
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.1		0.02	0.026	0.036	0.043	0.082	0.091
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	**0.095**	ND	0.017	0.03	0.041	0.048	**0.093**	**0.079**
Na	Lab	EPA 200.7	mg/L	0.05		39	24	24	24	26	28	40	41
NH3	Lab	EPA 350.1	mg/L	0.05		0.054	ND	ND				0.057	
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	ND				ND	
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	ND	0.2	ND	0.12	0.14	0.13	ND	ND
P (Total)	Lab		mg/L	0.001		0.11	0.19	0.14				ND	
pH	Lab	EPA 150.1	Std Units	0.01		7.3	7.5	7.4	7.6	7.7	7.7	7.6	7.6
SiO2	Lab	EPA 370.1	mg/L	2		61	18	27	36	46	51	61	62
SO4	Lab	EPA 300.0	mg/L	0.5	250	130	72	77	74	75	82	120	120
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND	ND				ND	
TDS	Lab	SM2540C	mg/L	5	500	470	260	290	290	310	340	460	440
TKN	Lab	EPA 351.2	mg/L	0.2		ND	ND	0.24				2.3	
Inorganic Trace Metals													
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND				ND	
Al	Lab	EPA 200.8	ug/L	10	200	ND	21	ND				ND	
As	Lab	EPA 200.8	ug/L	1	10	1.4	ND	ND	1.1	1.4	1.6	3.1	3.8
B	Lab	EPA 200.8	ug/L	50		ND	59	64				ND	
Ba	Lab	EPA 200.7	ug/L	1	1000	53	33	36				55	
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND				ND	
Br	Lab	EPA 200.9	ug/L	100		210	16	43	43	48	61	210	220
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND				ND	
Co	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND	
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND	ND				ND	
Cu	Lab	EPA 200.8	ug/L	5	1000	9.4	ND	ND				ND	
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND	ND	ND	ND	ND	ND
I	Lab	EPA 200.8	ug/L	100		3.6	ND	7.1				3.8	
Li	Lab	EPA 200.7	ug/L	1		14	14	15				14	
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND	ND				ND	
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND	
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND	ND				ND	
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND	ND				ND	
Sr (Total)	Lab	EPA 200.7	ug/L	1		250	270	260				280	
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND				ND	
U	Lab	EPA 200.8	ug/L	0.5		ND	ND	ND				ND	
V	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND	
Zn	Lab	EPA 200.8	ug/L	10	5000	46	ND	ND				ND	
Bio / Organics													
Coliform	Lab		CFU	<1		ND	ND	ND				ND	
HAA5's	Lab	EPA 552.2	ug/L	1	60	ND	33					ND	
HPCs	Lab	SM9215B	CFU	<1		150	4	2300				590	
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		0.77	1.9					0.89	
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		0.43	1.4					0.43	
TTHM's	Lab	EPA 502.2	ug/L	1	80	ND	52					0.99	
Miscellaneous													
CH4	Lab	RSK-175	ug/L	5		0.37	0.22	0.31				0.58	
Gross Alpha	Lab	EPA 900.0	pCi/L		15	6.4	3.6	5.4				4.6	
Color	Lab	SM2120B	Color Units	3	15	ND	ND	ND				ND	
Hardness	Lab	SM2340B	mg/L	10		260		180				280	
Tu	Lab	EPA 180.1	NTU	0.1	5	1.1	0.14	0.98				0.54	
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND				ND	

Notes:

Values denoted in **bold** text exceed MCL.

Table 15. Beltz 8 ASR Cycle 2 Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date								
Group ID						**3/30/20**	**4/8/20**	**4/15/20**	**4/16/20**	**4/17/20**	**4/18/20**	**4/19/20**	**4/20/20**	**4/21/20**
Field Parameters						**Injection**	**Storage**	**Recovery**						
Temperature	on-site	SM 2550	°C	0.5		17.1	17.3	17.9	17.4	18.1	18.7	20.0	20.7	21.4
EC	on-site	EPA 120.1	umho/cm	10		489	628	561	449	445	452	551	621	614
pH	on-site	EPA 150.1	Std Units	0.01		7.31	7.07	6.89	7.26	7.27	7.24	7.12	7.09	7.03
ORP	on-site	USGS	mV	10		606	71.7	7.3	114.5	227.8	203.6	204.2	15.1	-7.8
Cl Residual	on-site	Hach	mg/L	0.05		0.62	0.02	0.00	0.01	0.02	0.01	0.00	0.00	0.01
Diss O2	on-site	Hach	mg/L	0.2		9.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turbidity	on-site	Hach 2100Q	NTU	0.1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SDI	on-site		Std Units	0.01		2.76	NA	NA	NA	NA	NA	NA	NA	NA
General Mineral Analysis														
Alkalinity (Total)	Lab	SM2320B	mg/L	5		120	120	140	120	120	120	130	140	140
Ca	Lab	EPA 200.7	mg/L	0.03		52	65	72	54	53	52	62	69	71
Cl	Lab	EPA 300.0	mg/L	0.5	250	25	25	24	24	25	25	40	54	53
EC	Lab	EPA 120.1	umho/cm	10	900	420	500	540	460	460	460	570	660	640
F	Lab	EPA 300.0	mg/L	0.1	2	0.14	0.11	0.092		0.1		0.085		
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	ND	ND	ND	ND	0.022	ND	ND	ND
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	ND	**0.31**	0.2	0.037	0.03	0.029	0.035	0.045	0.049
K	Lab	EPA 200.8	mg/L	1		1.9	2.2	2.4	2	2.3	4.1	6.2	6.4	6.3
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	ND		ND		ND		
Mg	Lab	EPA 200.8	mg/L	0.5		9.2	12	13	9.7	9.4	9.4	13	17	18
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	0.021	0.025	0.019	0.033	0.044	0.067	0.078	0.093
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	ND	0.019	0.022	0.022	0.031	0.046	**0.063**	**0.085**	**0.1**
Na	Lab	EPA 200.7	mg/L	0.05		24	26	26	25	25	25	32	38	40
NH3	Lab	EPA 350.1	mg/L	0.05		ND	ND	ND		ND		ND		
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	ND		ND		ND		
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	0.29	ND	ND	ND	ND	ND	ND	ND	ND
P (Total)	Lab		mg/L	0.001		0.2	0.18	0.16		ND		0.1		
pH	Lab	EPA 150.1	Std Units	0.01		7.7	7.5	7.4	7.6	7.6	7.7	7.6	7.6	7.6
SiO2	Lab	EPA 370.1	mg/L	2		19	27	30	34	40	45	51	56	60
SO4	Lab	EPA 300.0	mg/L	0.5	250	72	110	120	76	76	77	100	120	120
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND	ND		ND		ND		
TDS	Lab	SM2540C	mg/L	5	500	280	340	380	290	300	290	380	450	460
TKN	Lab	EPA 351.2	mg/L	0.2		ND	ND	ND		ND		ND		
Inorganic Trace Metals														
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND		ND		ND		
Al	Lab	EPA 200.8	ug/L	10	200	22	ND	ND		ND		ND		
As	Lab	EPA 200.8	ug/L	1	10	ND	ND	1.2	4.2	6	5.5	5.8	4.9	4.5
B	Lab	EPA 200.8	ug/L	50		0.059	0.072	0.076		ND		ND		
Ba	Lab	EPA 200.7	ug/L	1	1000	32	44	48		33		51		
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND		ND		ND		
Br	Lab	EPA 200.9	ug/L	100		13	70	65	49	55	59	130	210	210
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND		ND		ND		
Co	Lab	EPA 200.8	ug/L	1		ND	ND	ND		ND		ND		
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND	ND		ND		ND		
Cu	Lab	EPA 200.8	ug/L	5	1000	ND	ND	ND		ND		ND		
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND	ND	ND	ND	ND	ND	ND
I	Lab	EPA 200.8	ug/L	100		ND	16	13		5.6		4.8		
Li	Lab	EPA 200.7	ug/L	1		13	15	20		10		11		
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND	ND		ND		ND		
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND		ND		ND		
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND	ND		ND		ND		
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND	ND		ND		ND		
Sr (Total)	Lab	EPA 200.7	ug/L	1		0.26	0.33	0.36		0.25		0.24		
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND		ND		ND		
U	Lab	EPA 200.8	ug/L	0.5		ND	ND	ND		ND		ND		
V	Lab	EPA 200.8	ug/L	1		ND	ND	ND		3.1		4.4		
Zn	Lab	EPA 200.8	ug/L	10	5000	ND	ND	ND		ND		ND		
Bio / Organics														
Coliform	Lab		CFU	<1		ND	ND	ND		ND		ND		
HAA5's	Lab	EPA 552.2	ug/L	1	60	24	19	12				ND		
HPCs	Lab	SM9215B	CFU	<1		<1	>5700	>5700		3100		3600		
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		1.3	1.4					0.8		
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		1.3	1.3	1.2				0.6		
TTHM's	Lab	EPA 502.2	ug/L	1	80	45	40	31				ND		
Miscellaneous														
CH4	Lab	RSK-175	ug/L	5		0.34	0.26	0.38		0.32		0.43		
Gross Alpha	Lab	EPA 900.0	pCi/L		15	ND	5.1	8.5		4.2		6.2		
Color	Lab	SM2120B	Color Units	3	15	ND	ND	5		3		ND		
Hardness	Lab	SM2340B	mg/L	10		170	210	230		170		210		
Tu	Lab	EPA 180.1	NTU	0.1	5	0.18	2	2.1		0.23		0.21		
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND		ND		ND		

Notes:

Values denoted in **bold** text exceed MCL.

Table 16. Beltz 8 ASR Cycle 3 Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date													
Group ID						4/1/21	4/6/21	4/13/21	4/20/21	4/27/21	5/5/21	5/12/21	5/18/21	5/20/21	5/23/21	5/25/21	5/27/21	5/30/21	6/1/21
Field Parameters						Pre-Inject	Injection			Storage			Recovery						
Temperature	on-site	SM 2550	°C	0.5		18.4	16.8	16.7	17.2	17.6	17.9	17.9	17.9	17.7	17.5	17.6	18.1	18.4	18.5
EC	on-site	EPA 120.1	umho/cm	10		538	392	403	407	511	635	591	567	468	475	479	573	641	644
pH	on-site	EPA 150.1	Std Units	0.01		6.98	7.25	7.32	7.30	6.96	6.84	6.85	6.84	7.14	7.12	7.11	7.03	6.99	6.97
ORP	on-site	USGS	mV	10		-24.8	649	622.1	659.5	-33.6	78.5	500?	-12.8	-26.8	-24.2	-11.5	-30.2	-6.4	241.3
Cl Residual	on-site	Hach	mg/L	0.05		0.00	0.77	0.62	0.74	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.02	0.00	0.01
Diss O2	on-site	Hach	mg/L	0.2		NA	10.10	9.90	10.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turbidity	on-site	Hach 2100Q	NTU	0.1		3.03	0.33	0.47	0.63	2.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SDI	on-site		Std Units	0.01		NA	2.76	2.16	2.22	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
General Mineral Analysis																			
Alkalinity (Total)	Lab	SM2320B	mg/L	5		140	120	120	120	120	150	150	140	120	120	120	130	140	140
Ca	Lab	EPA 200.7	mg/L	0.03		66	51	48	53	74	81	72	68	57	56	57	64	70	69
Cl	Lab	EPA 300.0	mg/L	0.5	250	54	28	30	30	30	30	30	30	30	30	30	44	53	53
EC	Lab	EPA 120.1	umho/cm	10	900	660	460	460	460	600	640	580	540	480	490	500	600	650	
F	Lab	EPA 300.0	mg/L	0.1	2	0.05	0.15				0.1		0.087		0.1		0.081		
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	**1.4**	ND	ND	ND	**0.3**	**0.34**	0.26	0.064	ND	ND	ND	ND	ND	ND
K	Lab	EPA 200.8	mg/L	1		6	2.2	2	2.3	2.7	2.8	2.7	2.6	2.2	2.7	3.9	5.8	6.4	6.3
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND				ND		ND		ND		ND		
Mg	Lab	EPA 200.8	mg/L	0.5		18	9.5	8.7	9.6	14	15	13	12	10	10	10	15	18	18
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.2	ND	ND	ND	0.017	0.03	0.033	0.038	0.026	0.047	0.054	0.087	0.11	0.13
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	**0.2**	ND	ND	ND	0.018	0.029	0.037	0.037	0.029	0.044	**0.06**	**0.08**	**0.12**	**0.14**
Na	Lab	EPA 200.7	mg/L	0.05		40	27	25	28	32	32	30	29	29	29	30	36	40	40
NH3	Lab	EPA 350.1	mg/L	0.05		0.073	ND				ND		ND		ND		ND		
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND				ND		ND		ND		ND		
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	ND	0.23	0.31	0.36	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
P (Total)	Lab		mg/L	0.001		0.3	0.21				0.17		0.17		ND		0.14		
pH	Lab	EPA 150.1	Std Units	0.01		7.5	7.6	7.8	7.8	7.4	7.5	7.6	7.7	7.4	7.7	7.8	7.6	7.8	7.8
SiO2	Lab	EPA 370.1	mg/L	2		64	18	17	20	29	32	33	33	36	44	50	55	59	61
SO4	Lab	EPA 300.0	mg/L	0.5	250	120	71	71	69	150	140	110	100	79	81	82	100	120	120
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND				ND		ND		ND	ND	ND		
TDS	Lab	SM2540C	mg/L	5	500	460	290	300	280	420	420	390	380	340	330	340	400	440	450
TKN	Lab	EPA 351.2	mg/L	0.2		ND	ND				ND		ND		ND		ND		
Inorganic Trace Metals																			
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND				ND		ND		ND		ND		
Al	Lab	EPA 200.8	ug/L	10	200	ND	21				ND		ND		ND		ND		
As	Lab	EPA 200.8	ug/L	1	10	2.3	ND	ND	ND	ND	1.3	1.9	1.9	2.1	3.4	3.3	3.5	3.1	3
B	Lab	EPA 200.8	ug/L	50		ND	0.067				0.082		0.07		0.055		ND		
Ba	Lab	EPA 200.7	ug/L	1	1000	51	37				67		54		39		47		
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND				ND		ND		ND		ND		
Br	Lab	EPA 200.9	ug/L	100		210	12	20	20	74	86	90	93	84	60	68	160	210	210
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND				ND		ND		ND		ND		
Co	Lab	EPA 200.8	ug/L	1		ND	ND				ND		ND		ND		ND		
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND				ND		ND		ND		ND		
Cu	Lab	EPA 200.8	ug/L	5	1000	ND	ND				ND		ND		ND		ND		
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
I	Lab	EPA 200.8	ug/L	100		2.6	ND				15		6.8		5.1		3.8		
Li	Lab	EPA 200.7	ug/L	1		0.012	0.012				0.02		0.02		0.011		0.012		
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND				ND		ND		ND		ND		
Pb	Lab	EPA 200.8	ug/L	1		ND	ND				ND		ND		ND		ND		
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND				ND		ND		ND		ND		
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND				ND		ND		ND		ND		
Sr (Total)	Lab	EPA 200.7	ug/L	1		0.22	0.27				0.42		0.35		0.26		0.25		
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND				ND		ND		ND		ND		
U	Lab	EPA 200.8	ug/L	0.5		ND	ND				ND		ND		ND		ND		
V	Lab	EPA 200.8	ug/L	1		ND	ND				ND		ND		ND		ND		
Zn	Lab	EPA 200.8	ug/L	10	5000	ND	ND				ND		ND		ND		ND		
Bio / Organics																			
Coliform	Lab		CFU	<1		<1	<1				<1		<1		<1		<1		
HAA5's	Lab	EPA 552.2	ug/L	1	60		24	22	22		8.6	ND	ND				2.2		ND
HPCs	Lab	SM9215B	CFU	<1		220	NA				>5700		>5700				760		
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1			1.3	1.3	1.2		1.4	1.4	1.7				1.2		0.84
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1			1.6	1.2	1.2		2	1.2	1.2				0.65		0.79
TTHM's	Lab	EPA 502.2	ug/L	1	80		45	44	45		27		3				ND		ND
Miscellaneous																			
CH4	Lab	RSK-175	ug/L	5		0.36	0.33				0.29		0.33		0.46		0.27		
Gross Alpha	Lab	EPA 900.0	pCi/L		15	ND	ND				ND		ND		ND		ND		
Color	Lab	SM2120B	Color Units	3	15	5	ND				5		ND		ND		ND		
Hardness	Lab	SM2340B	mg/L	10		240	170				260		220		180		220		
Tu	Lab	EPA 180.1	NTU	0.1	5	2.7	0.26				1		0.6		ND		0.11		
TSS	Lab	EPA 160.2	mg/L	1		ND	ND				ND		ND		ND		ND		

Notes:

Values denoted in **bold** text exceed MCL.

Table 17. Beltz 8 Monitoring Well Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date				Sample Date												
Group ID						**3/18/20**	**4/15/20**	**4/21/20 9:45**	**4/21/20 11:15**	**4/5/21**	**4/13/21**	**4/20/21**	**4/27/21**	**5/5/21**	**5/12/21**	**5/18/21**	**5/20/21**	**5/23/21**	**5/25/21**	**5/27/21**	**5/30/21**	**6/1/21**
Field Parameters						**Pre-Injection**	**ASR Cycle 2 Recovery**			**Pre-Inject**	**Injection**		**Storage**			**Recovery**						
Temperature	on-site	SM 2550	°C	0.5		20.21	18.55	21.72	21.86	18.5	17.5	17.8	17.6	18.08	18.13	18.07	17.86	18.03	18.42	18.65	18.66	18.85
EC	on-site	EPA 120.1	umho/cm	10		547	585	460	516	517	422	429	434	496	633	484	474	475	464	532	491	528
pH	on-site	EPA 150.1	Std Units	0.01		7.55	7.82	6.97	7.25	7.18	7.11	7.16	7.40	7.34	7.40	7.26	7.22	7.12	7.07	6.95	6.92	7.03
ORP	on-site	USGS	mV	10		-87.5	-28.6	-36.7	-70.6	-71.1	-62.4	16.0	-111.1	-110.3	-129.3	-122.1	-96.5	-88.3	-52.6	-88.7	-42.8	-64.2
Cl Residual	on-site	Hach	mg/L	0.05		0.00	0.00	0.02	0.00	ND	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Diss O2	on-site	Hach	mg/L	0.2		0.02	0.00	0.00	0.00	NA	0.10	0.10	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turbidity	on-site	Hach 2100Q	NTU	0.1		NA	NA	0.59	0.00	0.97	0.19	0.20	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SDI	on-site		Std Units	0.01		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
General Mineral Analysis																						
Alkalinity (Total)	Lab	SM2320B	mg/L	5		160	130	120	110	130	120	130	130	120	130	120	120	120	110	120	110	120
Ca	Lab	EPA 200.7	mg/L	0.03		55	74	48	36	59	42	48	49	49	69	44	44	43	41	49	39	46
Cl	Lab	EPA 300.0	mg/L	0.5	250	40	26	40	39	42	30	30	31	30	31	30	29	29	30	38	41	41
EC	Lab	EPA 120.1	umho/cm	10	900	670	630	540	480	650	490	480	510	510	640	470	480	480	470	560	500	530
F	Lab	EPA 300.0	mg/L	0.1	2	0.28	0.14	0.11		0.25		0.12		0.19		0.11		0.13		0.11		
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.3	0.092	ND	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.021	ND
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	0.34	0.14	0.56	0.87	**1.1**	**1**	**1**	**0.77**	**0.85**	**0.73**	**1**	**1.1**	**1.2**	**1.2**	**1.6**	**1.5**	**1.6**
K	Lab	EPA 200.8	mg/L	1		6.3	6.2	5.2	4.7	5.9		4.6	4.6	4.6	5.7	4.2	4.2	4.5	4.6	5.3	4.8	5.1
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	ND		ND	ND	ND		ND		ND		ND		ND		
Mg	Lab	EPA 200.8	mg/L	0.5		22	19	17	16	23	16	17	16	17	23	16	17	17	16	21	18	18
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.09	0.083	0.079		0.13	0.12	0.13	0.11	0.11	0.1	0.1	0.098	0.099	0.088	0.11	0.082	0.14
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	0.087	0.082	0.13	0.078	**0.13**	**0.12**	**0.13**	**0.11**	**0.1**	**0.11**	**0.1**	**0.1**	**0.097**	**0.097**	**0.1**	**0.094**	**0.16**
Na	Lab	EPA 200.7	mg/L	0.05		54	28	35	36	34	27	29	27	28	28	28	29	31	33	38	37	36
NH3	Lab	EPA 350.1	mg/L	0.05		ND	0.11	ND		0.051		ND		ND		ND		ND		ND		
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	ND		ND		ND		ND		ND		ND		ND		
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
P (Total)	Lab		mg/L	0.001		0.17	ND	0.4		0.31		ND		0.12		0.17		0.31		0.4		
pH	Lab	EPA 150.1	Std Units	0.01		7.8	8	7.6	7.5	7.6	7.9	7.8	7.6	7.8	7.9	7.7	7.6	7.6	7.7	7.6	7.7	7.7
SiO2	Lab	EPA 370.1	mg/L	2		55	49	61	59	64	41	35	41	44	51	40	45	53	57	61	61	62
SO4	Lab	EPA 300.0	mg/L	0.5	250	130	140	86	80	140	81	82	86	89	160	81	79	78	79	99	78	87
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND	ND		ND		ND		ND		ND		ND		ND		
TDS	Lab	SM2540C	mg/L	5	500	470	440	380	330	440	340	320	360	330	450	320	340	320	320	380	330	360
TKN	Lab	EPA 351.2	mg/L	0.2		ND	ND	ND		ND		ND		ND		ND		ND		ND		
Inorganic Trace Metals																						
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND		ND		ND		ND		ND		ND		ND		
Al	Lab	EPA 200.8	ug/L	10	200	ND	ND	ND		ND		ND		ND		ND		ND		ND		
As	Lab	EPA 200.8	ug/L	1	10	**29**	6.5	7.4	5.4	3.8	1.4	1.2	1.8	2.2	2.3	3.6	3.5	4	ND	4.3	4.4	3.9
B	Lab	EPA 200.8	ug/L	50		ND	53	ND		ND		0.068		0.066		0.06		ND		ND		
Ba	Lab	EPA 200.7	ug/L	1	1000	50	40	49		47		37		37		43		45		53		
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND		ND		ND		ND		ND		ND		ND		
Br	Lab	EPA 200.9	ug/L	100		140	67	150	150	150	60	74	62	66	78	73	64	58	61	140	150	170
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND		ND		ND		ND		ND		ND		ND		
Co	Lab	EPA 200.8	ug/L	1		ND	ND	ND		ND		ND		ND		ND		ND		ND		
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND	ND		ND		ND		ND		ND		ND		ND		
Cu	Lab	EPA 200.8	ug/L	5	1000	ND	ND	ND		ND		ND		ND		ND		ND		ND		
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
I	Lab	EPA 200.8	ug/L	100		2.1	5.2	2		2.1		7		5.5		5.1		4.4		2.5		
Li	Lab	EPA 200.7	ug/L	1		20	17	11		0.018		0.012		0.013		0.011		0.011		0.012		
Mo	Lab	EPA 200.8	ug/L	5																		
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND	ND		ND		ND		ND		ND		ND		ND		
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND		ND		ND		ND		ND		ND		ND		
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND	ND		ND		ND		ND		ND		ND		ND		
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND	ND		ND		ND		ND		ND		ND		ND		
Sr (Total)	Lab	EPA 200.7	ug/L	1		400	300	310		0.39		0.32		0.32		0.32		0.33		0.41		
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND		ND		ND		ND		ND		ND		ND		
U	Lab	EPA 200.8	ug/L	0.5		ND	ND	ND		ND		ND		ND		ND		ND		ND		
V	Lab	EPA 200.8	ug/L	1		ND	ND	ND		ND		ND		ND		ND		ND		ND		
Zn	Lab	EPA 200.8	ug/L	10	5000	ND	ND	ND		ND		ND		ND		ND		ND		ND		
Bio / Organics																						
Coliform	Lab		CFU	<1		180	110	1		<1		<1		<1		<1				<1		
HAA5's	Lab	EPA 552.2	ug/L	1	60	ND	ND	ND		ND	ND	ND		ND	ND	ND				ND		ND
HPCs	Lab	SM9215B	CFU	<1		1900	3200	59		63		>5700		2400		2000				340		
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		8.3	1.5	0.55		0.49	1.1	1		1.1	0.92	1.4				1.1		0.72
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		7.6	1	0.45		0.98	1.6	1.1		1.3	0.86	1				0.52		0.72
TTHM's	Lab	EPA 502.2	ug/L	1	80	ND	0.88	ND		ND	12	0.53		ND		ND				ND		ND
Miscellaneous																						
CH4	Lab	RSK-175	ug/L	5		0.25	0.59	0.12		0.35		0.37		0.25		0.34		0.49		0.22		
Gross Alpha	Lab	EPA 900.0	pCi/L		15	14	13	ND		ND		ND		ND		ND		ND		ND		
Color	Lab	SM2120B	Color Units	3	15	5	ND	3		5		ND		10		10		10		5		
Hardness	Lab	SM2340B	mg/L	10		230	260	160		240		190		190		180		180		210		
Tu	Lab	EPA 180.1	NTU	0.1	5	0.34	0.55	1.2		4.2		7.8		4.4		5.5		6.9		5.8		
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND		ND		ND		ND		ND		ND		ND		

Notes:

Values denoted in **bold** text exceed MCL.

As shown, the majority of water-quality data collected from the monitoring well was during ASR Cycle 3 (**Table 16**), because the volumes and durations of injection for ASR Cycles 1 and 2 were more limited and not sufficient to provide meaningful data.[9]

Recovery Efficiency

Recovery efficiency is defined as the percentage of stored water volume that is recovered before a water-quality limitation is exceeded. In most cases, the water quality limitation is the potable water standards set by the State of California or by the U.S. EPA. It is assumed that for the SCWD, the minimum standard would be State Drinking Water Standards, and that the desired recovery efficiency would be 100 percent, i.e., the SCWD would recover 100 million gallons (mg) of potable water for every 100 mg of water injected (minus any hydraulic losses from the basin). From an operational standpoint, ASR typically involves repeated ISR cycles, either on a seasonal basis or for extended periods to mitigate drought or emergency conditions. As ISR cycles are repeated, the aquifer minerals and background water quality typically change (incrementally) towards the chemical nature of the injectate. This is a result of the development of a "buffer zone" of mixed water that gradually increases over time, and a natural effect of the equilibration of the injected water with aquifer minerals during storage.

It is important to note that in this context, the term “recovery efficiency” refers to the water-quality of the recovered water relative to both the injectate and native groundwater water chemistries and is important for quantifying and understanding the effects of dilution on the water-quality results. The most pertinent constituent that applies to the Beltz 8 well is manganese, which exceeds the secondary Maximum Contaminant Level (MCL) in the native groundwater. Recovery efficiency should not be confused with ASR project recoverable yields (i.e., water quantity/volume), as there should be no expectation for “molecule-for-molecule” recovery of water that is recharged from a water-supply perspective. Some of the molecules of water injected via an ASR well would be expected to drift downgradient and away from the capture zone of the ASR well, but nevertheless goes into basin storage. The amount of drift would be dependent on a variety of factors, such as the duration of storage, amount of seasonal pumping by offsite wells, etc. Numerical groundwater modeling is utilized to quantify estimates of volumetric increases in outflow from the basin (hydraulic losses) and associated recoverable yields of a SCWD ASR project in the basin.

A total of three ISR cycles were implemented during the Beltz 8 ASR Pilot Test Program. Each cycle consisted of injection of a predetermined amount of potable water from the SCWD distribution system; followed by a storage, or idle period, to allow subsurface equilibrium and simulate "off season" storage of water; and finally a recovery process whereby approximately 100 to 150 percent of the volume of previously injected water was recovered[10] as part of the test program to assess the level of subsurface mixing of the injectate with native groundwaters and monitor for other chemical reaction processes.

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[9] It is noted that samples collected at Beltz 8 during the Injection periods shown on Tables 14 through 16 are of the injectate (i.e., the water being actively injected) and are not pumped samples from the well.

[10] Normal ASR operations would likely not recover more than the previously injected volume.

Based on review of the chemistry of injected and native groundwaters, chloride ion was identified as a natural tracer, or "tag" ion to differentiate the two waters. Chloride ion was selected as a viable tracer based on the following criteria:

1. It does not degrade in the subsurface environment.
2. It does not readily adsorb on aquifer minerals.
3. It rarely participates in ion exchange reactions with aquifer minerals.
4. The ion ratio is approximately 2:1 between the native groundwater and injectate, thus providing a robust ion differential[11].
5. The analytic detection of chloride ion is highly reliable, inexpensive, and has no "interference" with other ion concentrations present in the aqueous mix.

As ISR cycles progressed, chloride ion was monitored to determine the mix ratio of injected and native groundwaters, and to "dilution correct"[12] the compositional analysis of other pertinent constituents in the evaluation of subsurface degradation, oxidation, or ion exchange processes. Water quality was monitored at the following ASR process points during the pilot test project:

1. **Injection Supply**. Monitored for all constituents to establish a baseline of injected water quality.
2. **ASR Well**. Monitored for all constituents during storage and recovery of injected water to assess subsurface mixing and reactions occurring during storage.
3. **Monitoring Wells**. Monitored for general mineral and redox parameters to assess the occurrence of ion exchange and/or redox reactions in the subsurface.

The results of the chloride analysis versus pumping time (and recovered water volume) for ASR Cycles 1, 2, and 3 recovery tests are presented on **Figures 38, 39 and 40**, respectively. A comparison of the recovery efficiency for ASR Cycles 1, 2, and 3 Recovery Tests is presented **Figure 41** and **Figure 42** shows an idealized recovery curve for an ASR well. As shown, the recovery efficiency curves during the Beltz 8 ASR recovery tests were generally consistent with the idealized recovery curve. There was relatively little contribution of chloride (i.e., from the native groundwater) until the approximate 75 percent volume recovery levels. At the 100 percent volume recovery levels, all three tests contained approximately 50 to 90 percent native groundwater and by the 125 percent volume recovery levels, all three tests contained 95 to 100 native groundwater.

Disinfection Byproducts

The occurrence and fate of DBP's has been the subject of concern for ASR programs throughout the state. Both Total Trihalomethanes (TTHMs) and Haloacetic acids (HAAs) occur

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[11] Pre-injection native groundwater at Beltz 8 showed a chloride level of 55 mg/L, whereas the GHWTP injected water averaged 27 mg/L (ratio of 2.04:1)

[12] "Dilution Correction" removes the effects of mixing between the native groundwater and injected water that would affect the concentration of any given constituent and allows for the identification of geochemical changes absent mixing and dilution, such as changes in TTHM concentrations during storage and recovery.

as a result of free chlorine reacting with organic materials present in the injected and/or native groundwater and these compounds are regulated within Title 22 standards due to their known carcinogenic potential in humans. For ASR operations, it is generally desirable to maintain a free chlorine residual in injection waters to both maintain potability and to mitigate biofouling in the well screens and near-borehole aquifer zone. Unfortunately, the presence of free chlorine residual in injected waters also often supports the continued creation of DBP's during aquifer storage due to the presence of even minor amounts of organic compounds in the injected water, the native groundwater, and even within the aquifer mineral matrix. This continued DBP creation is referred to as "ingrowth" and can continue during aquifer storage operations until the supply of free chlorine or organic material is exhausted.

DBP reactivity typically includes both ingrowth and decay processes; however, they can vary substantially based on the specific DBP compound, the character of the injected and native groundwaters, the aquifer mineralogy, organic content, and other site-specific factors.

For the Beltz 8 ASR pilot test program, the evaluation of DBP occurrence focused on ASR Cycle 3 because ASR Cycles 1 and 2 cycles were of insufficient duration to fully assess both ingrowth and decay DBP processes. **Figures 43 and 44** graphically present the DBP data for ASR Cycle 3 for both TTHM and HAA compounds, respectively.

TTHM behavior apparent in **Figure 43** during ASR Cycle 3 showed the following trends:

- TTHM ingrowth during aquifer storage did not occur, as is often observed at other ASR sites, and TTHMs at all times were well below the state Maximum Contaminant Level (MCL) of 80 micrograms per liter (ug/L)
- Dilution-corrected TTHM values are comparable to the raw values, consistent with the relatively limited mixing between injected water and native groundwater until approximately the 75 percent recovery level, as discussed above.
- The onset of TTHM decay corresponded with a decline in redox conditions. Oxidation-Reduction Potential (ORP) values declined from approximately +660 mV for the injectate to less than approximately -30 mV as THM degradation occurred during aquifer storage. This correlation between declining redox potential and TTHM degradation is consistent with the majority of other ASR operations observed by PWR.
- Migration of the injected water and its TTHM content was only observed at the onsite monitoring well during the ASR Cycle 3 injection test, when the well showed 100 percent influence of injected water and a maximum THM concentration of 12 ug/L after approximately one week of injection, while concurrent sampling at the ASR test well showed an injectate value of 45 ug/L. TTHMs were non-detect (ND) at the monitoring well throughout the aquifer storage and recovery periods.

HAA behavior followed a similar trend of near-immediate decay following the cessation of injection; however, the process was more rapid than with TTHMs. This accelerated degradation behavior is typical of HAA reactivity in our experience at other ASR sites. Specific HAA trends apparent in **Figure 44** include the following:

- HAA ingrowth during aquifer storage did not occur, as is often observed at other ASR sites, and HAAs at all times were well below the state MCL of 60 ug/L.

- Similar to TTHMs, dilution-corrected HAA values are generally comparable to the raw values, consistent with the relatively limited mixing between injected water and native groundwater until approximately the 75 percent recovery level, as discussed above.
- Dilution-corrected HAA values rapidly decayed over 22 days and were essential non-detectable at the start of recovery pumping.
- As with TTHMs, the onset of HAA decay corresponded with a decline in redox conditions, and this correlation between declining redox potential and HAA degradation is also consistent with the majority of other ASR operations observed by PWR.
- Although migration of the recharge water was observed at the onsite monitoring well, HAAs were not detected at this well during the ASR pilot test.

Overall, the behavior of DBP's was generally consistent with, but even more favorable than, other ASR programs utilizing slightly anoxic aquifer systems, including during the Beltz 12 ASR pilot test. The results are considered more favorable than typical because DBPs did not show the typical period of DBP ingrowth followed by decay; rather, DBPs at the Beltz 8 site began degrading at the beginning of aquifer storage.

It is noted that both the chlorine residual and organic carbon content of the GHWTP injectate were fairly typical of other ASR injectate sources. The mechanism(s) associated with DBP degradation during aquifer storage are not completely understood, but some ASR investigators have suggested it may be associated with subsurface microbial activity (e.g., iron- and/or sulfate-reducing bacteria), which may be at least part of the cause for the observed levels of degradation at the Beltz 8 site. Nonetheless, DBP fate should be carefully monitored in subsequent longer-term ASR testing and/or a permanent ASR program at the site, concurrent with redox conditions monitoring.

Leaching Reactions

ASR projects typically involve the conjunctive utilization of waters that have different origins, and in most cases the quality of the recharge and receiving (i.e., native aquifer) waters are measurably different. In a broad context, water-quality changes during aquifer storage can occur from simple dilution/mixing (as discussed above) as well as chemical interaction between injected and native groundwaters and/or from reactions between the newly introduced injection water and the aquifer minerals. The potential for adverse chemical reaction during ASR operations therefore exists and can occur under certain circumstances. Specifically, experience at some other ASR sites has shown the potential for the leaching of undesirable regulated metals from aquifer minerals in recovered waters that can affect potability, such as the following constituents:

- Arsenic (As)
- Mercury (Hg)
- Nickel (Ni)
- Uranium (U)

During the Beltz 8 ASR Pilot Test Program, the SAP implemented included robust monitoring of these constituents, as well as all other Title 22 regulated metals. As noted previously, **Tables 14, 15, and 16** provide the laboratory results for Beltz 8 from ASR Cycles 1, 2 and 3, respectively, and **Table 17** provides laboratory results for the onsite monitoring well. As shown, mercury (Hg), nickel (Ni) and uranium (U) were not detected in any sample collected during the ASR pilot test program.

During ASR Cycles 1 and 2, however, arsenic (As) concentrations in the recovered waters were shown to have been elevated relative to pre-injection concentrations in the native groundwater, indicating that potentially adverse geochemical reactions between the injected water, native groundwater and/or aquifer minerals were occurring at the site. Although the arsenic concentrations in the recovered waters did not exceed the MCL for As of 10 micrograms per liter (ug/L), peaking at a concentration of 6.0 ug/L, the increase relative to the baseline concentration of 1.4 ug/L (an approximate four-fold increase) was of sufficient concern for the ASR pilot test program to be suspended following completion of ASR Cycle 2 and a geochemical interaction evaluation of the ASR Cycle 1 and 2 results was performed before continuing ASR pilot test operations.

A geochemical interaction evaluation was performed on the results of ASR pilot test Cycles 1 and 2 by Dr. Richard Glanzman (a subconsultant to PWR) which is documented in a Technical Memorandum (TM) dated October 1, 2020, and is presented in **Appendix E**. The key finding of the evaluation was that the increase in arsenic concentration was likely the result of dissolution of pyrite minerals present in the aquifer geologic matrix from the highly oxygenated injection source water, mobilizing arsenic into the groundwater. Based analysis of the Cycle 1 and 2 results, and an understanding of the geochemical reactions involved, the evaluation concluded that it was unlikely that continued ASR operations at the site would result in arsenic concentrations that would exceed the MCL of 10 ug/L, and continuation of the ASR Cycle 3 program was recommended.

Given these findings, PWR recommended proceeding with ASR Cycle 3 to further investigate arsenic behavior at the site and validate the findings of the geochemical interaction evaluation; however, it was recommend that the originally planned entire volume of Cycle 3 recovery water not be placed into the distribution system as originally planned due to the potential risk that arsenic may exceed the MCL without further testing; therefore, it was recommend that the original ASR Cycle 3 program be bifurcated into two separate ASR Cycles (e.g., Cycles 3a and 3b) in order to both develop the additional data needed for the arsenic investigation and mitigate the risk that water exceeding the MCL be pumped into the distribution system.

ASR Cycle 3a was subsequently performed during the period April 6 through June 1, 2021. Arsenic data for the ASR Cycles 1 through 3 recovery periods are presented on **Figure 45**. As shown, during the relatively short-duration ASR Cycle 1 recovery test (1 day of recovery following 1 day of injection), the concentration of arsenic in the recovered water reached a maximum of 3.8 ug/L, an approximate 3-fold increase above the pre-injection native groundwater concentration of 1.4 ug/L. During the ASR Cycle 2 recovery test, which was significantly longer in duration (6 days of recovery following 7 days of injection) and injected volume than ASR Cycle 1, the (i.e., Finding 2 above) arsenic concentration reached a maximum concentration of 6.0 ug/L, an approximate 4-fold increase above the pre-injection concentration. During the ASR Cycle 3 recovery period, however, which consisted of 14 days of recovery following 14 days of injection, the maximum concentration of arsenic was only 3.5 ug/L, significantly less than the maximum concentration observed during ASR Cycle 2.

A follow-up geochemical interaction analysis of ASR Cycle 3a was performed by Dr. Glanzman, which is documented in a TM dated August 28, 2021, and is also presented in **Appendix E**. The key findings developed from analysis of the ASR Cycle 3a results were as follows:

1. Based on evaluating the water chemistry data developed from ASR Cycle 3a, the arsenic concentrations at Beltz 8 are believed to primarily result from the dissolution of obsidian, and secondarily from pyrite, minerals that are present in the geologic matrix of the target aquifer at the site (the A Aquifer Unit of the Purisima Aquifer system).
2. The availability of arsenic in the aquifer matrix initially exposed during ASR Cycles 1 and 2 was decreased during ASR Cycle 3a, which indicates an arsenic reduction with incremental ASR cycles such that repeated ASR cycles are likely to result in progressively lower arsenic concentrations in the recovered water. In addition, the analysis suggests that increasing the storage time of the injected water could result in further lowering of arsenic concentrations in recovered waters at the site.
3. There is no apparent need for additional short-term ASR Cycle tests; rather, it was recommended that the next step for the project be to perform an initial injection period at the planned volume of recharge for long-term ASR operations at Beltz 8 (as practicable), followed by at least one month of storage and then recovery of the previously injected volume.

Given the findings developed from ASR Cycle 3a, it was recommended to not proceed with the previous planned ASR Cycle 3b, and rather implement a full season of injection at the well and recharge and recover as large a volume as possible during Water Year 2022 (depending on the availability of excess surface water for injection). This longer-term ASR cycle should include the implementation of a robust SAP, similar to that implemented during ASR Cycles 1 through 3, to confirm that the water-quality behavior is consistent with the current expectations.[13]

Beneficial Reactions

Water quality was also monitored during the recovery phases to evaluate the potential occurrence of "beneficial" reactions during aquifer storage. For this project, the native groundwater is demerited by the presence of manganese (Mn) of up to 0.2 mg/L, compared to the MCL of 0.05 mg/L. The Phase 1 geochemical interaction analysis identified a potential ancillary benefit of aquifer recharge with treated GHWTP water, which could be the reduction of manganese in the stored and recovered waters, perhaps persisting after 100 percent of the previously injected water has been recovered.

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[13] As a result of these findings and recommendations, the previously planned ASR Cycle 3b was not performed and Cycle 3a is simply referred to as Cycle 3 in the majority of this report.

Figure 46 presents manganese data for the stored and recovered water in ASR Cycle 3. As the graph shows, the presence of manganese in the stored water showed gradual increase during the storage period compared to the injected water, ending at a value of 0.037 mg/L. At the start of the recovery period, the concentration was approximately 0.029 mg/l and gradually increased during the recovery period, with the concentration exceeding the MCL 0.050 mg/L after approximately 7 days of pumping and 75 percent of the previously injected volume had been recovered. At the end of the recovery period and 150 percent of the previously injected volume had been recovered, the concentration was 0.140 mg/L.

These results compare to the native groundwater concentration of 0.200 mg/L, representing a significant improvement, and indicate that during future ASR operations at the well, the manganese concentrations will likely be improved compared to the native groundwater at the initial stages of recovery pumping periods due to mixing and dilution in the buffer zone around the well, but as pumping progresses beyond the previously injected volume, the concentrations can be expected to gradually increase back to native groundwater concentrations.

ASR CAPACITY ANALYSIS

Injection Capacity

The injection capacity of any given dual-purpose ASR well is dependent on a variety of site-specific factors, which can be generally categorized into issues associated with;

1) Well response to injection, and;
2) Aquifer response to injection.

Examples of issues associated with the well response include allowable drawup within the well casing before some head limitation is reached, and the available drawdown for well backflushing. Issues associated with aquifer response to injection involve the available "freeboard" in the aquifer for water levels (piezometric head) to be increased without inducing undesirable results. As part of the Phase 1 Technical Feasibility Investigation, PWR analyzed the various site-specific factors affecting the injection capacity of Beltz 8 and developed a theoretical injection capacity estimate of approximately 270 gpm, which was constrained by the "well response" criterion (for non-pressurized injection) [14].

Analysis of the results of the Beltz 8 well response to injection during the ASR pilot test program allows for an empirically based well response to injection capacity estimate utilizing similar methods applied to pumping capacity analysis presented above. The injection capacity of any given well is also a function of injection specific capacity (aka specific injectivity) and the available drawup in the well before some head limitation is reached. During injection, the water level (head) in the injection well and aquifer will increase due to mounding in the aquifer. The available "freeboard" for water level drawup in the well casing for injection is determined based on the depth to water prior to injection (static water level) plus the amount of wellhead pressurization considered reasonable (if any). For purposes of this analysis, it is conservatively

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[14] Pueblo Water Resources, Inc. (May 2017), *Task 1.2 Site-Specific Injection Capacity Analysis*, Technical Memorandum prepared for Santa Cruz Water Department.

assumed that no casing pressurization during injection will be allowed; therefore, the maximum drawup water-level in the well casing is at the ground surface.

Estimates of the injection capacity of Beltz 8 can be developed through analysis of the drawup curves for specific injection scenarios. As discussed previously, in the absence of plugging, the long-term hydraulic response of a well to injection is a logarithmic function and the drawup (and corresponding specific injectivity) for any given injection duration scenario can be reasonably predicted by extrapolating the time-drawdown curve with a straight line plotted on a semi-log plot (assuming the well is routinely backflushed to limit the effects of plugging during injection). The extrapolated specific injectivity is multiplied by available drawup to calculate the long-term injection capacity.

The anticipated ASR injection period for Beltz 8 is 6 months (i.e., during the period of excess available flows during the months of November through April). The water-level drawup curves for the initial week of injection (approximately 10,000 minutes) for ASR Cycles 2 and 3 injection tests[15] are shown on **Figures 47 and 48**, respectively. As shown on **Figure 47**, extrapolation of the ASR Cycle 2 injection test drawup curve results in an estimated 6-month injection water-level of approximately 7.6 ft bgs at an injection rate of 313 gpm, corresponding to a 6-month specific injectivity of 11.8 gpm/ft. Utilizing a conservative available drawup value of 30 feet yields a 6-month sustainable injection capacity of approximately 355 gpm (11.8 gpm/ft x 30 ft). As shown on **Figure 48**, similar extrapolation of the first week of the ASR Cycle 3 injection test drawup curve results in an estimated 6-month specific injectivity of 12.9 gpm/ft and a corresponding 6-month injection capacity estimate of approximately 390 gpm (12.9 gpm/ft x 30 ft). Based on these results, the estimated nominal injection capacity is approximately 375 gpm.

Pumping Capacity

The pumping capacity of any given well is a function of specific capacity and the available drawdown in the well. While this relationship seems relatively straightforward, it is complicated by the fact that both factors vary with the duration of pumping. In addition, available drawdown itself can vary, depending on the operational assumptions utilized in its calculation. The pumping capacity of an ASR well is somewhat unique in that it needs to be considered for the two different primary pumping duties it will need to perform during its service life:

1. Backflush pumping (short-term), and,
2. Recovery pumping (long-term)

An evaluation of the Beltz 8 capacity for each of these pumping duties is presented below:

Backflush Pumping Capacity. As discussed previously, no source of injection water is completely free of particulates; therefore, backflushing (i.e., pumping) of ASR wells must be routinely performed to create flow reversals in the well, which removes particles introduced into the well during injection (this is analogous to backwashing of media filters to clean the filter media). Periodic, vigorous backflushing is necessary to maintain injection capacity and remove the particulate loading of the gravel pack and well bore. The ability to adequately backflush ASR wells while maintaining a flooded perforated section, therefore, is a critically important

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[15] ASR Cycle 1 Injection Test as only 1-day in duration and, therefore, of less value for purposes of this analysis compared to the longer-duration ASR Cycles 2 and 3 Injection Tests.

consideration when designing and operating ASR wells. Based on experience at other injection and ASR wells, it has been shown that it is desirable to backflush injection wells at rates of at least two-times the rate of injection in order to maximize backflushing effectiveness. This is done to create pore throat velocities that are sufficient to remove particulates introduced during injection that have filled pore spaces and cling to grains of sand; therefore, for an injection rate of 375 gpm a backflush pumping capacity of 750 gpm is recommended.

Backflush pumping is typically a short-duration operation of one hour (or less); therefore, estimating the backflushing capacity by multiplying the 24-hour specific capacity by the entire available drawdown is a conservative way to account for variations in aquifer water levels and gradual losses in well efficiency that may occur over the life cycle of the well. The best operational practice for pumping wells is to maintain pumping water levels above the perforations in order to avoid cascading water conditions, which can result in air entrainment and increased wear on the pump and discharge piping. The maximum available drawdown in the well is, therefore, typically defined to be the amount of water above the top of the screen.

The available drawdown at Beltz 8 is approximately 65 feet, based on the top of screen at 100 feet bgs and a conservative static water level of approximately 35 feet bgs. As presented previously, Beltz 8 displays a 24-hour specific capacity of approximately 17 gpm/ft, which yields a theoretical backflushing capacity estimate of approximately 1,100 gpm, exceeding the recommended capacity of 750 gpm.

It is noted that the actual well pumping capacity is practically limited by the capacity of the pump that is installed in the well. The currently installed Beltz 8 25 HP pump (Grundfos 385S250-3) is limited to a pumping capacity of approximately 520 gpm @ 100 ft of total dynamic head (TDH); therefore, a larger capacity pump would be needed for an injection rate of 375 gpm and an associated backflushing capacity of 750 gpm.

Recovery Pumping Capacity. While no strict guidelines exist for determining the recommended long-term pumping rates for wells, a typical rule-of-thumb for estimating the long-term production rate of a well completed in semi-consolidated sediments is to multiply the 24-hour specific capacity by two-thirds of the available drawdown. Utilizing two-thirds of the available drawdown is a conservative way to account for variations in pumping durations, seasonal changes (long-term or short-term) in aquifer water levels, and gradual losses in well efficiency that may occur over the life cycle of the well.

As discussed above, the available drawdown in Beltz 8 is estimated to be 65 feet. Two-thirds of the available drawdown of 65 feet is approximately 43 feet, which yields a theoretical recovery pumping capacity estimate of approximately 730 gpm (17 gpm/ft x 43 feet).

ASR Capacity Summary

In summary, based on analysis of the ASR pilot test data the estimated nominal injection capacity of Beltz 8 is approximately 375 gpm and the nominal recovery pumping capacity is estimated at approximately 730 gpm.

It is noted that these are the estimated injection and pumping capacities of the Beltz 8 well itself based on analysis of empirically derived site-specific data, without considering the effects of mutual well interference from multiple ASR wells operating simultaneously and/or aquifer boundary conditions on basin water-levels that may limit available drawup/drawdown at the Beltz 8 site and/or impact coastal monitoring wells. Groundwater modeling is required to evaluate the capacities of an ASR wellfield that can be sustained under various climatic and ASR project operational scenarios, while also maintaining coastal water levels within the Sustainable Management Criteria (SMCs) established by the GSP.

In the absence of groundwater modeling of various ASR operational scenarios under differing basin conditions to optimize the range of injection and recovery pumping rates that may be potentially feasible, based on the results of the Phase 1 investigation groundwater modeling performed previously and experience at other ASR wells in the MGB and elsewhere in coastal California, the following relationships between the nominal injection capacity and the associated pumping capacities are recommended for Beltz 8 for planning and facility design purposes:

- Injection Capacity: **375 gpm**
- Recovery Pumping Capacity (1.5 times the injection capacity): **565 gpm**
- Backflush Pumping Capacity (2.0 times the injection capacity): **750 gpm**

CONCLUSIONS

Based on our evaluation of the data and findings developed from the Beltz 8 ASR pilot test program, we conclude the following:

WELL AND AQUIFER HYDRAULICS

Analysis of the ASR pilot testing program results showed the following key findings:

- The nominal injection rate of Beltz 8 is estimated to be approximately 375 gpm (0.54 mgd) while maintaining water levels below ground surface. On a seasonal storage basis, this is equivalent to injecting approximately 100 million gallons (mg) of surplus water over a 6-month injection season.
- The nominal recovery pumping capacity is estimated at approximately 730 gpm; however, in the absence of groundwater modeling to determine the potential impacts on water levels at the coast, a rate of 565 gpm (i.e., 1.5 times the injection rate) is considered reasonable for conservative planning purposes. This recovery pumping rate is equivalent to approximately 590 mg over a 2-yr drought period.
- The well has a theoretical backflushing capacity of approximately 1,100 gpm, which is approximately three-times the estimated injection capacity of 375 gpm and, therefore, exceeds the needed backflushing capacity of 750 gpm (i.e., two-times the injection rate).
- Observed active plugging rates during injection were relatively low, averaging approximately 0.215 ft/d (normalized rate of 0.075 ft/d). The low plugging rates are due largely to the low particulate content (as measured by Silt Density Index) and maintenance of pH below 7.6 in the GHWTP injection source water.
- Residual plugging of Beltz 8 observed at the end of the ASR pilot test program was insignificant, indicating that the weekly double-backflush routine implemented during ASR pilot testing was effective at maintaining overall well performance.
- The observed responses of the aquifer system to injection at various rates and durations at Beltz 8 were generally greater than the expected responses; however, water levels in the aquifer system were maintained below ground surface at all times, indicating that the aquifer system is capable of receiving recharge at Beltz 8 without undesirable results (i.e., groundwater “daylighting” at the ground surface).

WATER QUALITY

The Beltz 8 ASR pilot test program results were in general agreement with the geochemical interaction analysis performed by PWR as part of the Phase 1 Technical Feasibility Investigation, and generally indicated the following key findings:

- The use of GHWTP produced waters appears to be suitable for ASR operations utilizing A Unit of the Purisima Aquifer system at the Beltz 8 site.
- The program results verified that stored waters maintained full Title 22 compliance at the conclusion of all three ASR Cycles, both in waters stored in the aquifer and in the recovered waters.

- The generally low levels of active well plugging during ASR operations, and the restoration of well performance after well backflushing, support the lack of well and/or aquifer porosity plugging due to adverse water-quality reactions.
- Disinfection Byproducts showed a very favorable degradation reaction during aquifer storage, with no apparent ingrowth period and both TTHMs and HAAs steadily degrading to near non-detect levels within 40 days of cessation of injection.
- Arsenic concentrations in the recovered waters were shown to have been elevated relative to pre-injection concentrations in the native groundwater resulting from the dissolution of obsidian and pyrite minerals in the aquifer matrix, which are believed to harbor trace amounts of arsenic.
- Although arsenic leaching was observed, the concentrations did not exceed the MCL of 10 ug/L and were observed to decrease through the successive ASR pilot test cycles. In addition, the availability of arsenic in the aquifer matrix is expected to be incrementally reduced with repeated ASR cycles, such that repeated ASR cycles are likely to result in progressively lower arsenic concentrations in the recovered waters.
- No leaching of any other regulated metals or other constituents of concern was observed.
- The evaluation of changes in other water-quality constituents during ASR pilot testing were found to be predominantly the result of simple dilution/mixing mechanisms, further supporting the lack of significant geochemical interaction.
- Overall, the test program results did not identify any fatal flaws or critical issues with respect to water quality that would jeopardize the feasibility of long-term ASR program implementation.

RECOMMENDATIONS

Based on the findings and conclusions developed from the Beltz 8 ASR pilot test program, and our experience with similar ASR projects, we offer the following recommendations:

- For planning and facility design purposes, we recommend the following nominal ASR capacities for Beltz 8:
    - Injection rate: 375 gpm
    - Recovery pumping rate: 565 gpm
    - Backflush pumping rate: 750 gpm
- Given the favorable results of the ASR pilot test program, Beltz 8 should be converted to a permanent ASR facility, which will require the following minimum items:
    a) Compliance with CEQA requirements for a permanent ASR project at the site.
    b) Filing of a Notice of Intent (NOI) to operate the facility as a permanent ASR facility with the Central Coast RWQCB under the Statewide General ASR Order (Water Quality Order 2012-0010). The results of the subject ASR pilot test

will provide the information needed to support an NOI application for a permanent ASR facility.

   c) Replacement of the existing 25 HP pumping with a higher capacity pump capable of up to approximately 750 gpm (30 to 40 HP depending on TDH assumptions) for both backflushing to maintain injection capacity and for recovery pumping. The pump should be equipped with a variable frequency drive (VFD) to allow for operational flexibility over a range of pumping rates.
   d) Installation of a downhole flow control valve (FCV) on the existing permanent pump assembly (either a Baski Valve or V-Smart Valve) for controlling injection flows into the well.
   e) Modifications to the site facility's piping, valving and metering to allow injection at the well (via the pump column and a new FCV) using source water from the SCWD distribution system.

- During injection periods, routine backflushing at 750 gpm (i.e., two-times the injection rat) should be performed on a weekly basis (minimum) to limit residual plugging and maintain long-term well performance. The backflushing procedure should consist of the same double-backflush procedure developed for and implemented during the ASR pilot test program.
- Permanent ASR operations at the well should include ongoing monitoring for geochemical interactions during aquifer storage and ASR recovery, with particular focus on long-term water-quality interactions such as solubilization/leaching of arsenic and DBP fate processes. An appropriate Sampling and Analysis Plan (SAP) should be developed and included in the NOI for a permanent ASR facility.
- The calibration of the existing groundwater flow model of the MGB should checked by comparing model predicted water level responses to the Beltz 8 ASR pilot test operations to the observed basin water level responses. If necessary, the model should be recalibrated and various ASR project operational scenarios of interest to the SCWD performed with the recalibrated model, as warranted.

CLOSURE

This report has been prepared exclusively for the Santa Cruz Water Department for the specific application to the Beltz 8 ASR Pilot Test Project. The findings, conclusions, and recommendations presented herein were prepared in accordance with generally accepted hydrogeologic practices. No other warranty, express or implied, is made.

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FIGURES

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Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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N
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S

1 inch = 50 feet

0 25 50 100
Feet

FIGURE 1. SITE LOCATION MAP
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

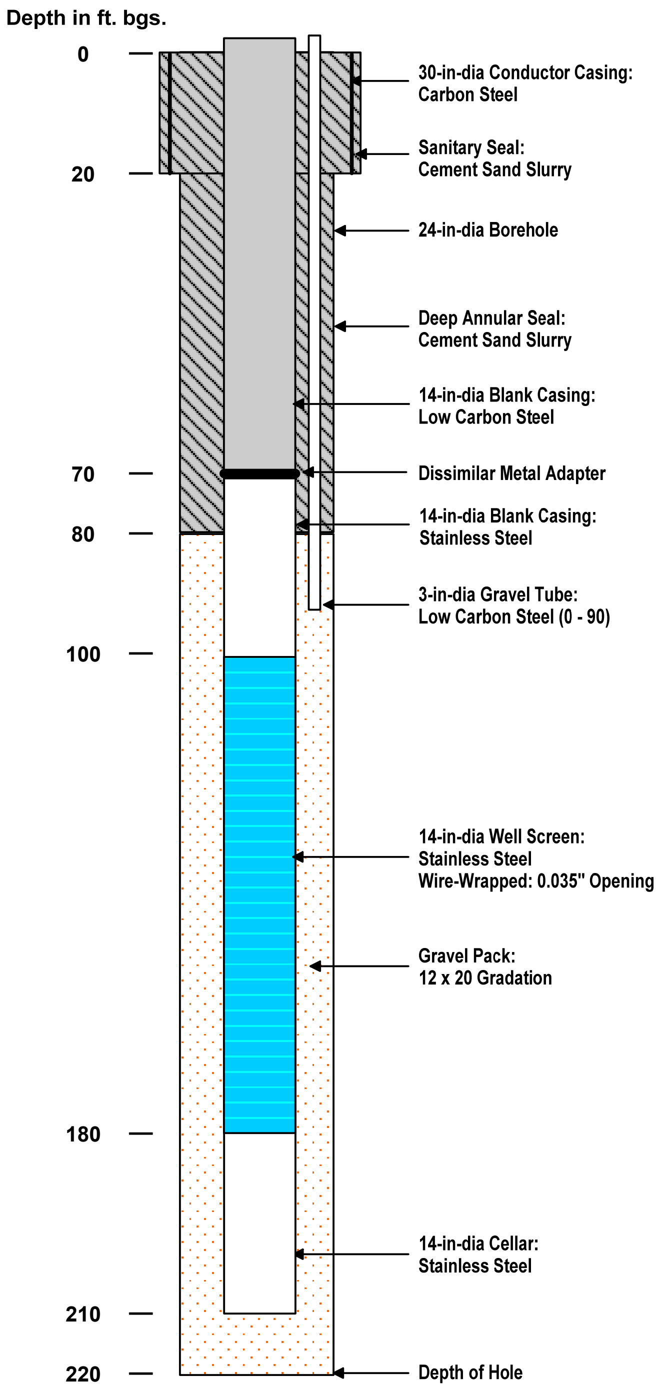

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FIGURE 2. AS-BUILT WELL SCHEMATIC
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

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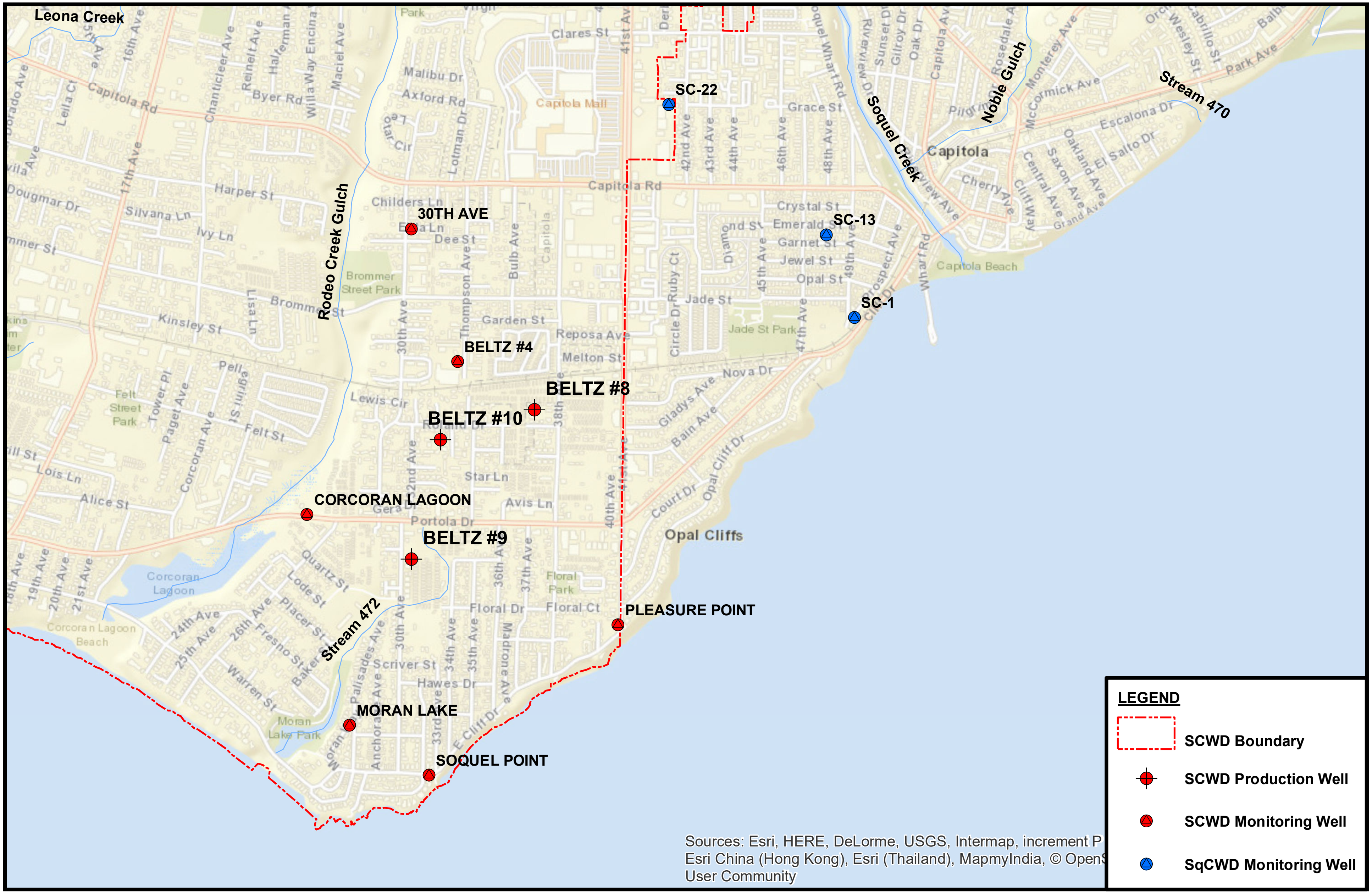
Project No. 15-0113



N
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1 inch = 1,500 feet

0 750 1,500 3,000 Feet

FIGURE 3. WELL LOCATION MAP
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

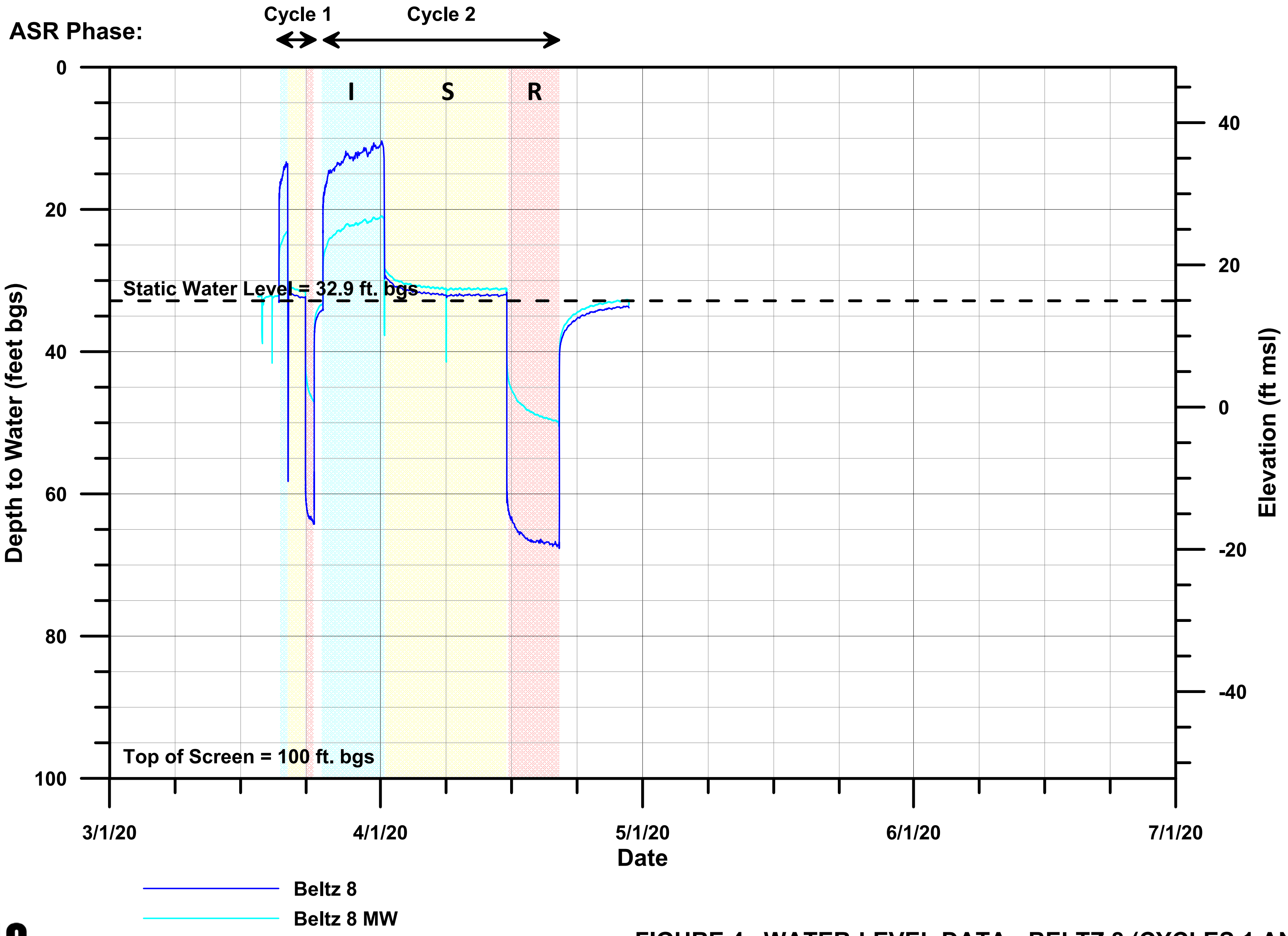

FIGURE 4. WATER-LEVEL DATA - BELTZ 8 (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

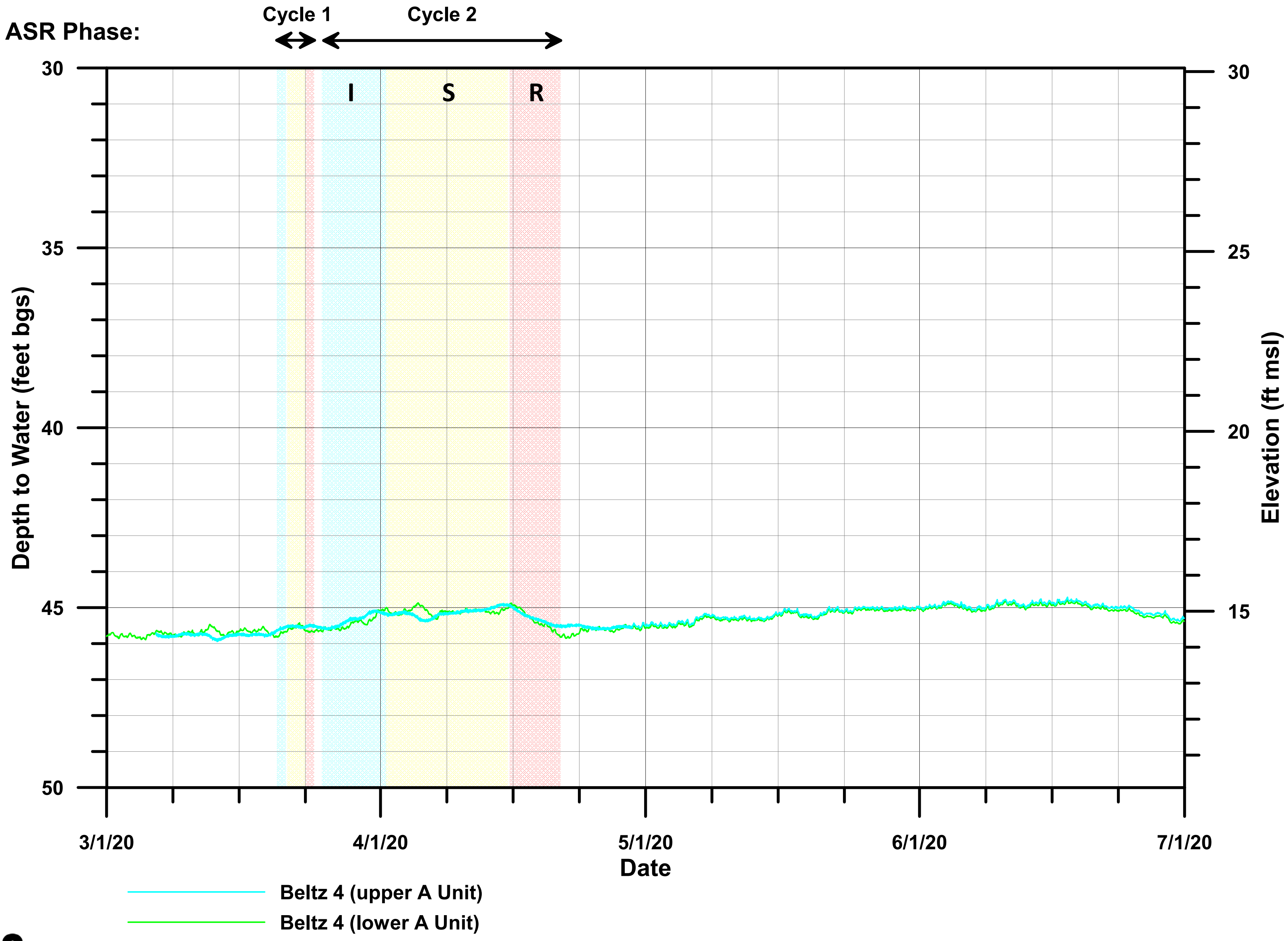

FIGURE 5. WATER-LEVEL DATA - BELTZ 4 (CYCLES 1 AND 2)
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Santa Cruz Water Department

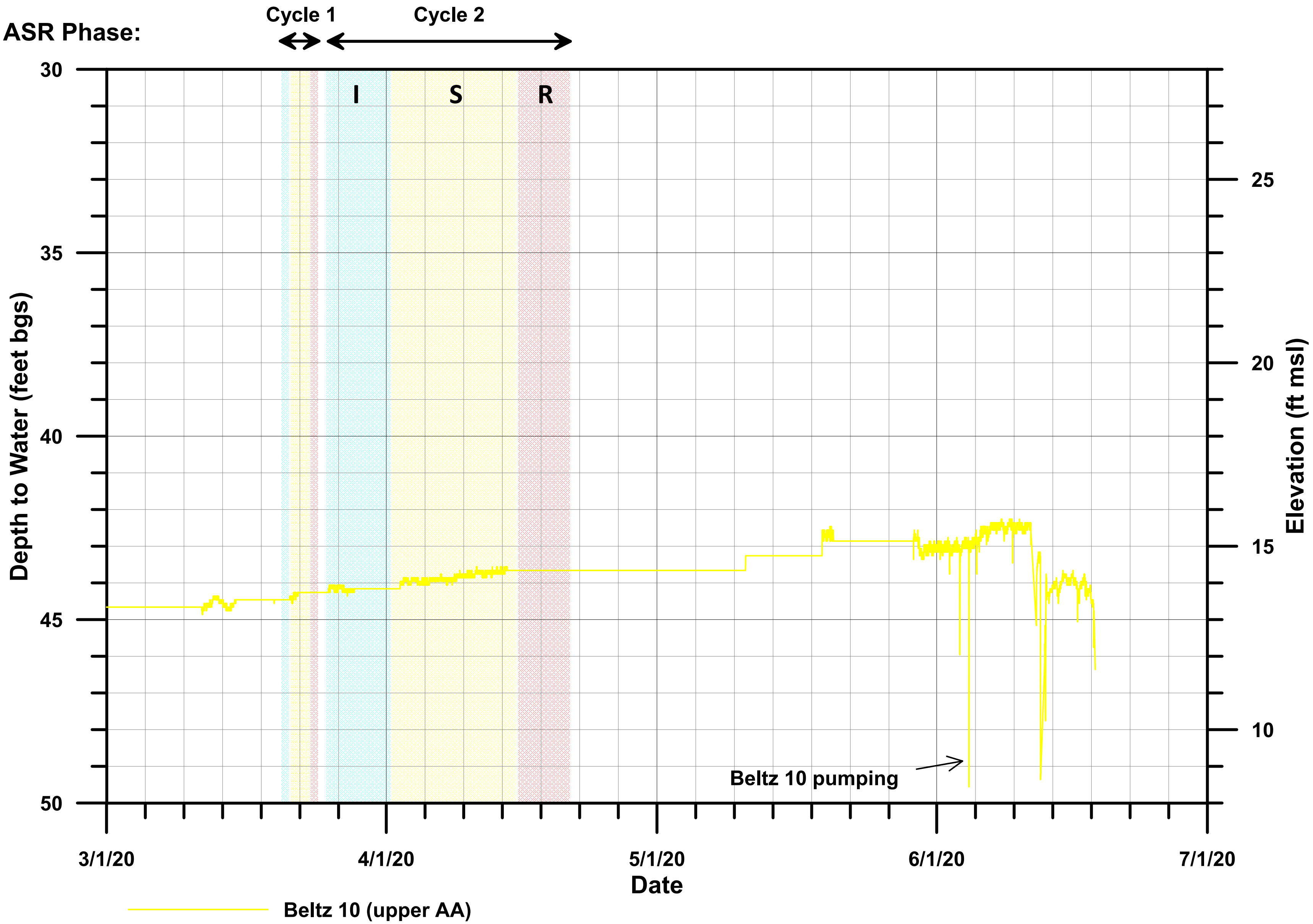

FIGURE 6. WATER-LEVEL DATA - BELTZ 10 (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

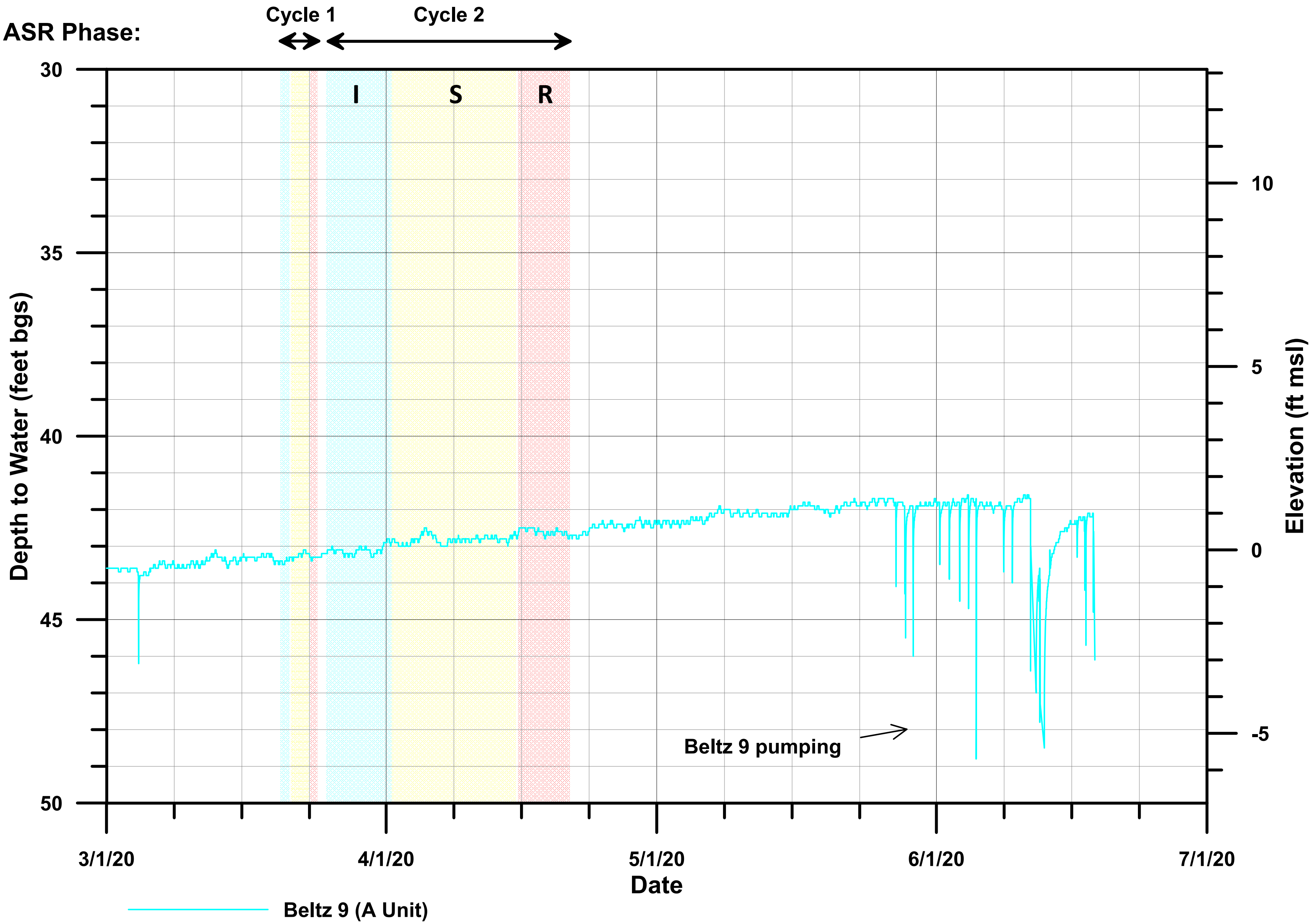

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FIGURE 7. WATER-LEVEL DATA - BELTZ 9 (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

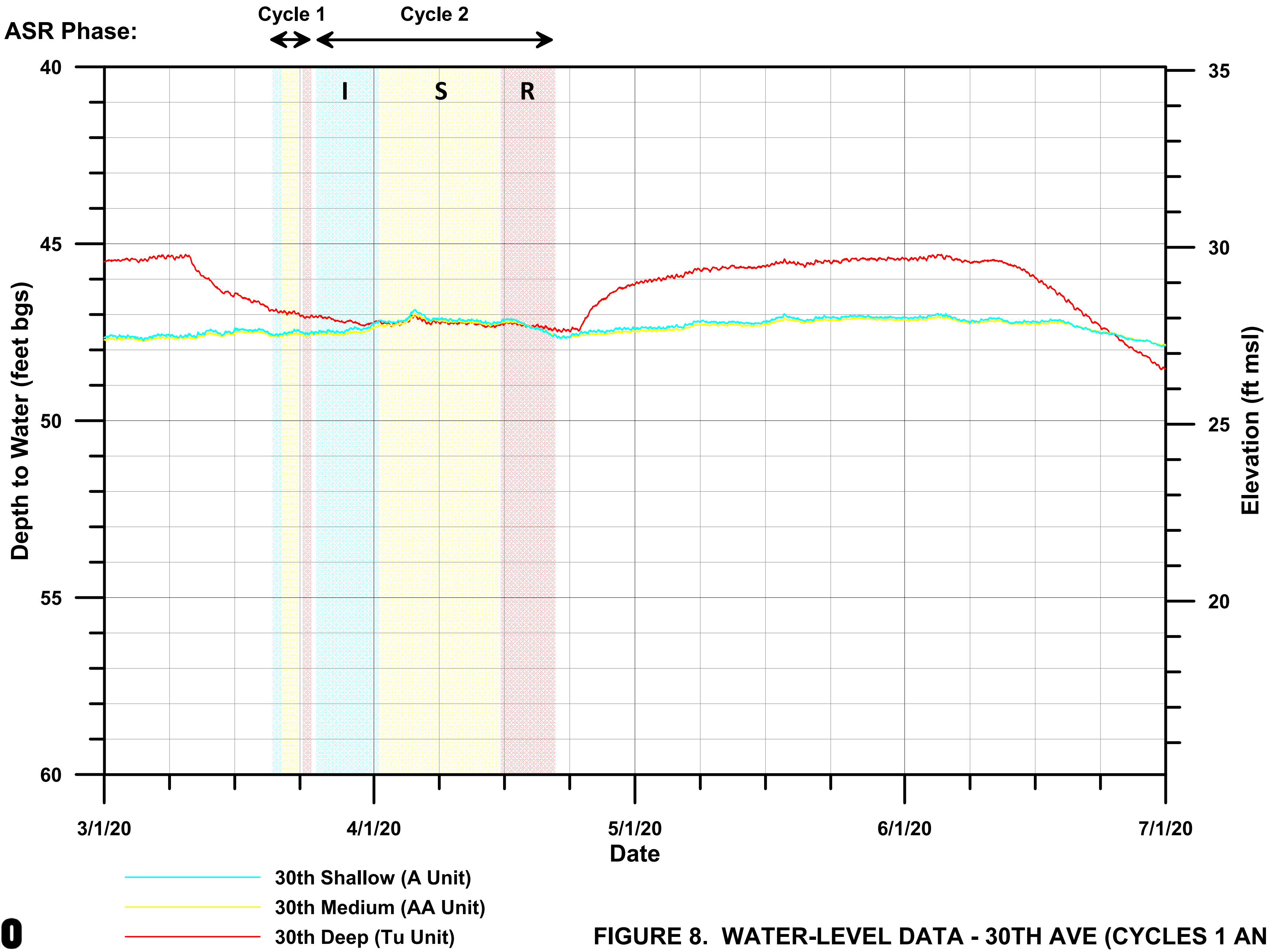

FIGURE 8. WATER-LEVEL DATA - 30TH AVE (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

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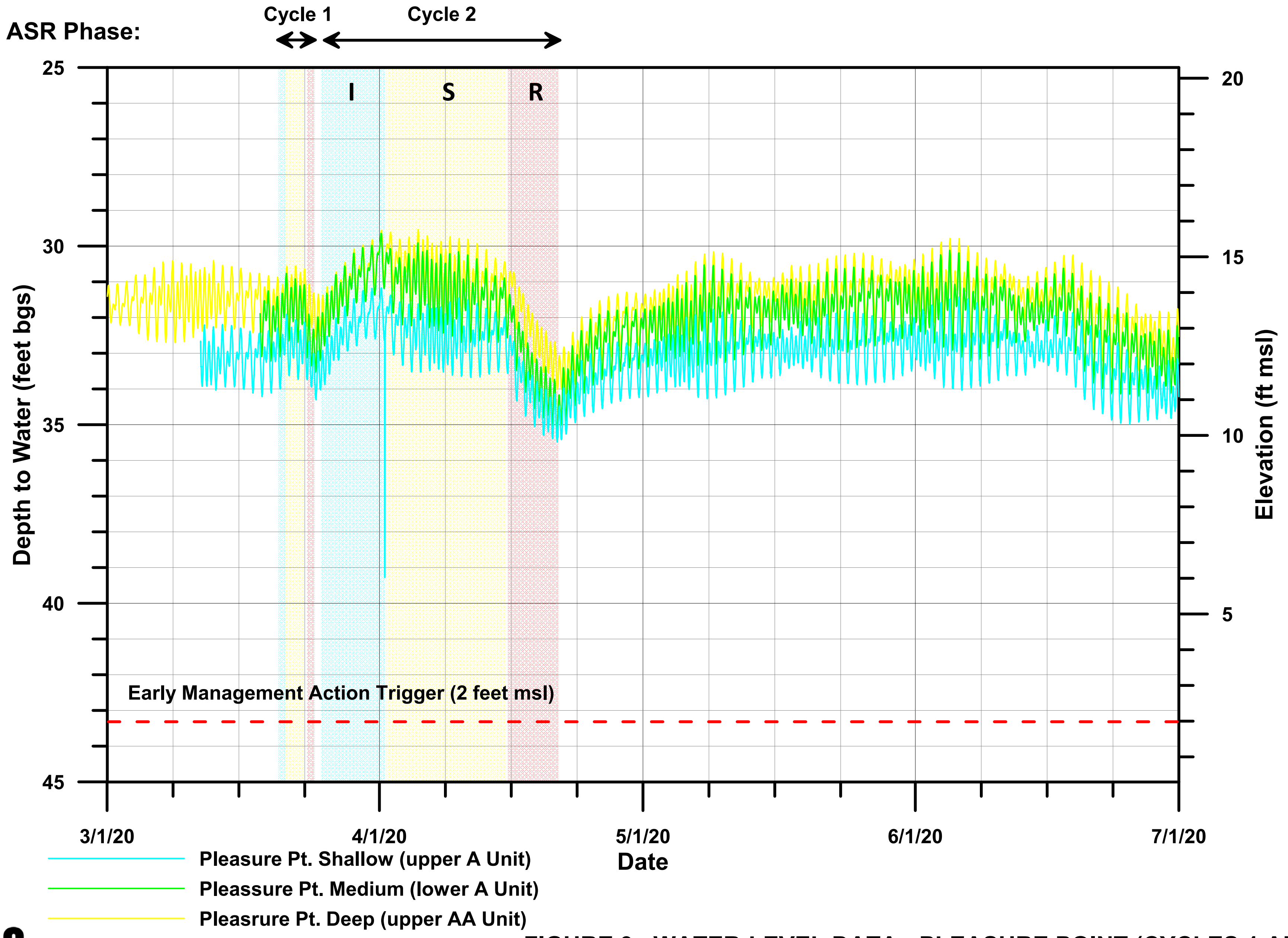

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FIGURE 9. WATER-LEVEL DATA - PLEASURE POINT (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

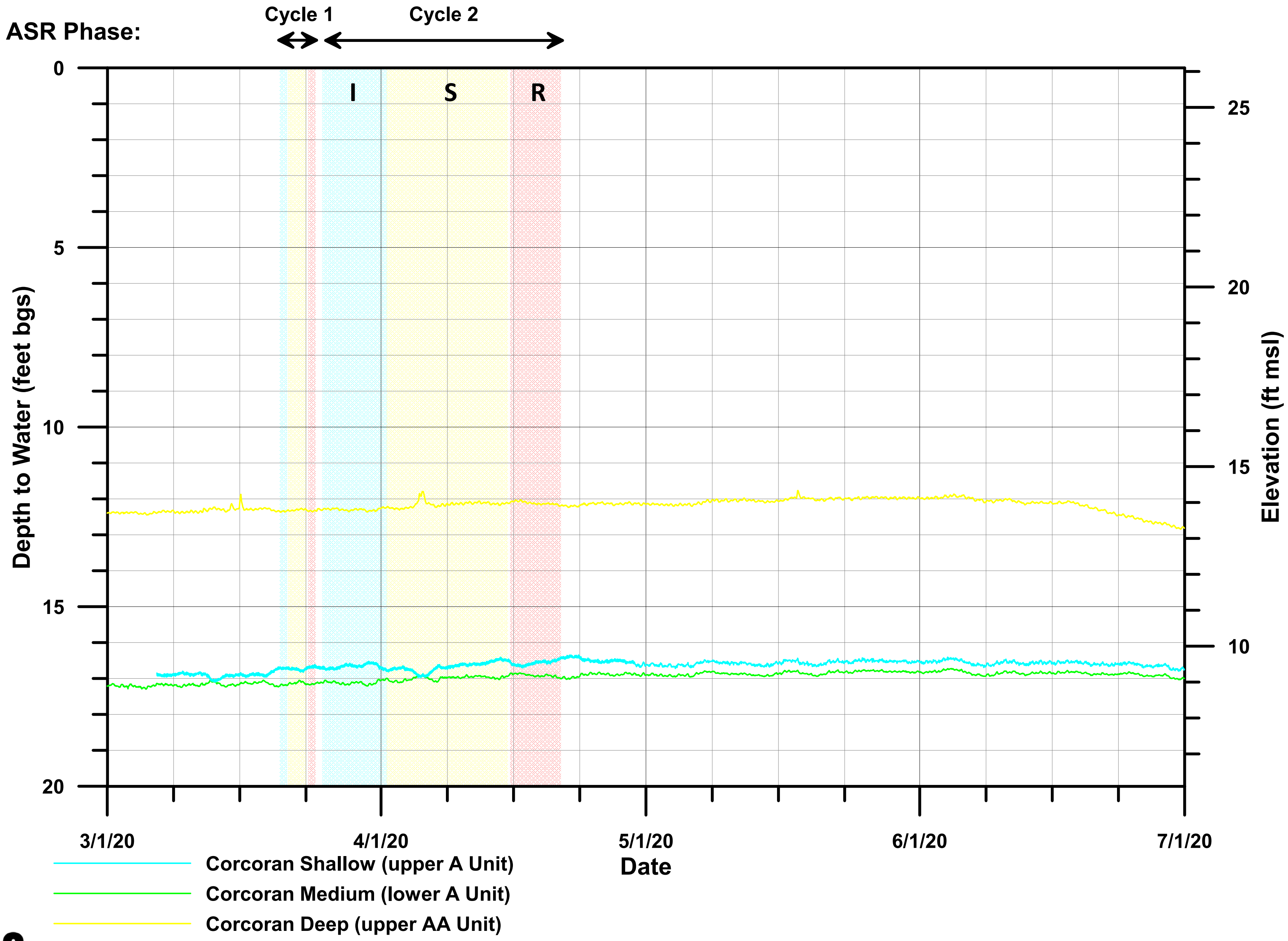

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FIGURE 10. WATER-LEVEL DATA - CORCORAN LAGOON (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

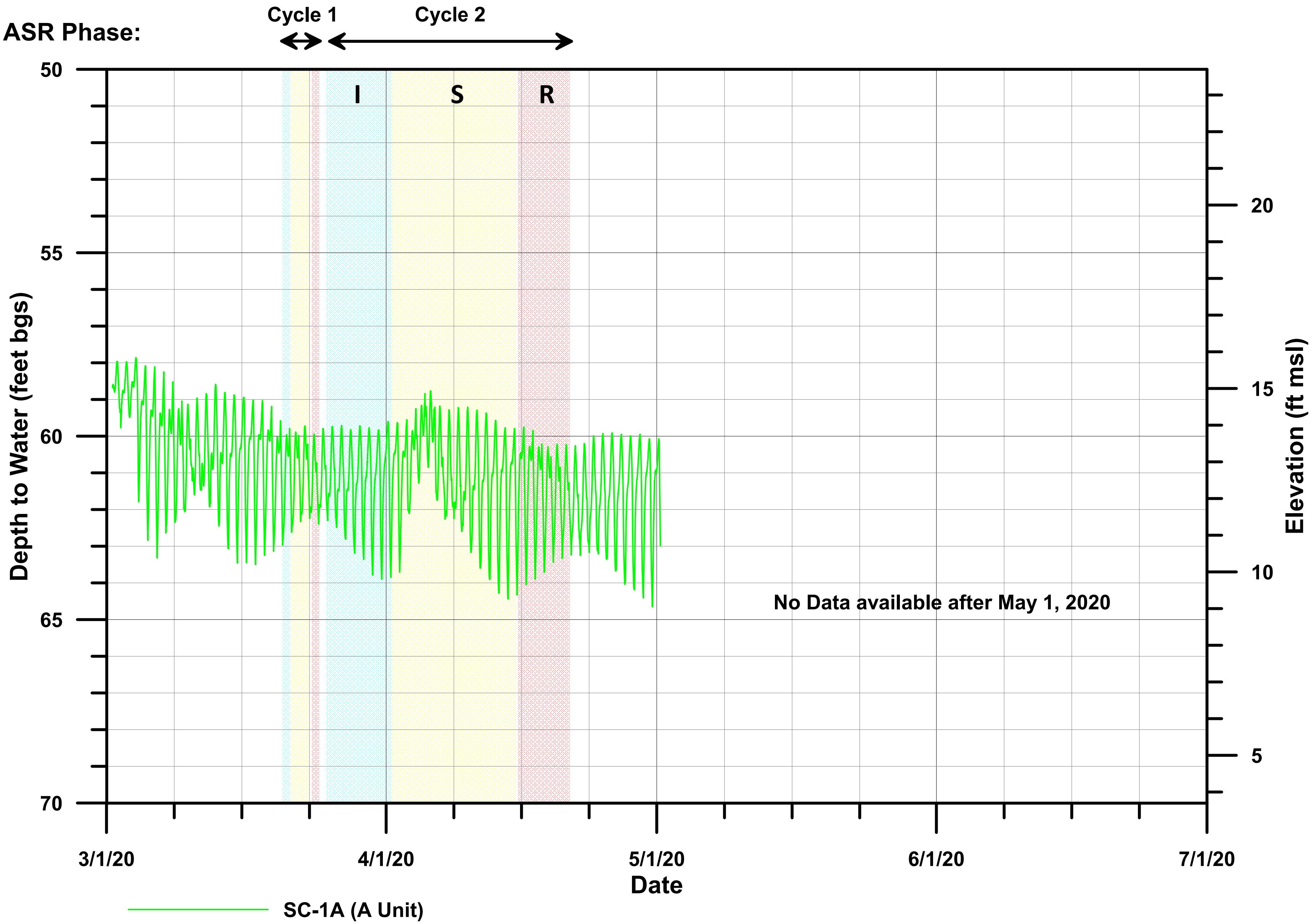

FIGURE 11. WATER-LEVEL DATA - SC-1A (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

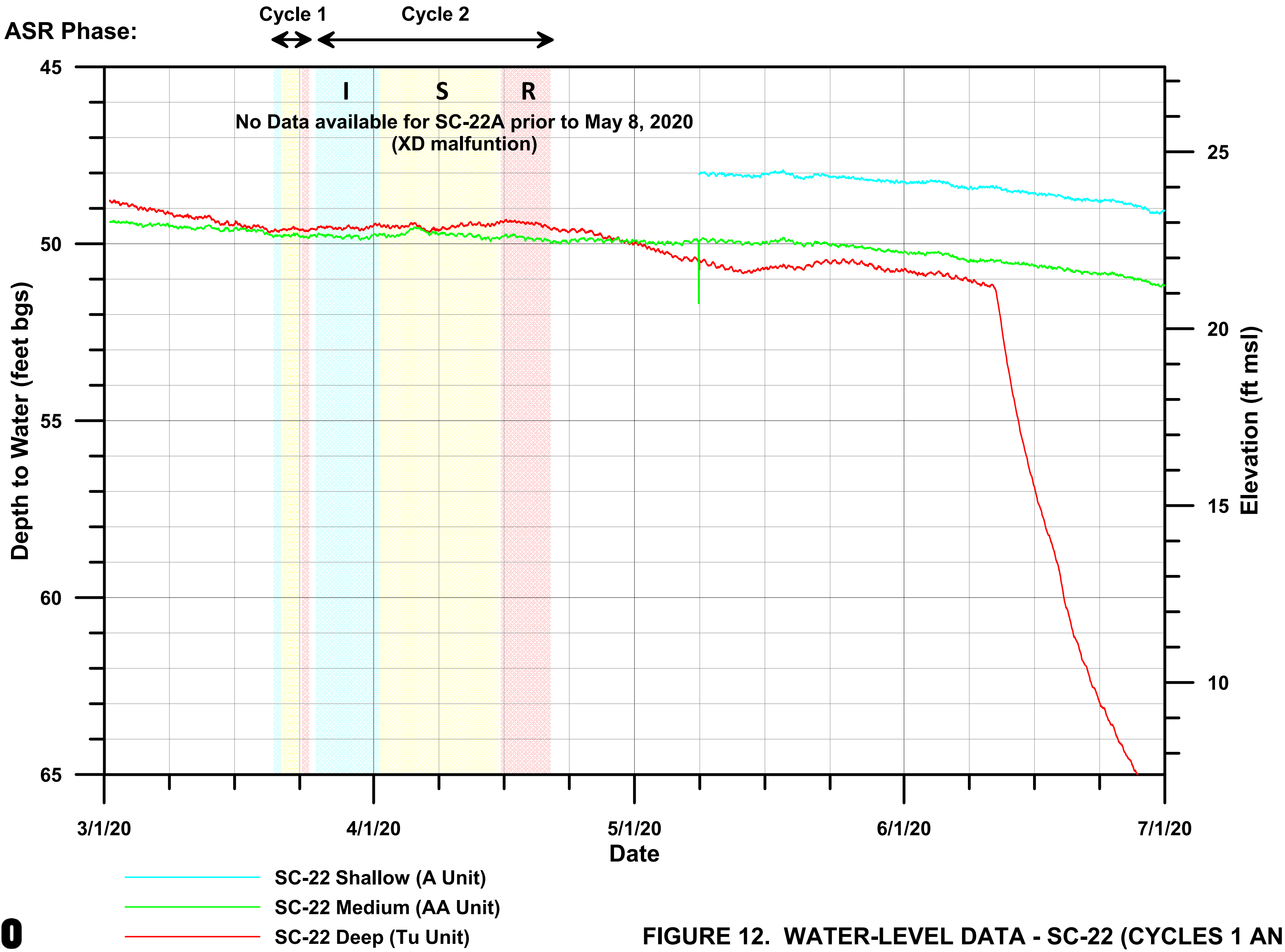

FIGURE 12. WATER-LEVEL DATA - SC-22 (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

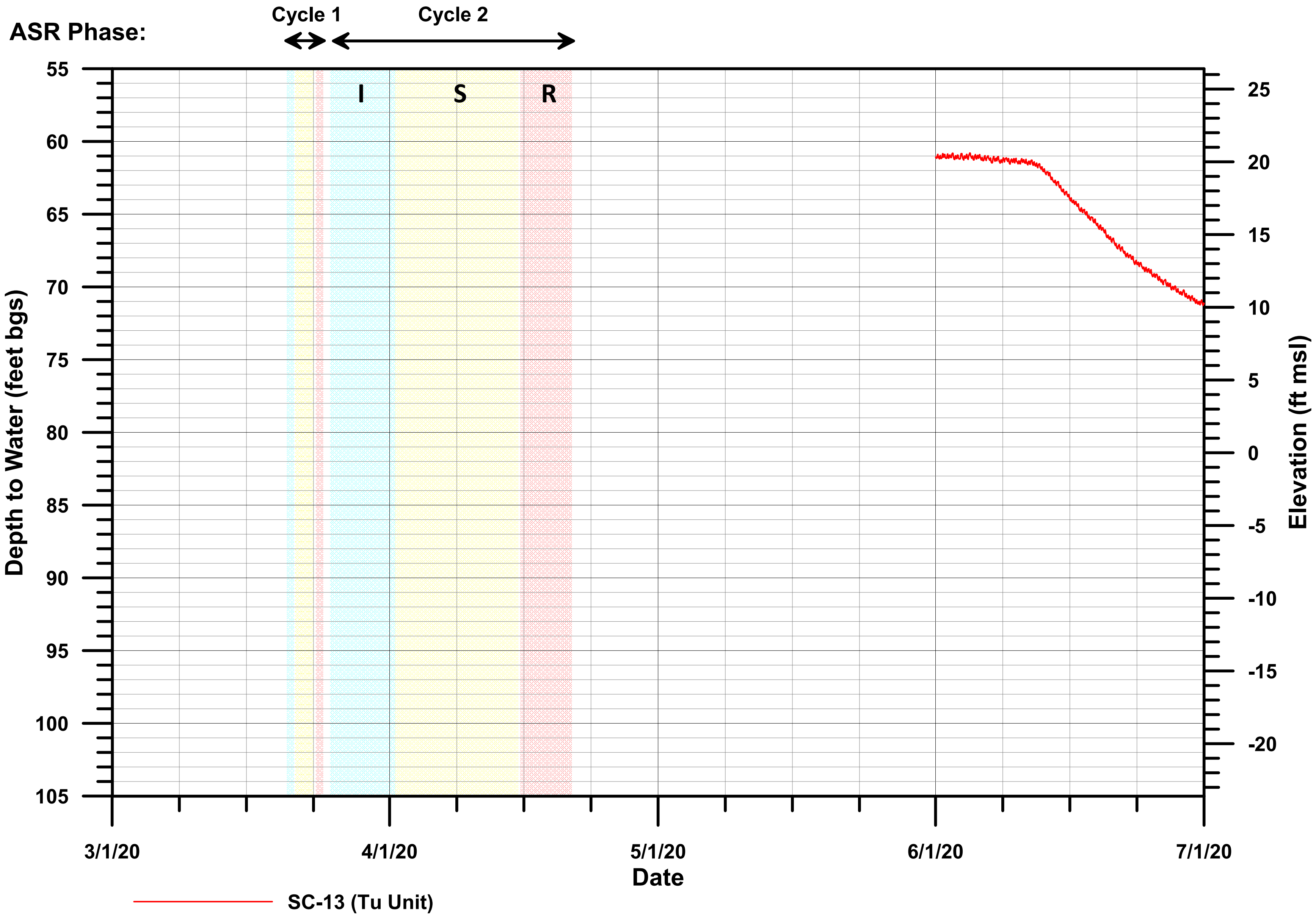

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FIGURE 13. WATER-LEVEL DATA - SC-13 (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

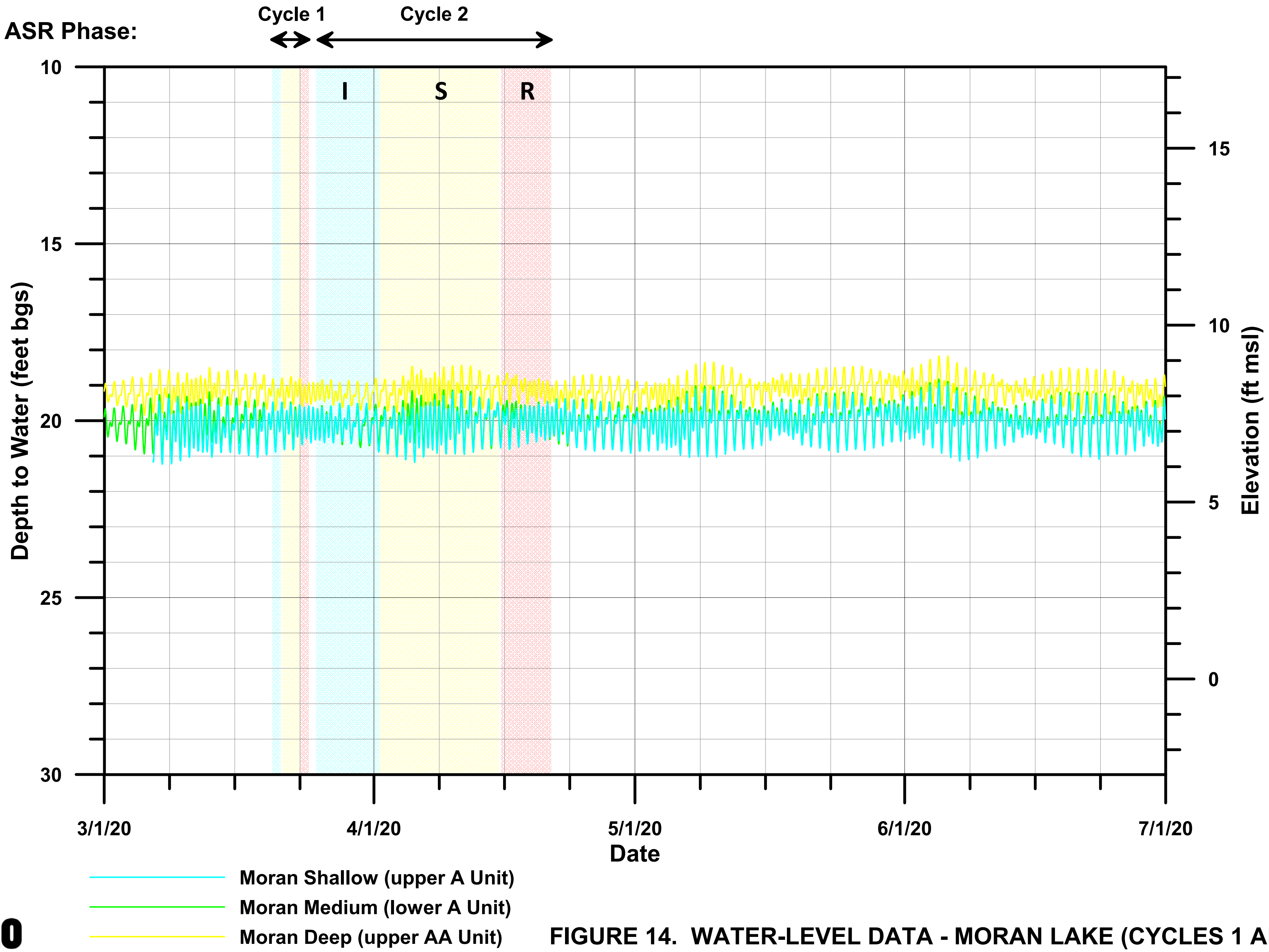

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FIGURE 14. WATER-LEVEL DATA - MORAN LAKE (CYCLES 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

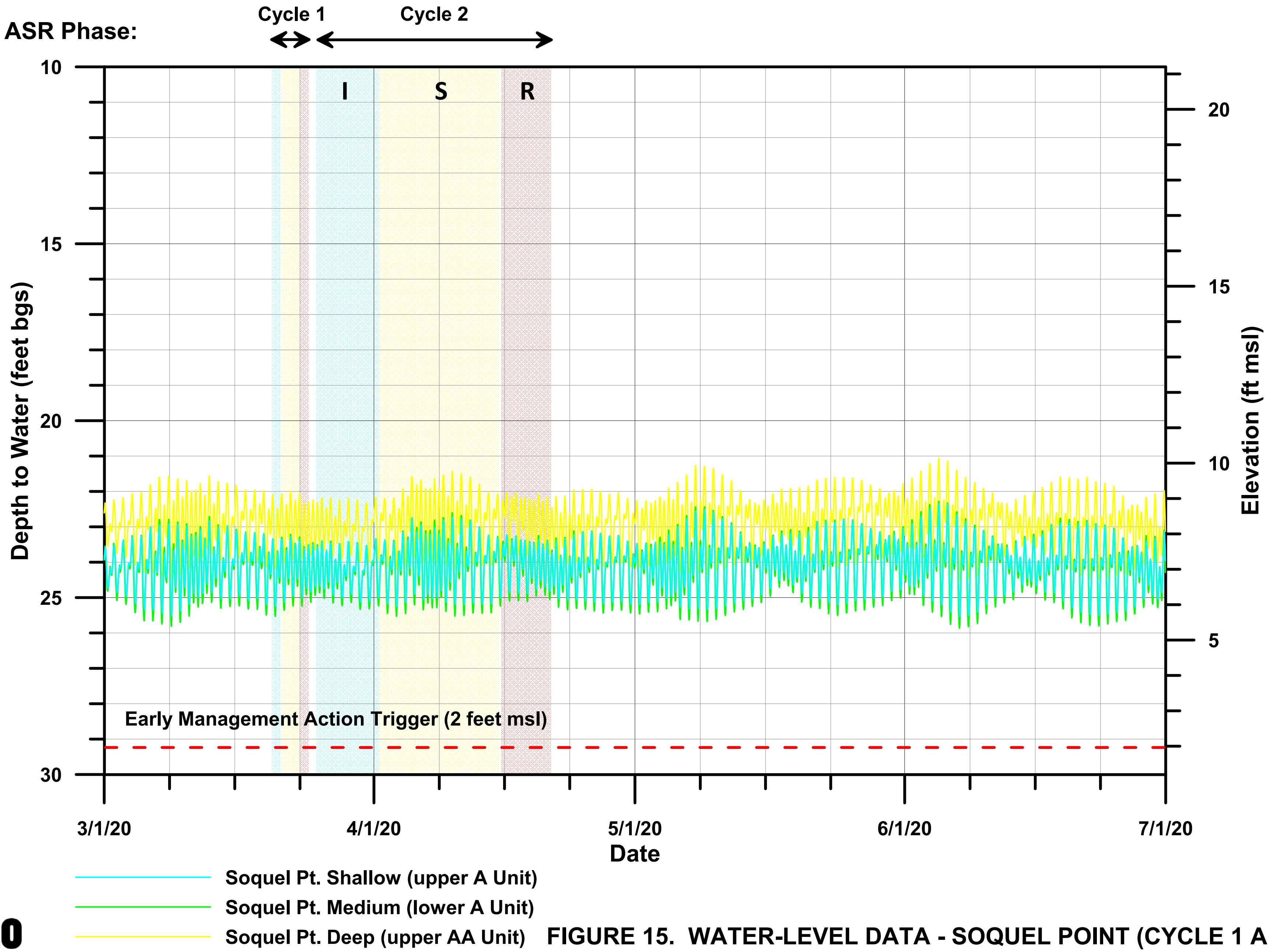

FIGURE 15. WATER-LEVEL DATA - SOQUEL POINT (CYCLE 1 AND 2)
Phase 2 ASR Pilot Test - Beltz 8
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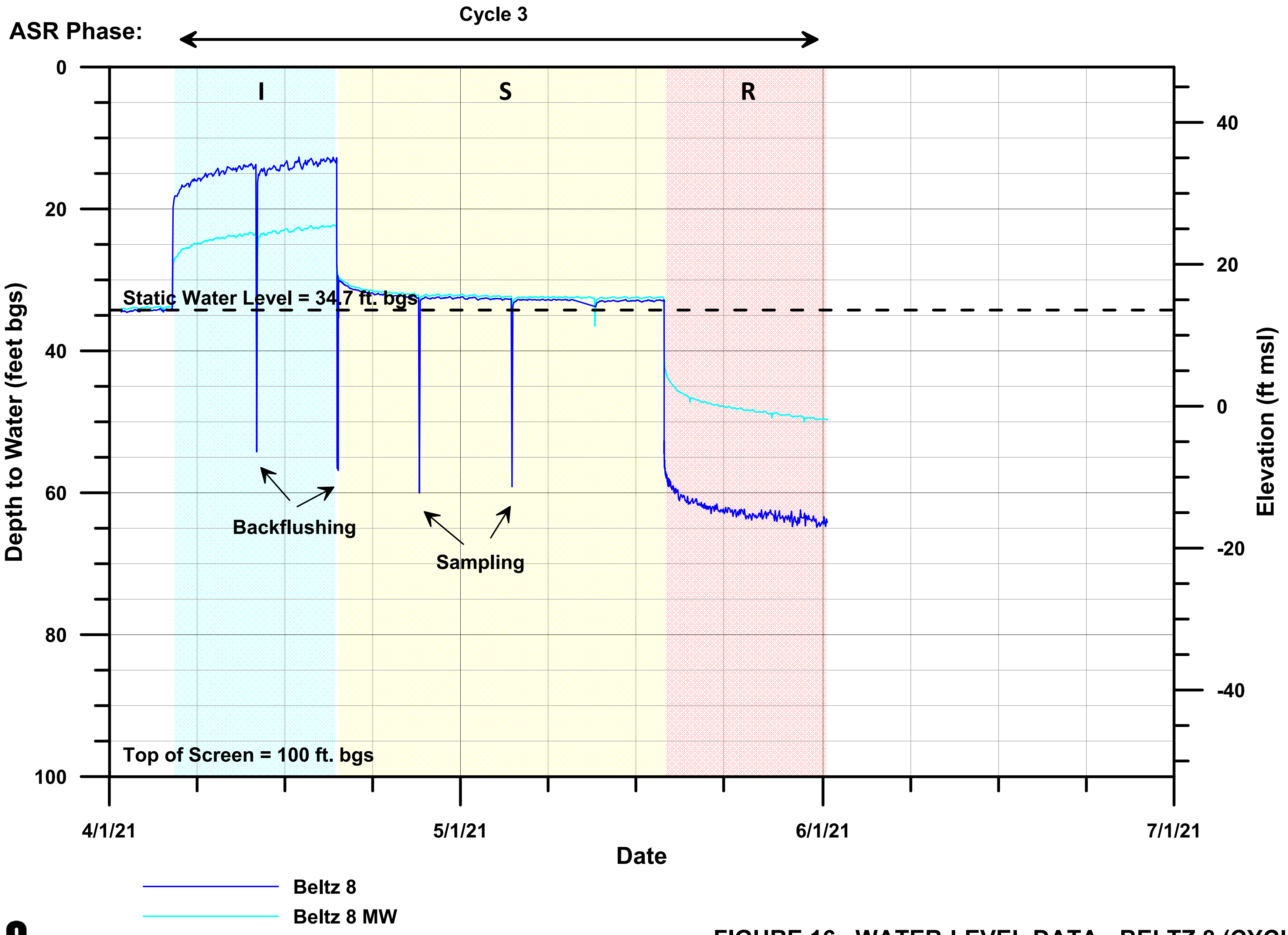

FIGURE 16. WATER-LEVEL DATA - BELTZ 8 (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

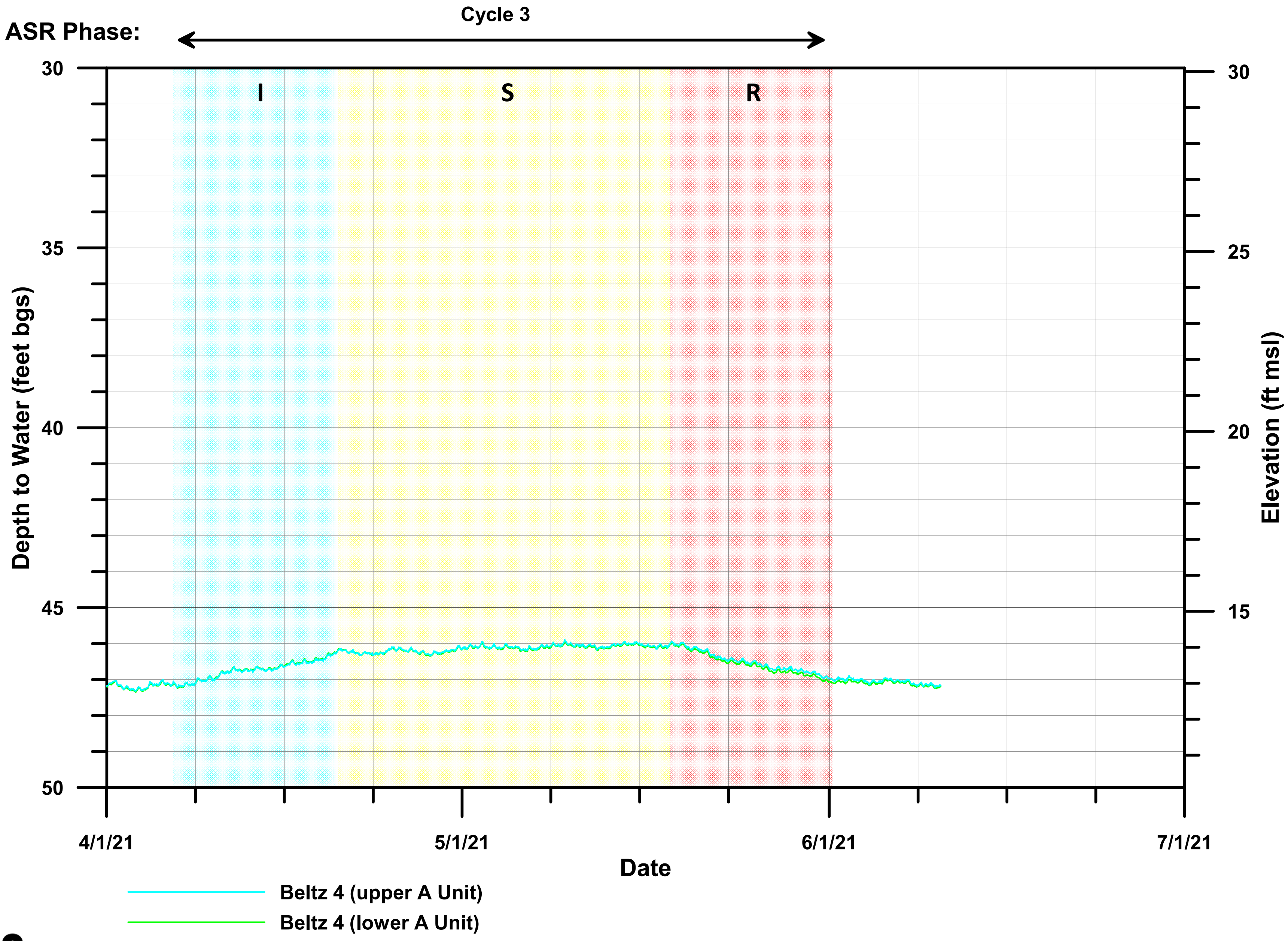

FIGURE 17. WATER-LEVEL DATA - BELTZ 4 (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

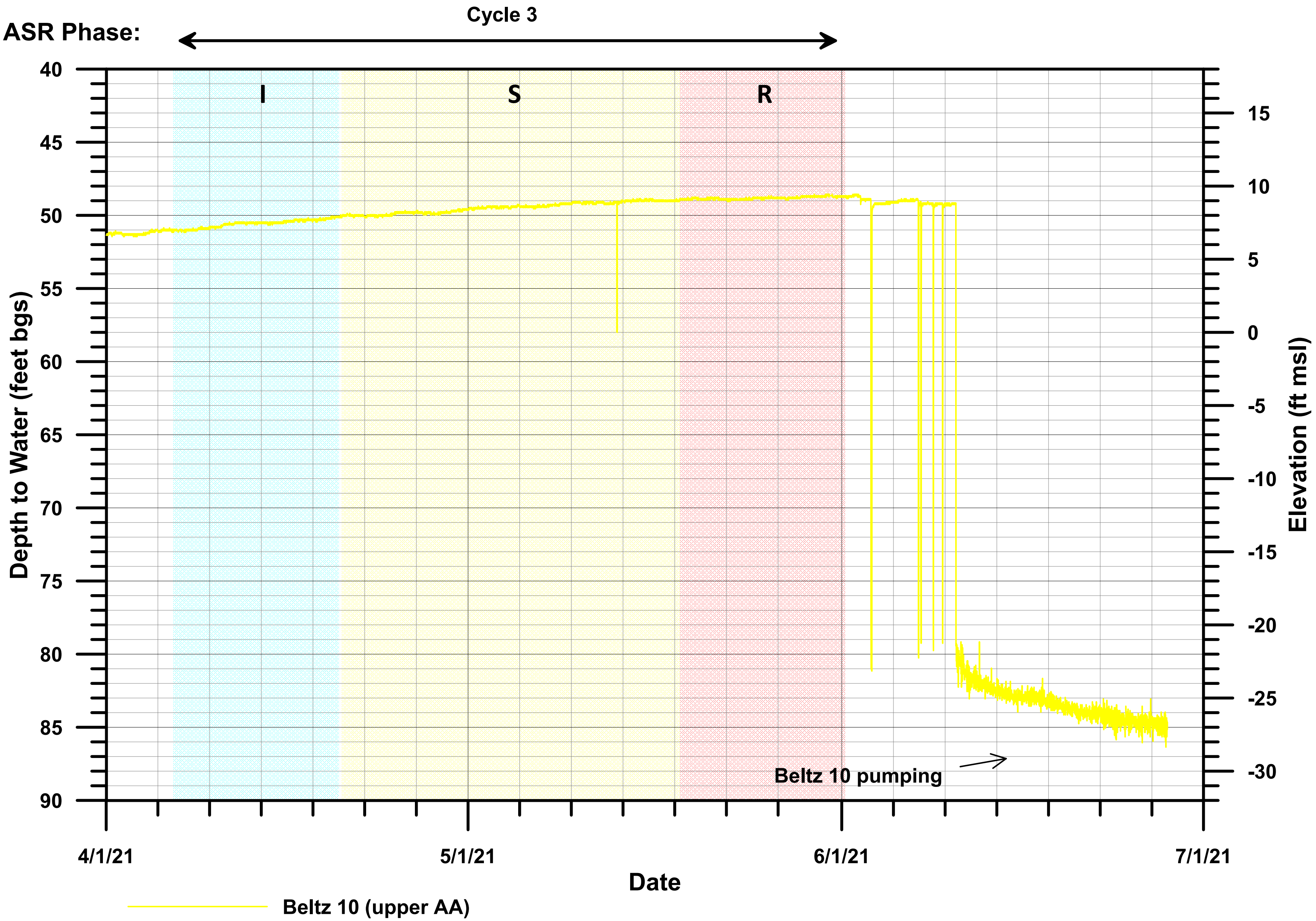

FIGURE 18. WATER-LEVEL DATA - BELTZ 10 (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

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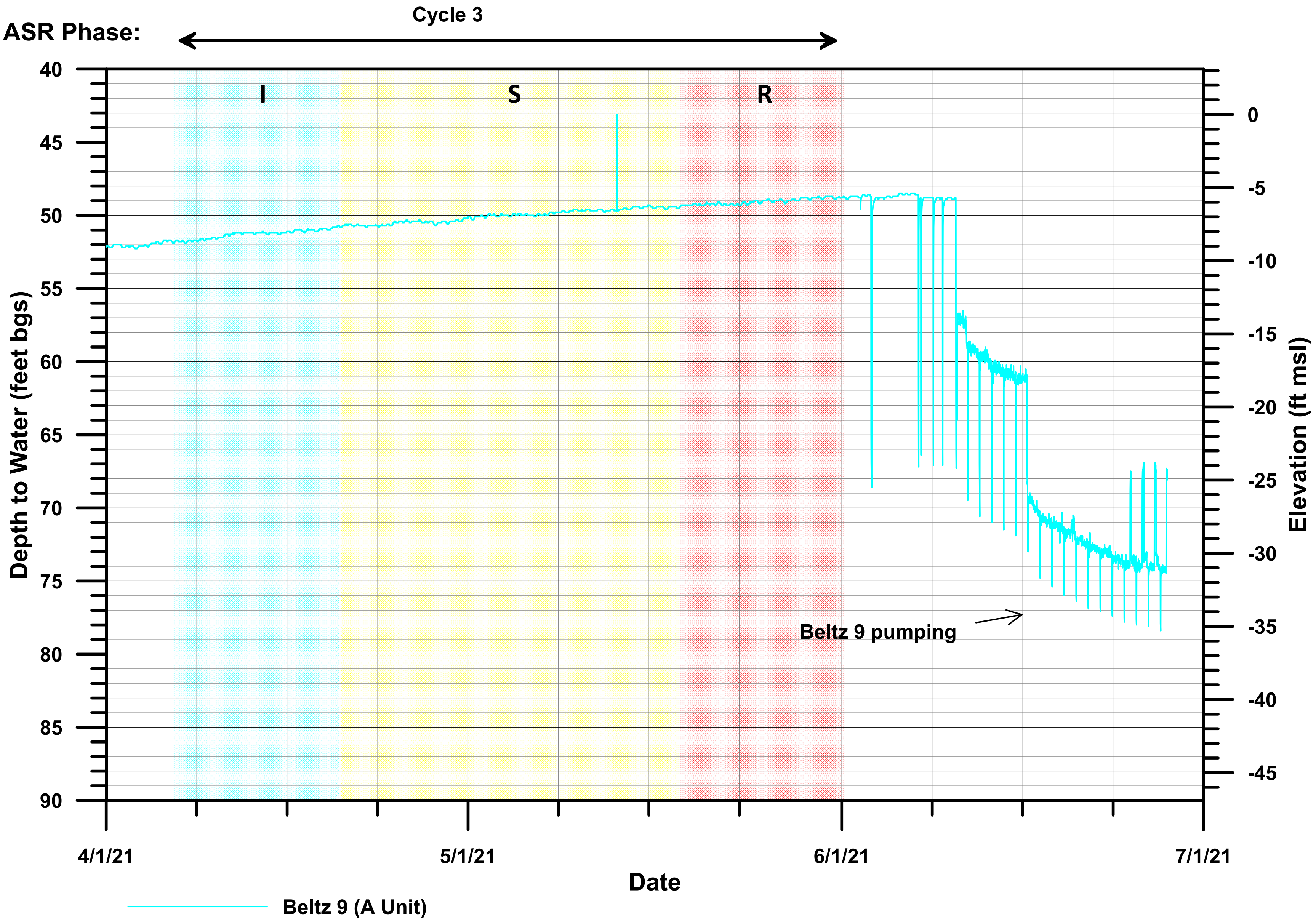

FIGURE 19. WATER-LEVEL DATA - BELTZ 9 (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

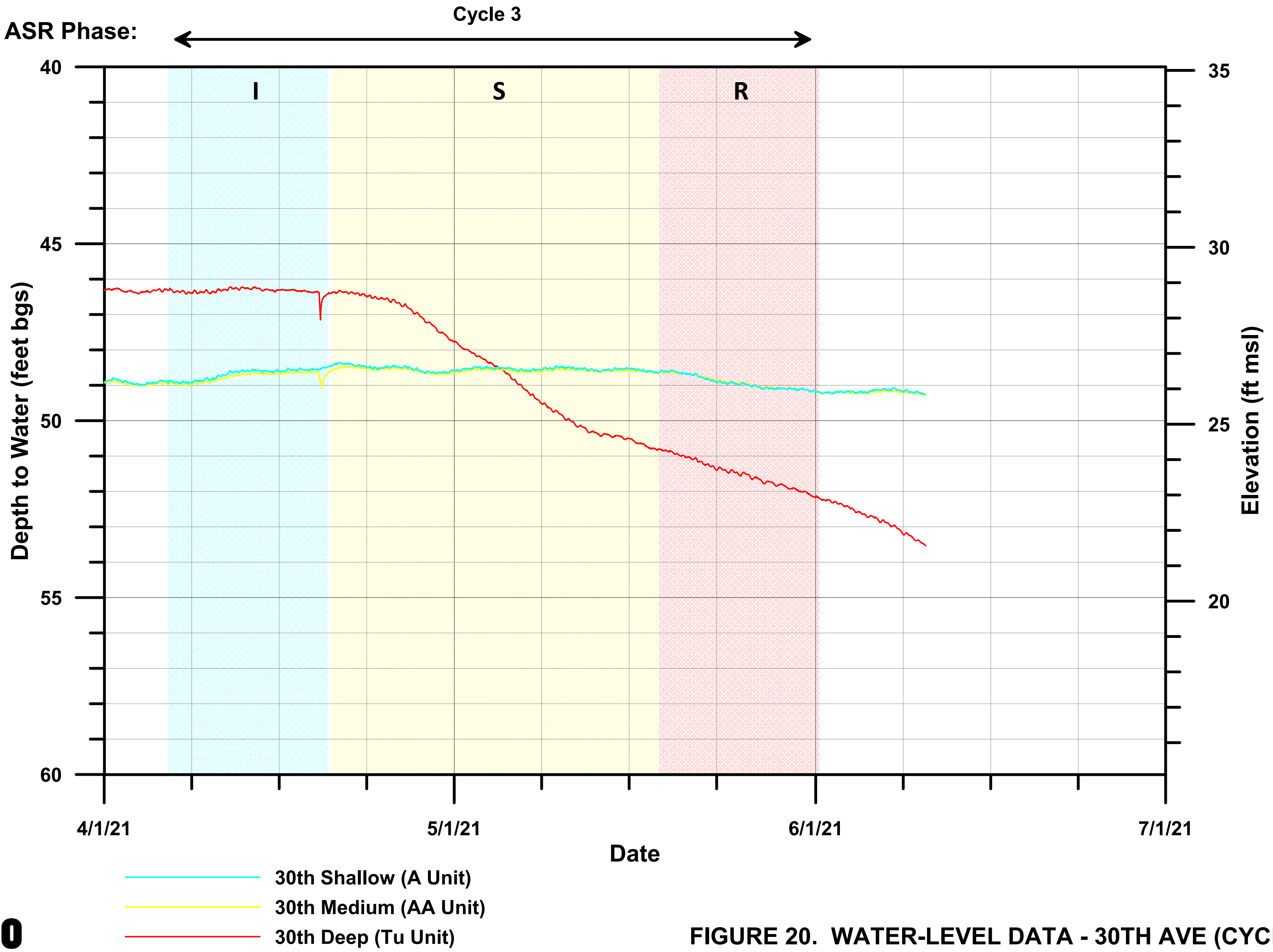

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FIGURE 20. WATER-LEVEL DATA - 30TH AVE (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

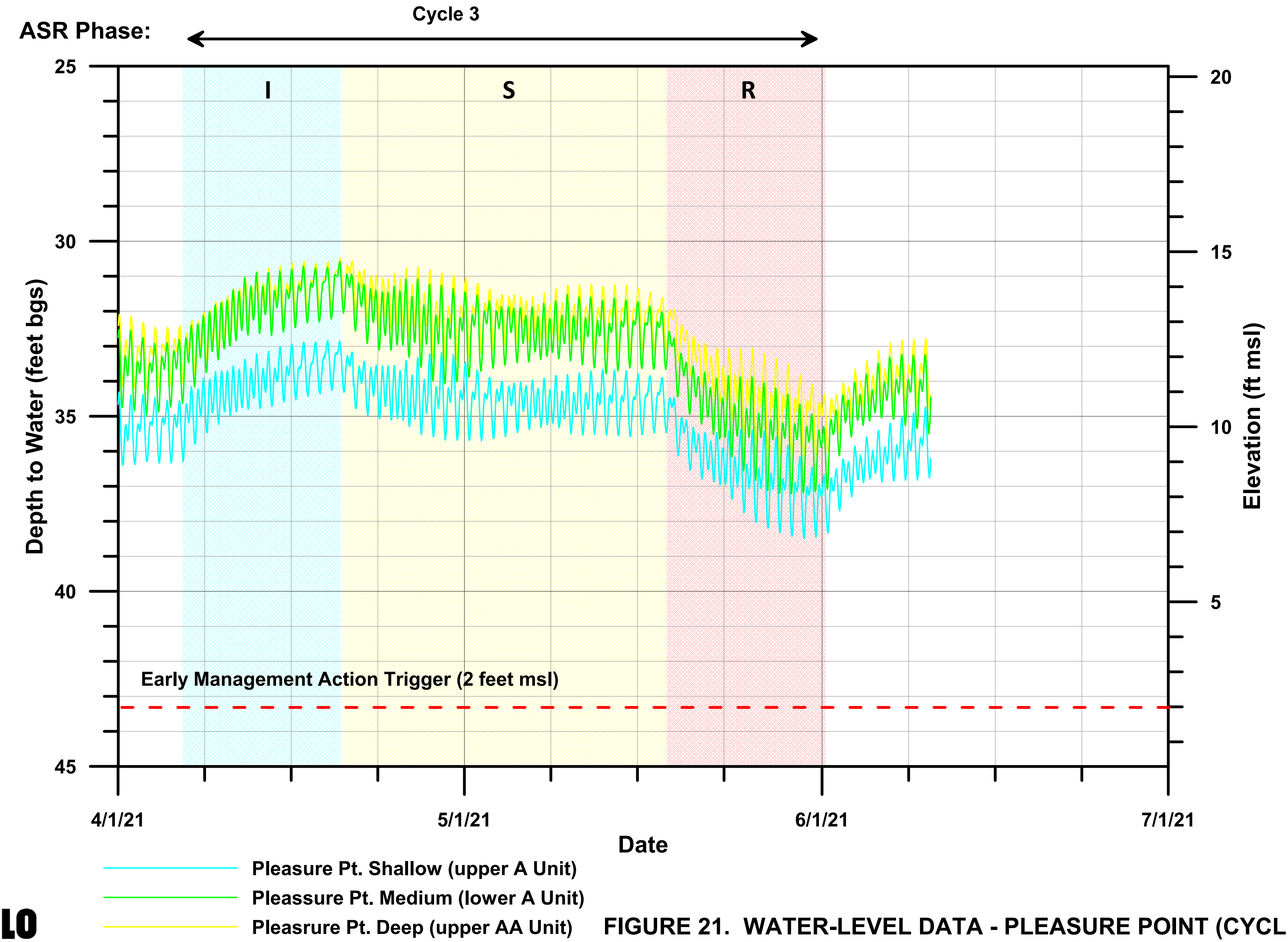

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FIGURE 21. WATER-LEVEL DATA - PLEASURE POINT (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

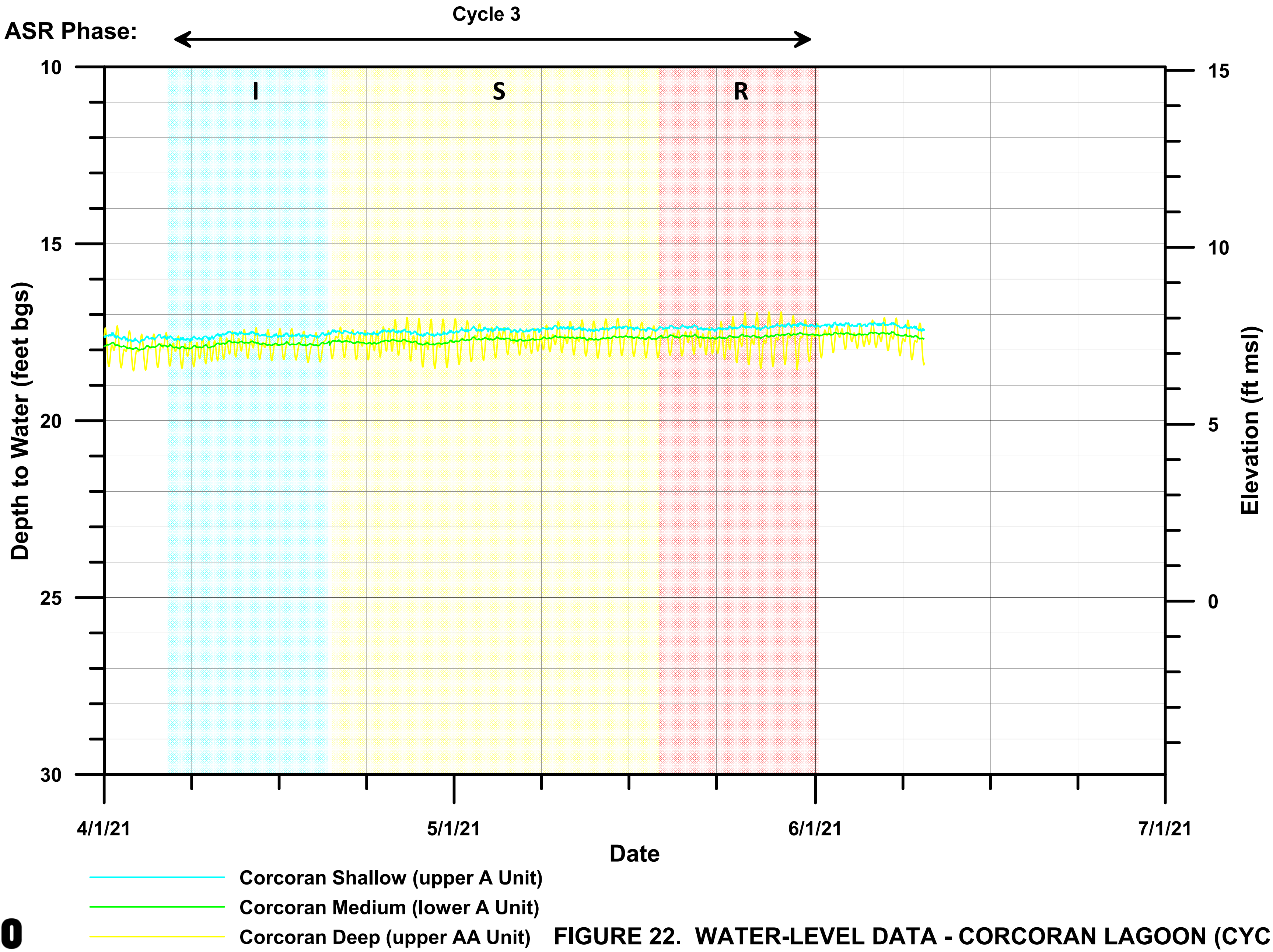

FIGURE 22. WATER-LEVEL DATA - CORCORAN LAGOON (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

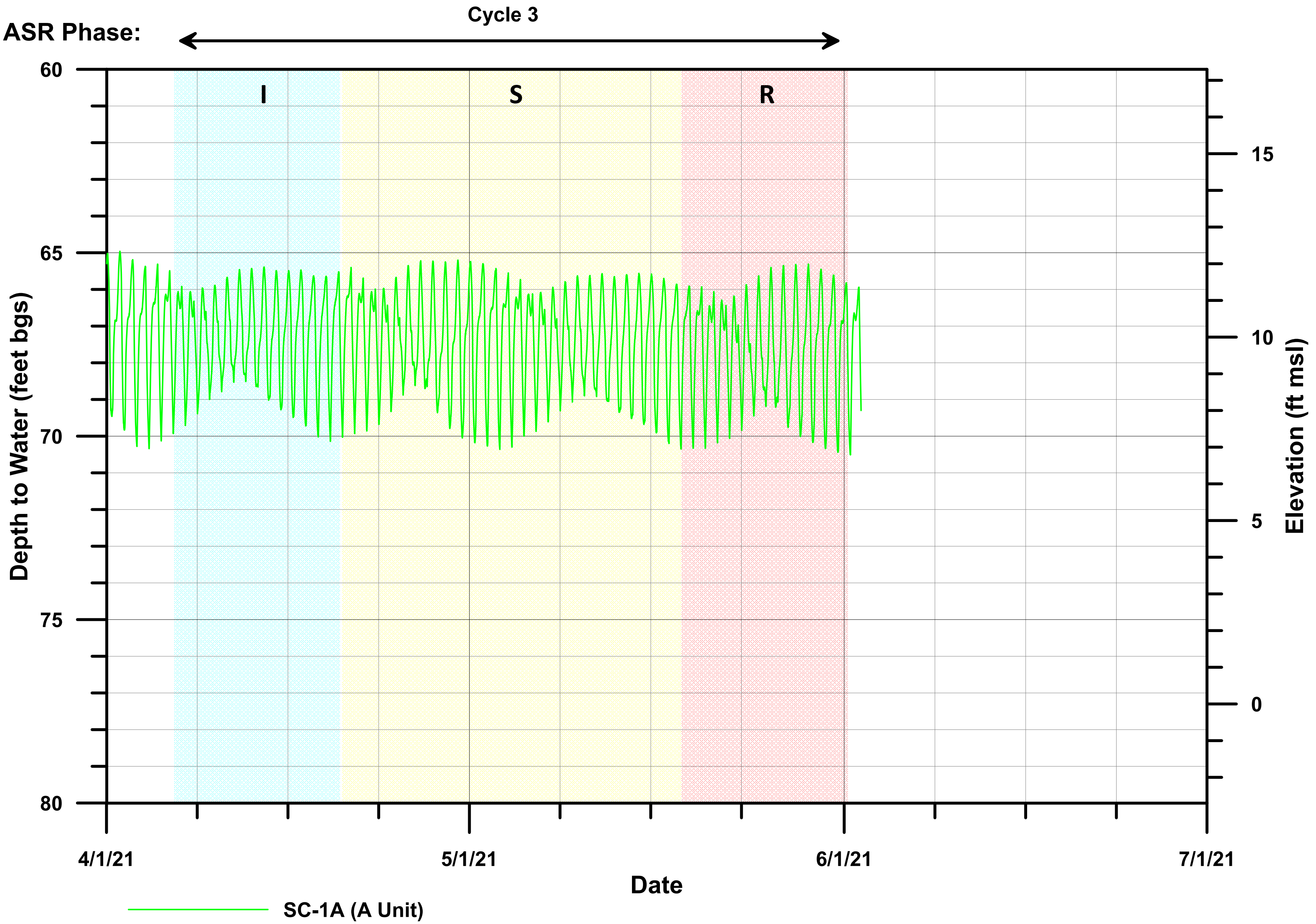

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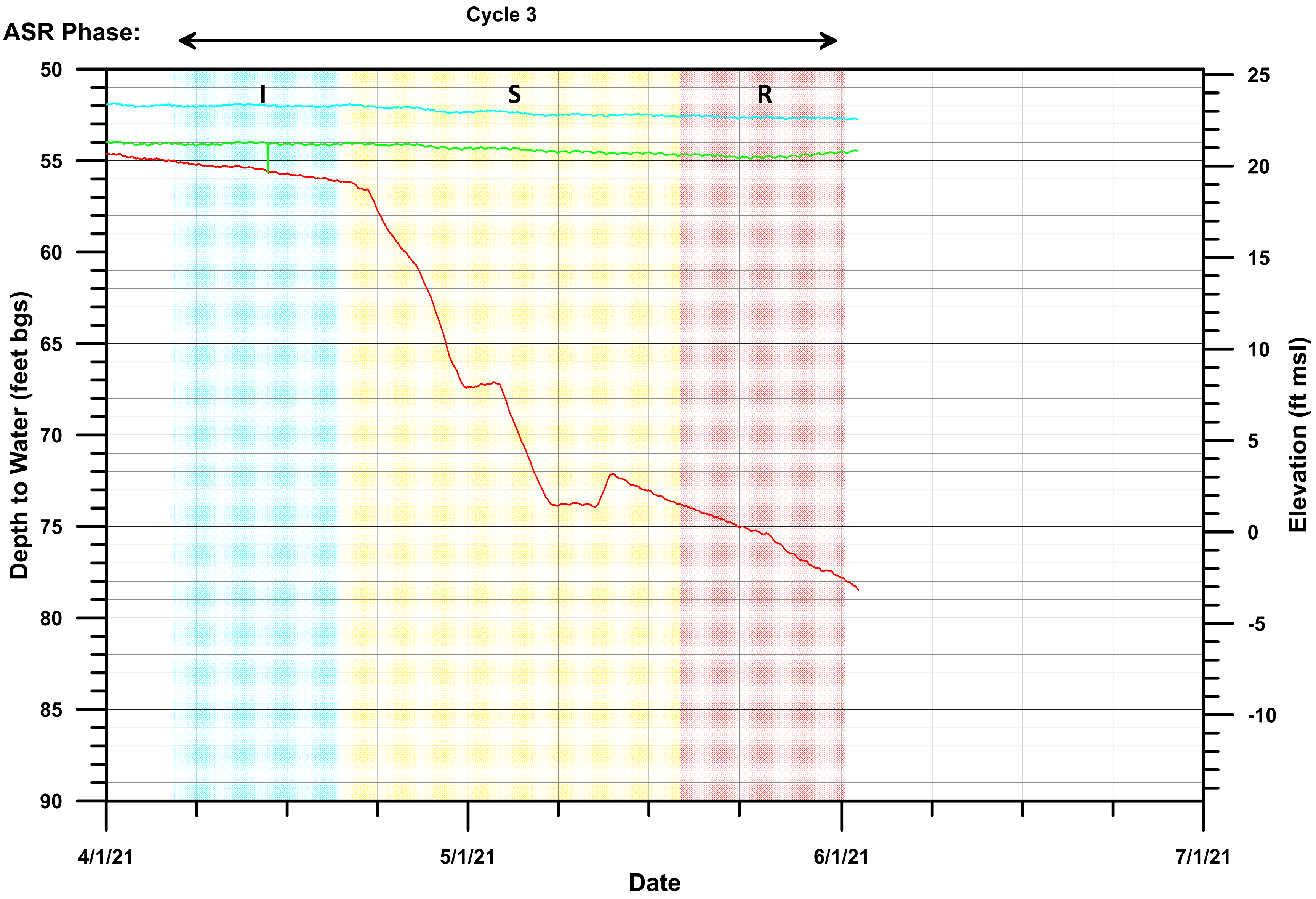
FIGURE 23. WATER-LEVEL DATA - SC-1A (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department



SC-22 Shallow (A Unit)
SC-22 Medium (AA Unit)
SC-22 Deep (Tu Unit)

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FIGURE 24. WATER-LEVEL DATA - SC-22 (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

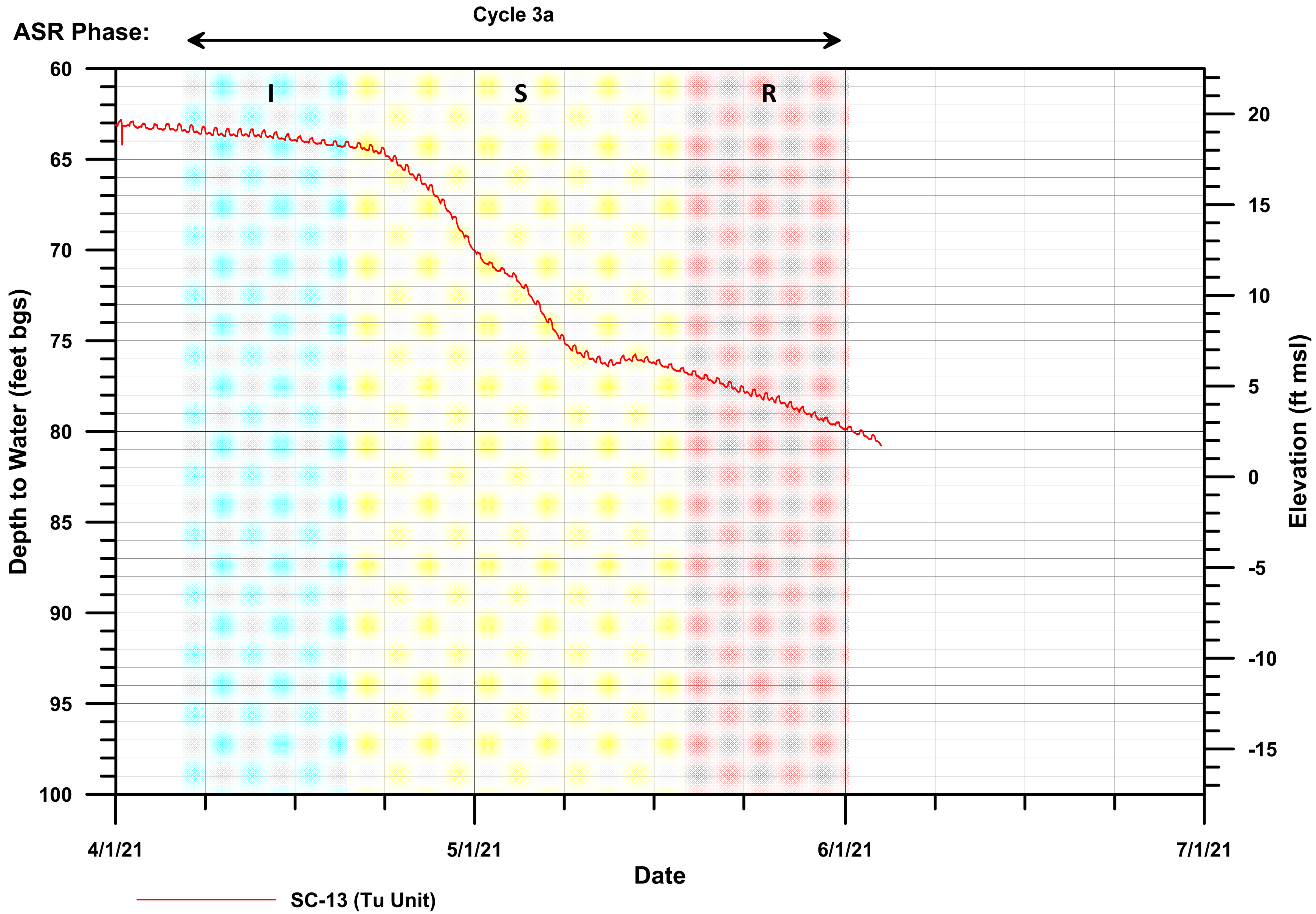

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FIGURE 25. WATER-LEVEL DATA - SC-13 (CYCLE 3)
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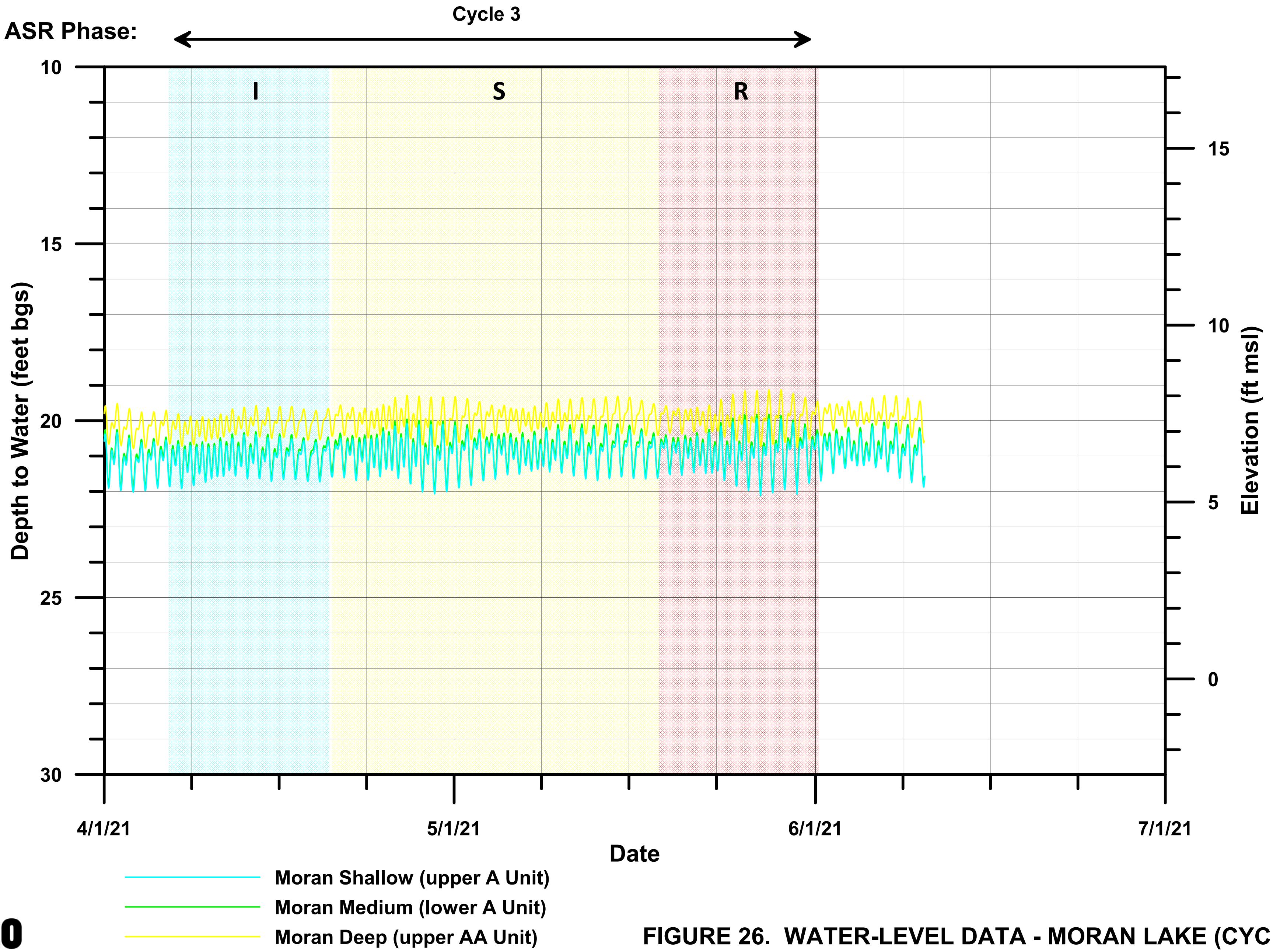

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FIGURE 26. WATER-LEVEL DATA - MORAN LAKE (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

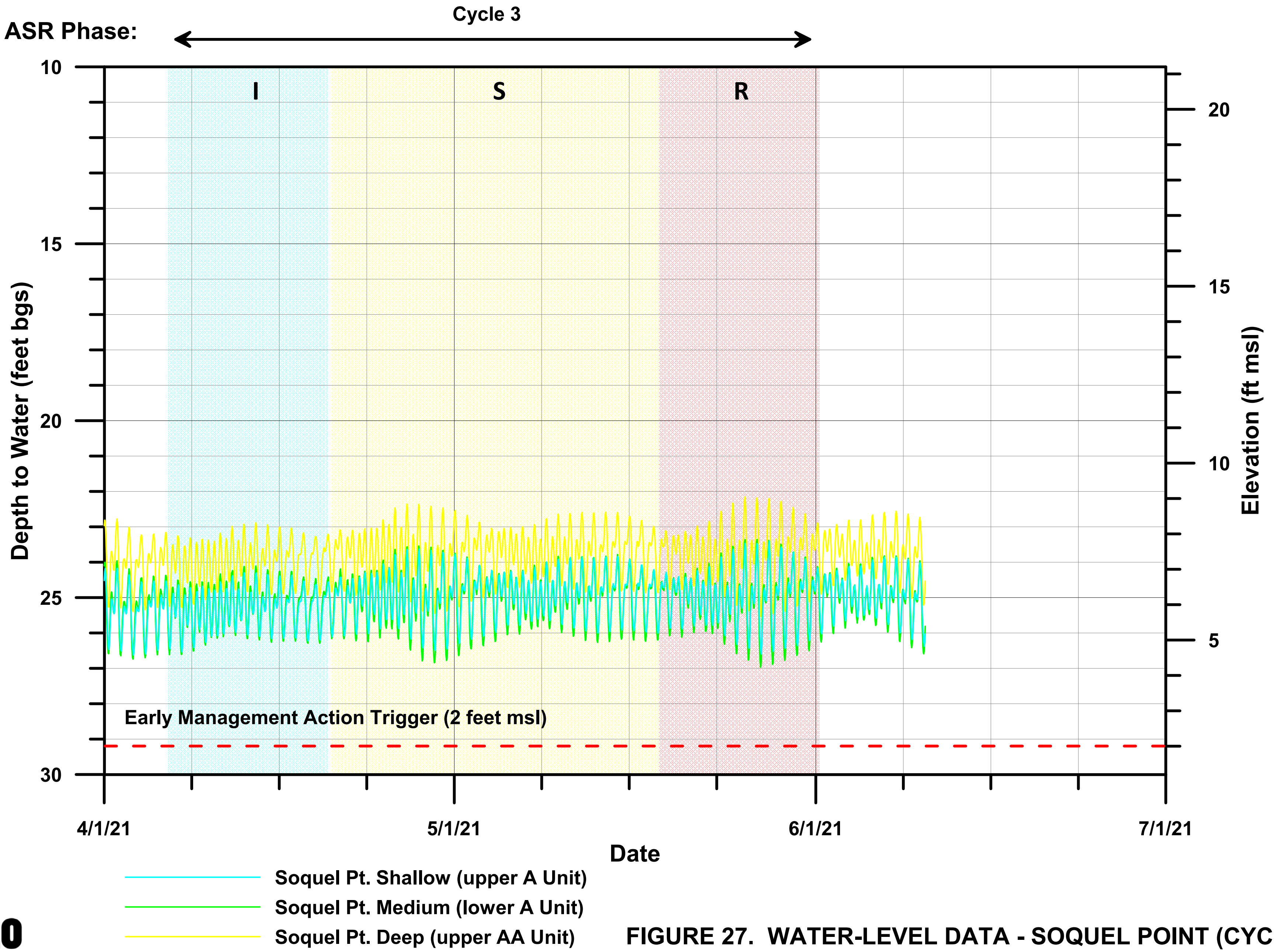

FIGURE 27. WATER-LEVEL DATA - SOQUEL POINT (CYCLE 3)
Phase 2 ASR Pilot Test - Beltz 8
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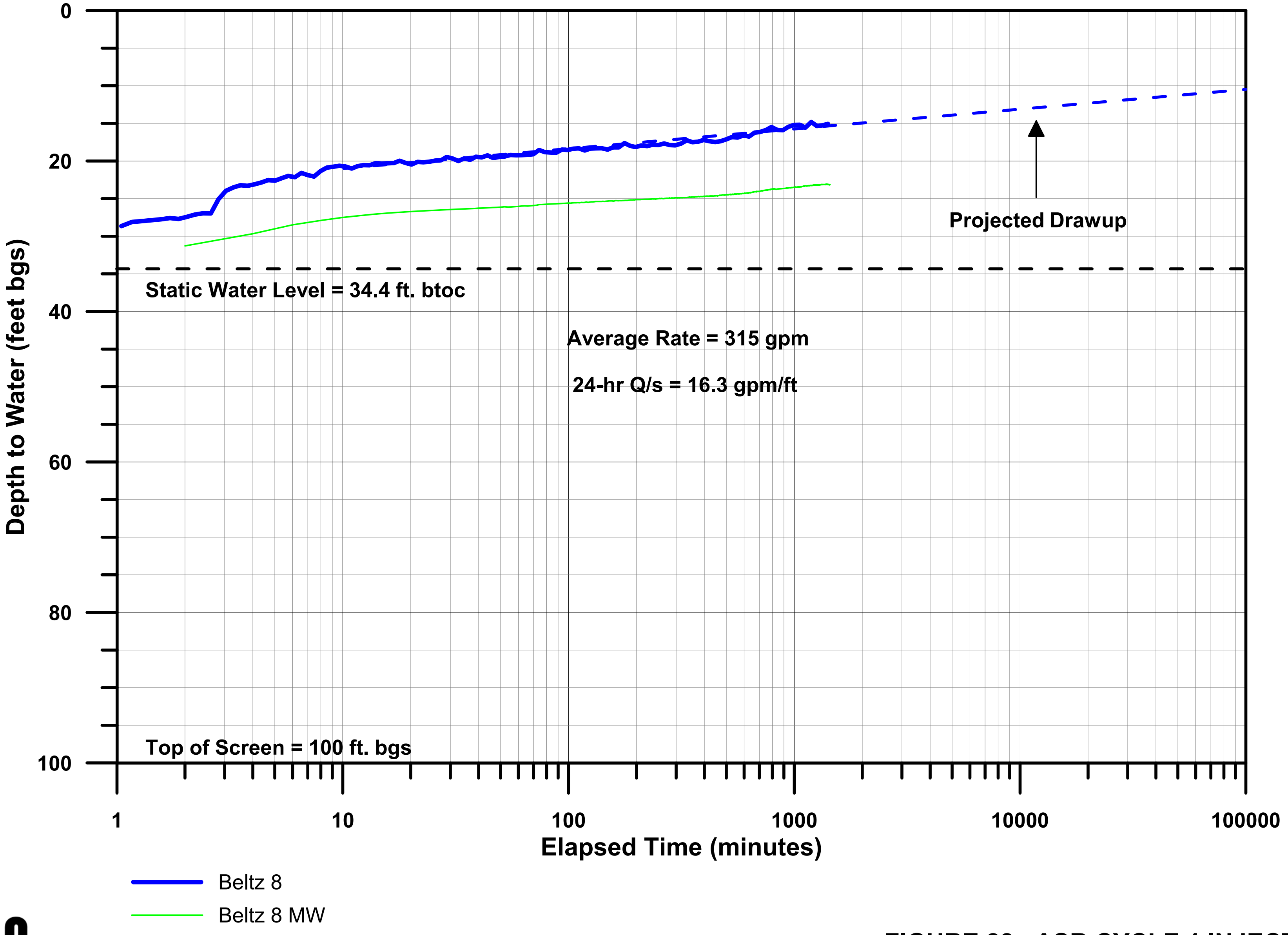

FIGURE 28. ASR CYCLE 1 INJECTION TEST
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

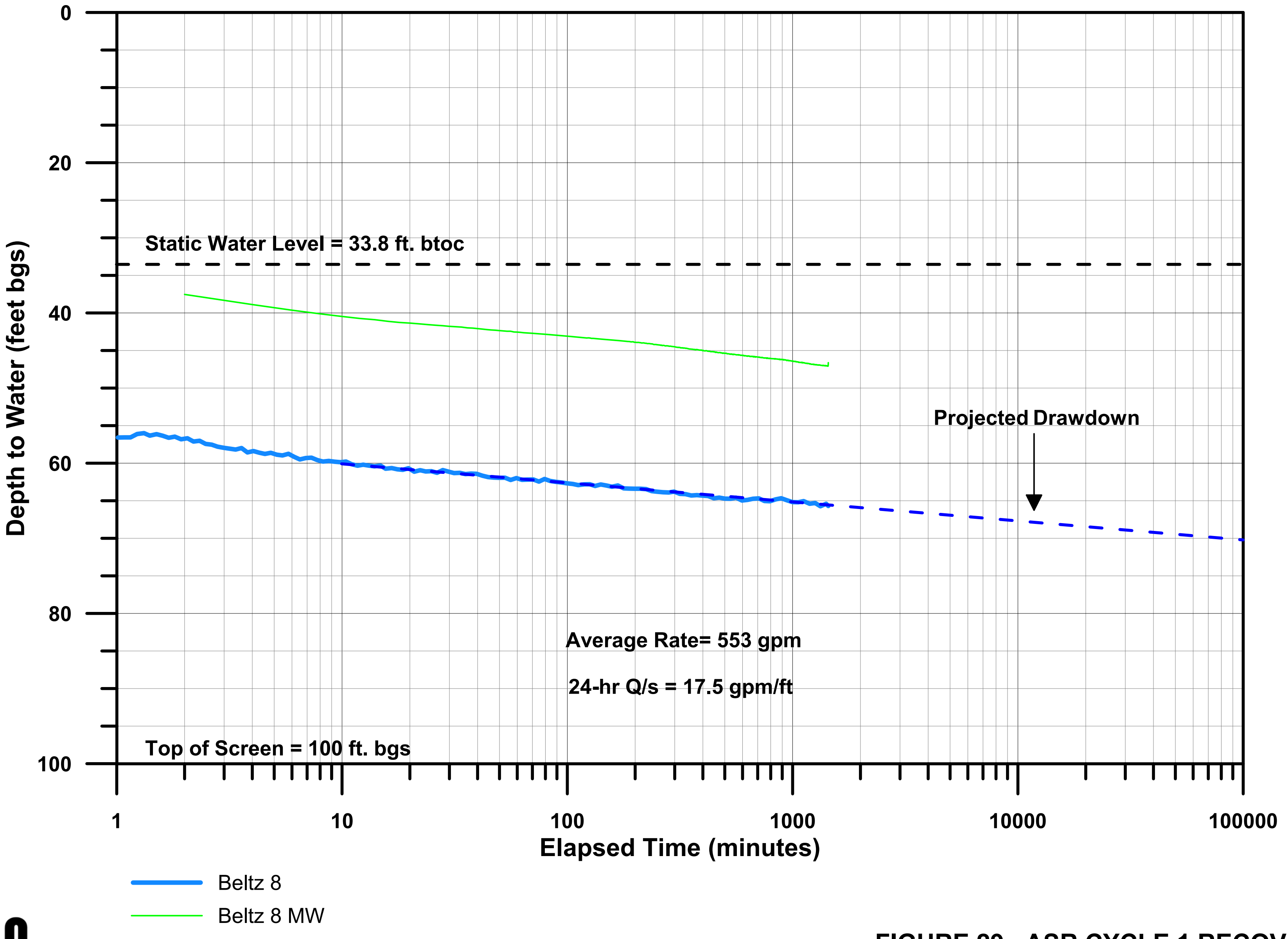

FIGURE 29. ASR CYCLE 1 RECOVERY TEST
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

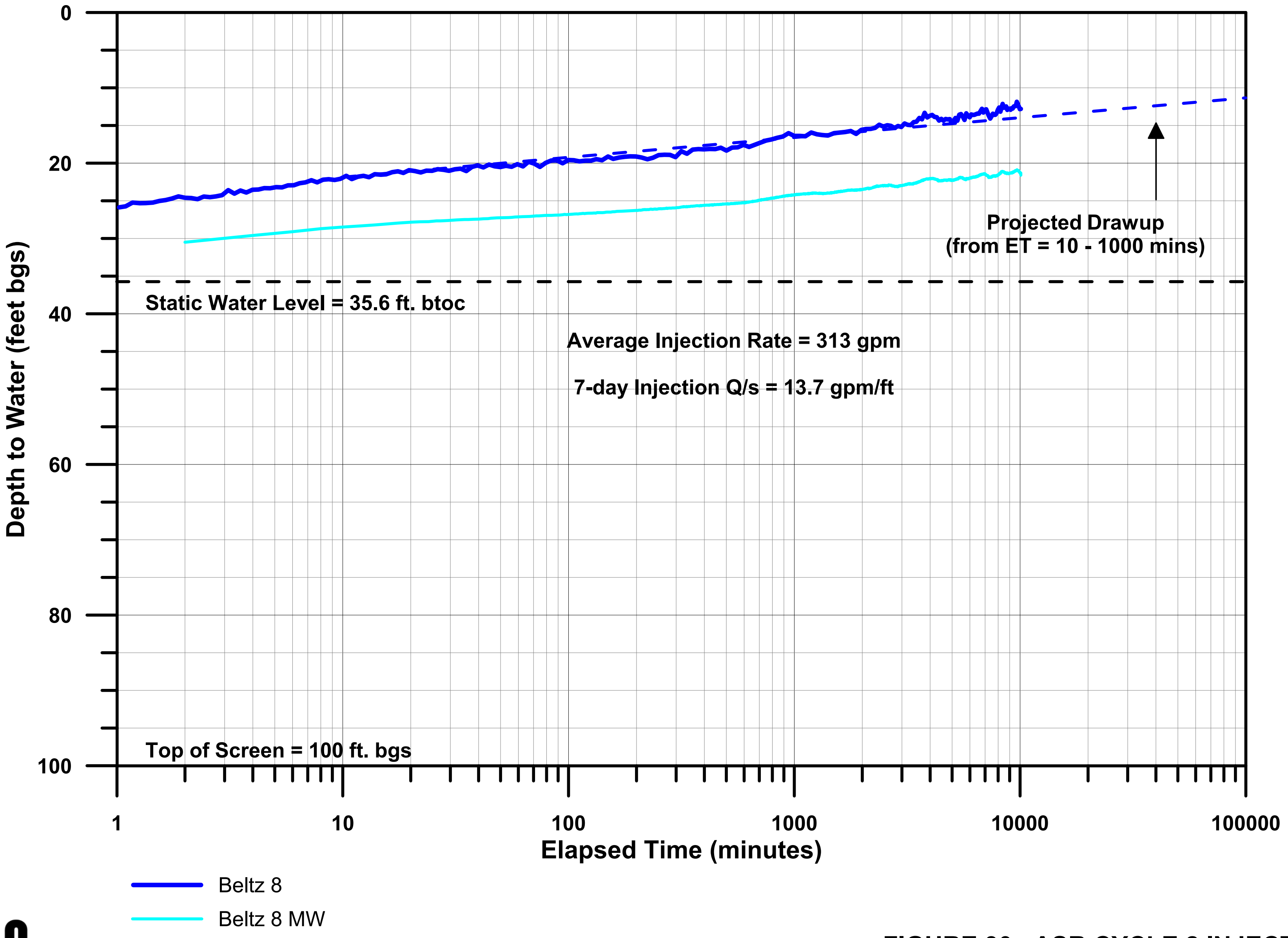

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FIGURE 30. ASR CYCLE 2 INJECTION TEST
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

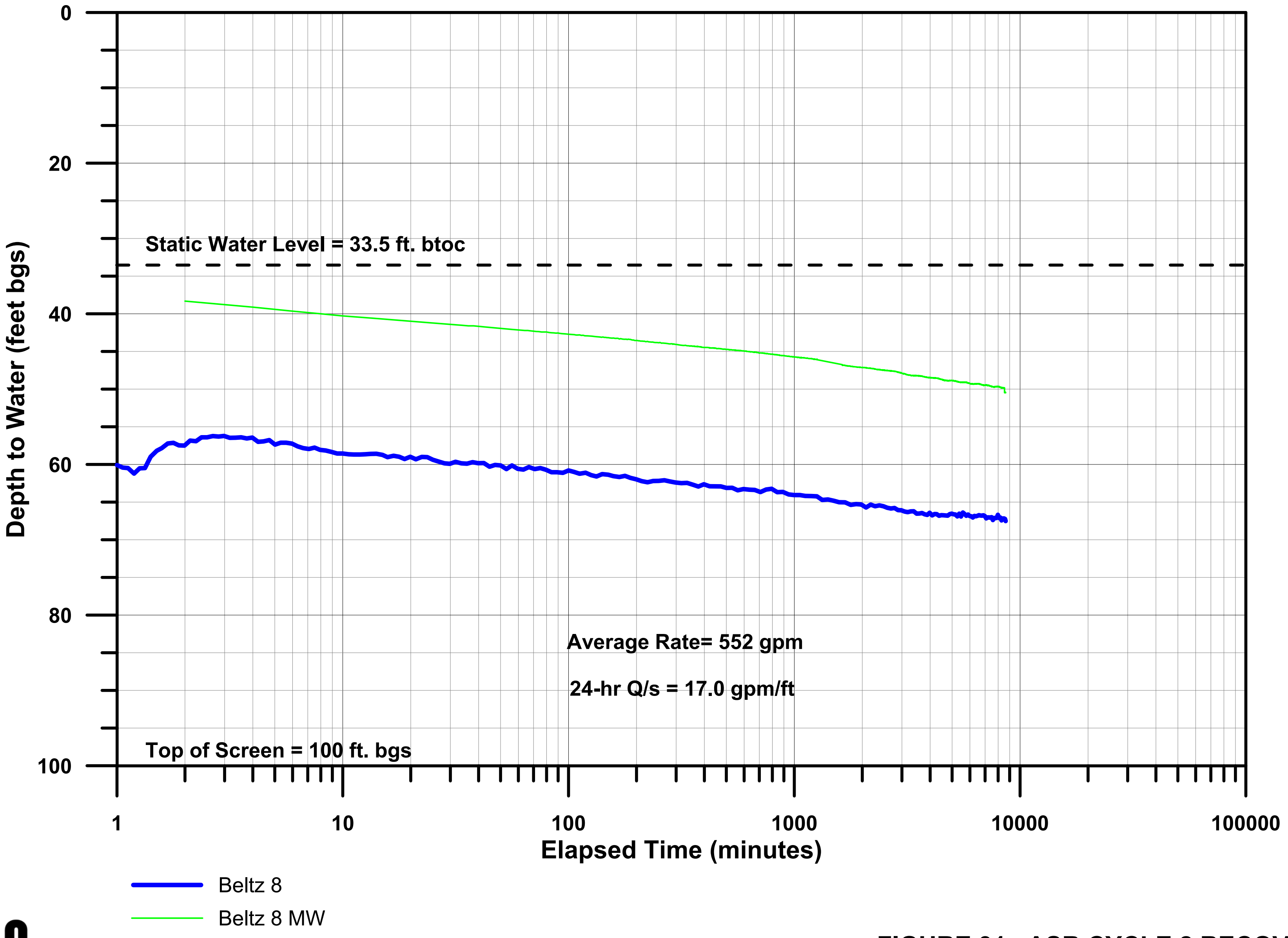

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FIGURE 31. ASR CYCLE 2 RECOVERY TEST
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

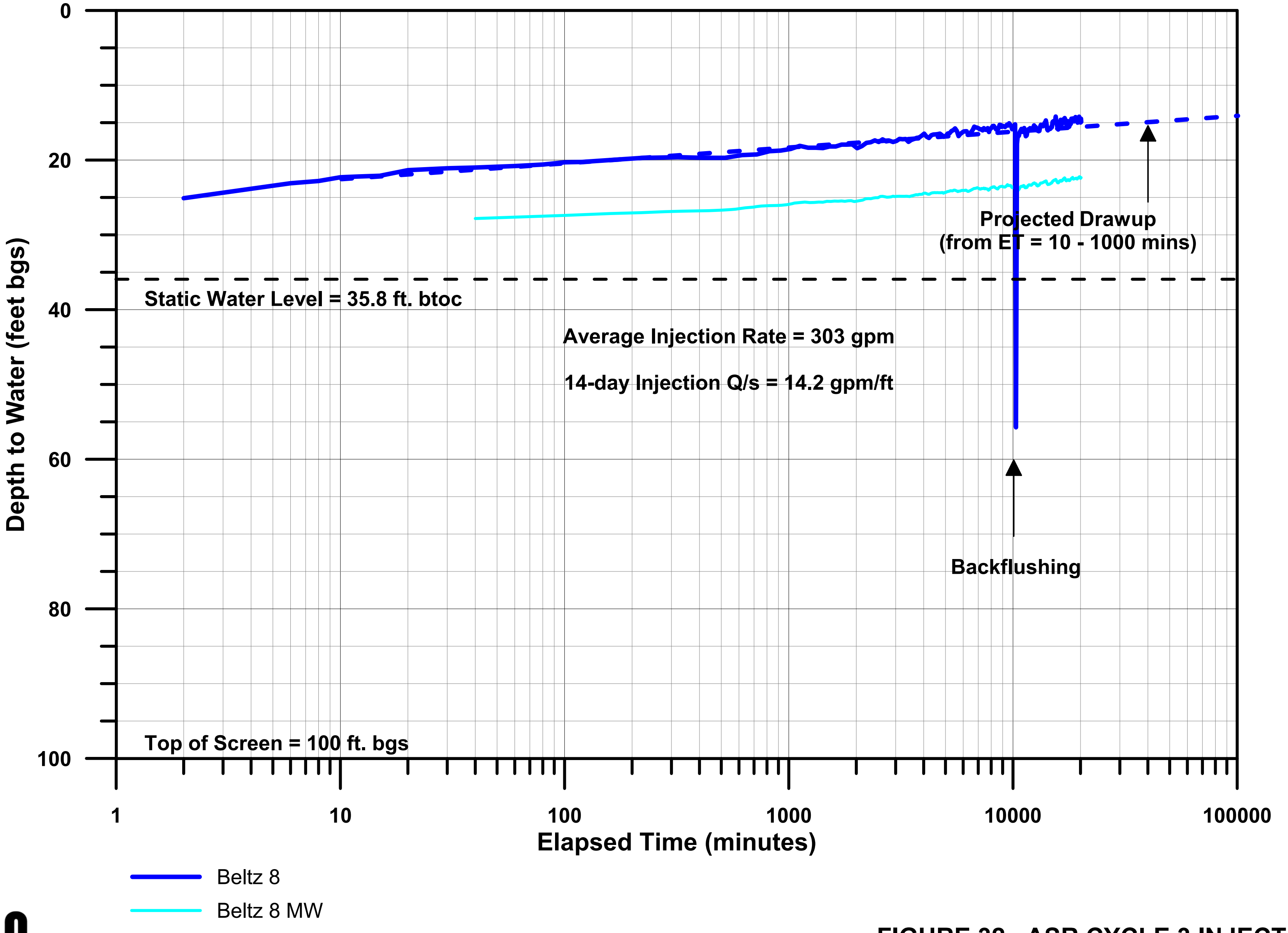

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FIGURE 32. ASR CYCLE 3 INJECTION TEST
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

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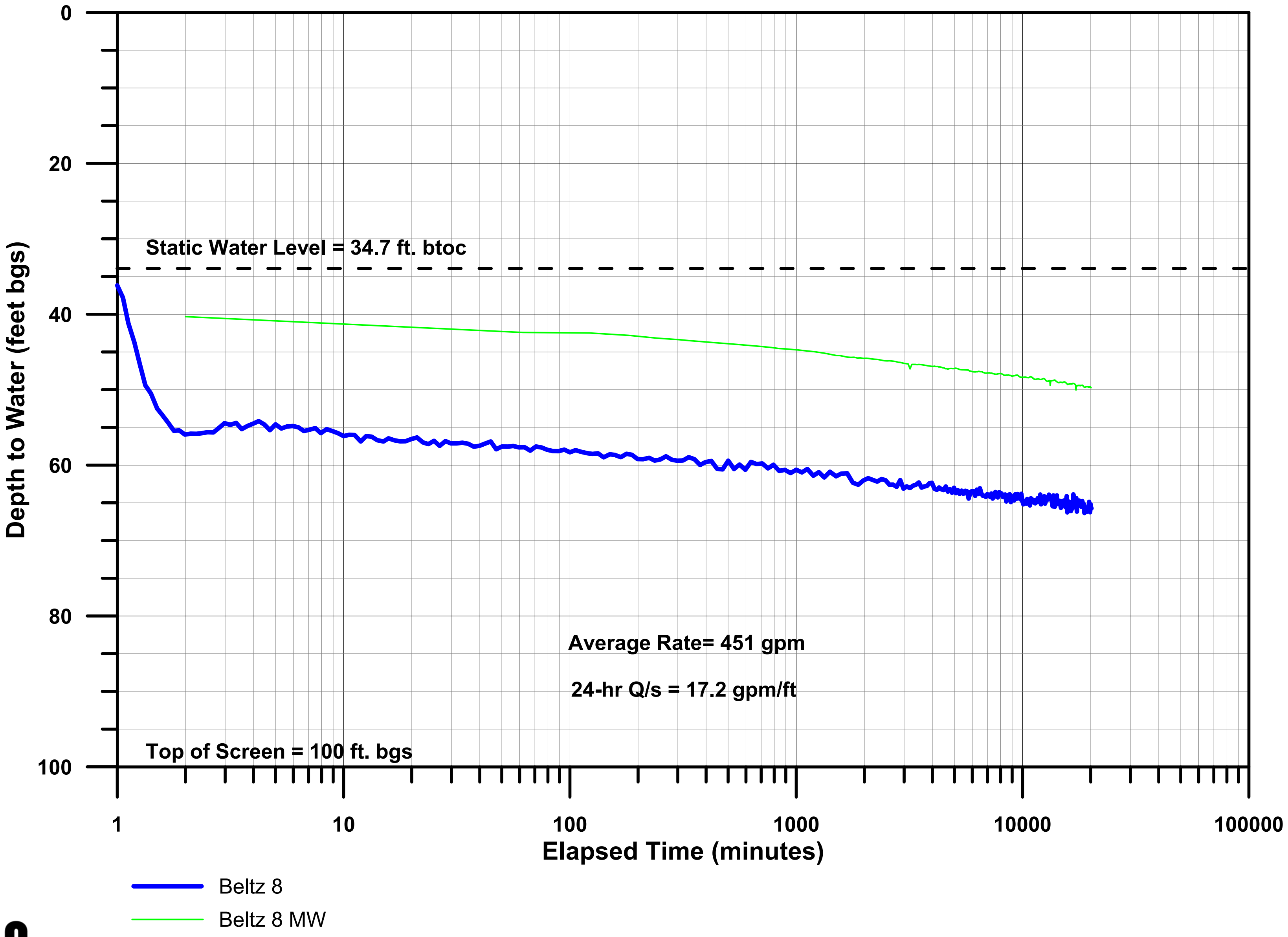

FIGURE 33. ASR CYCLE 3 RECOVERY TEST
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

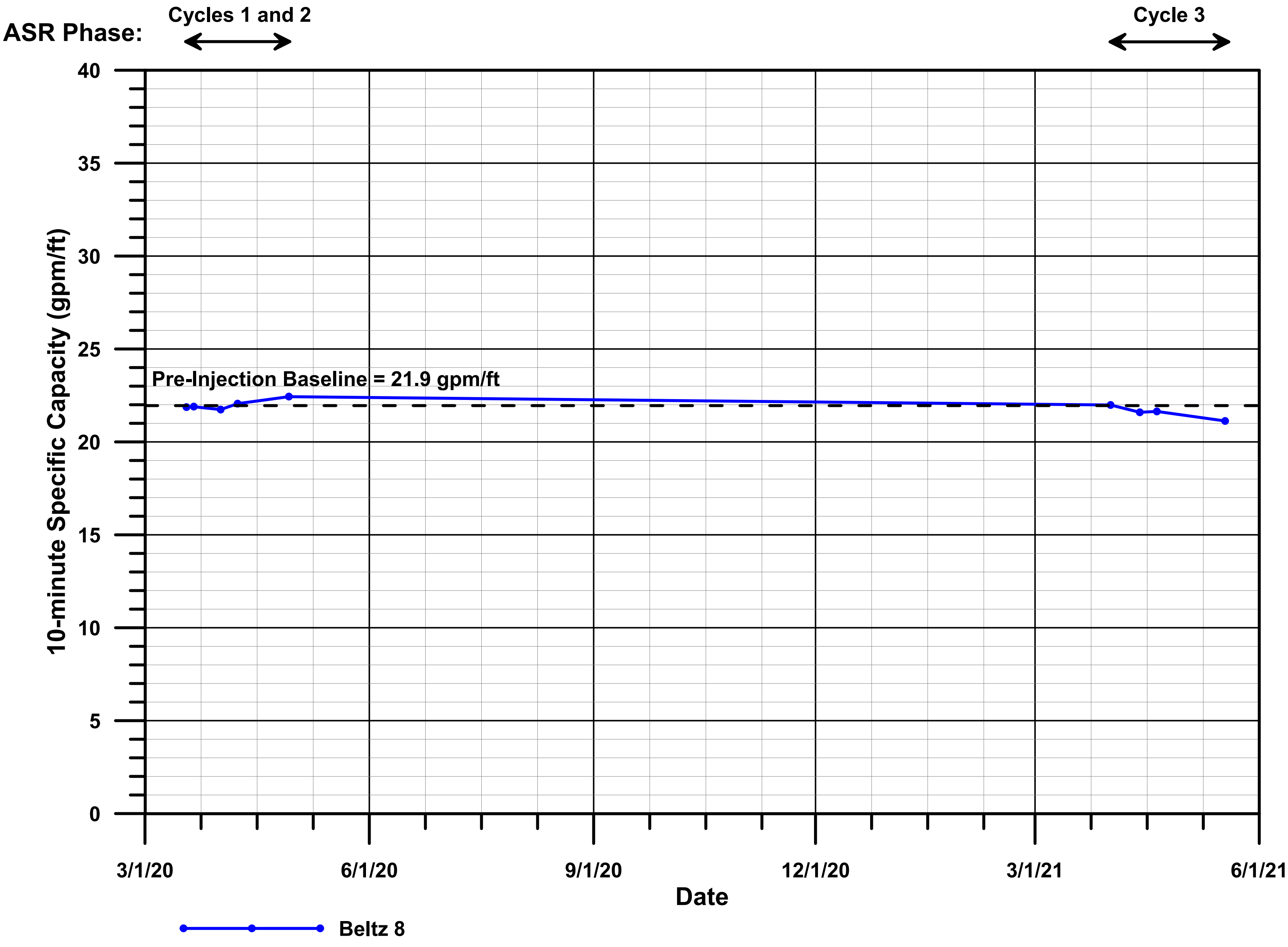

FIGURE 34. 10-MINUTE SPECIFIC CAPACITY DATA
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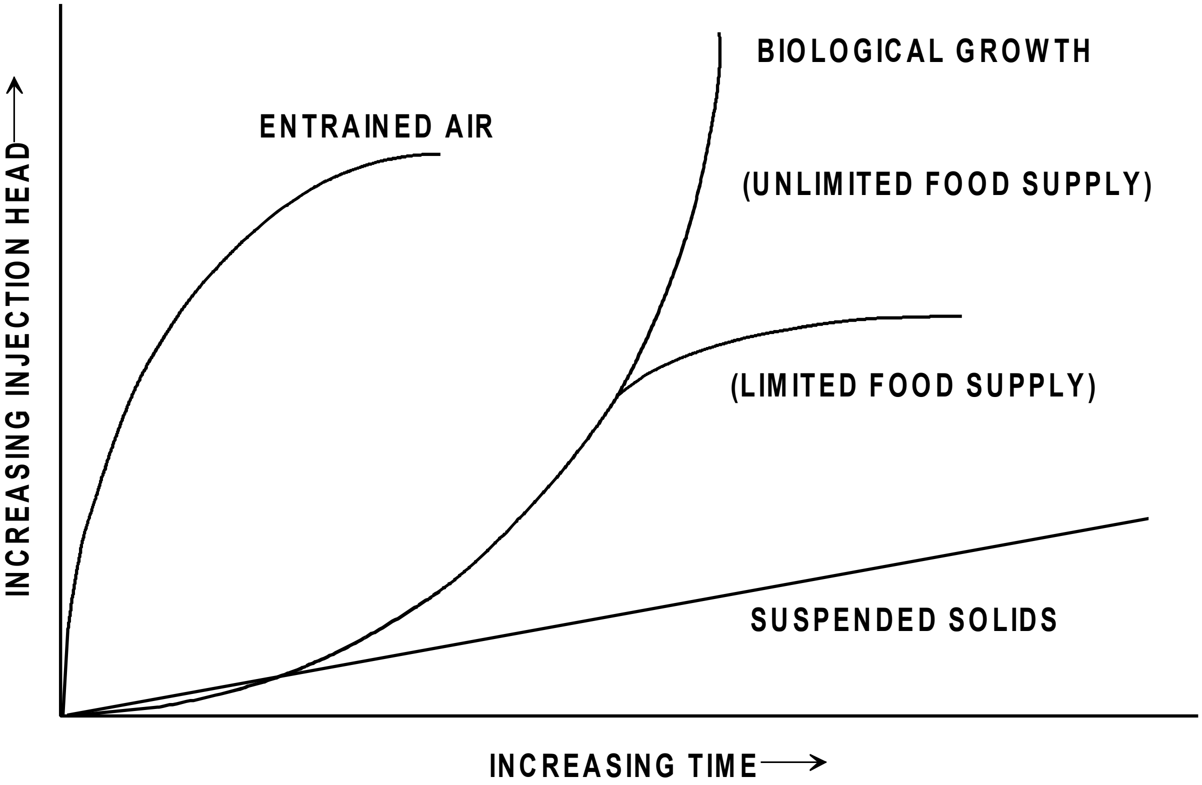
Santa Cruz Water Department



SOURCE: After Huisman and Olsthoorn, 1983.

FIGURE 35. INJECTION WELL PLUGGING MECHANISIMS
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

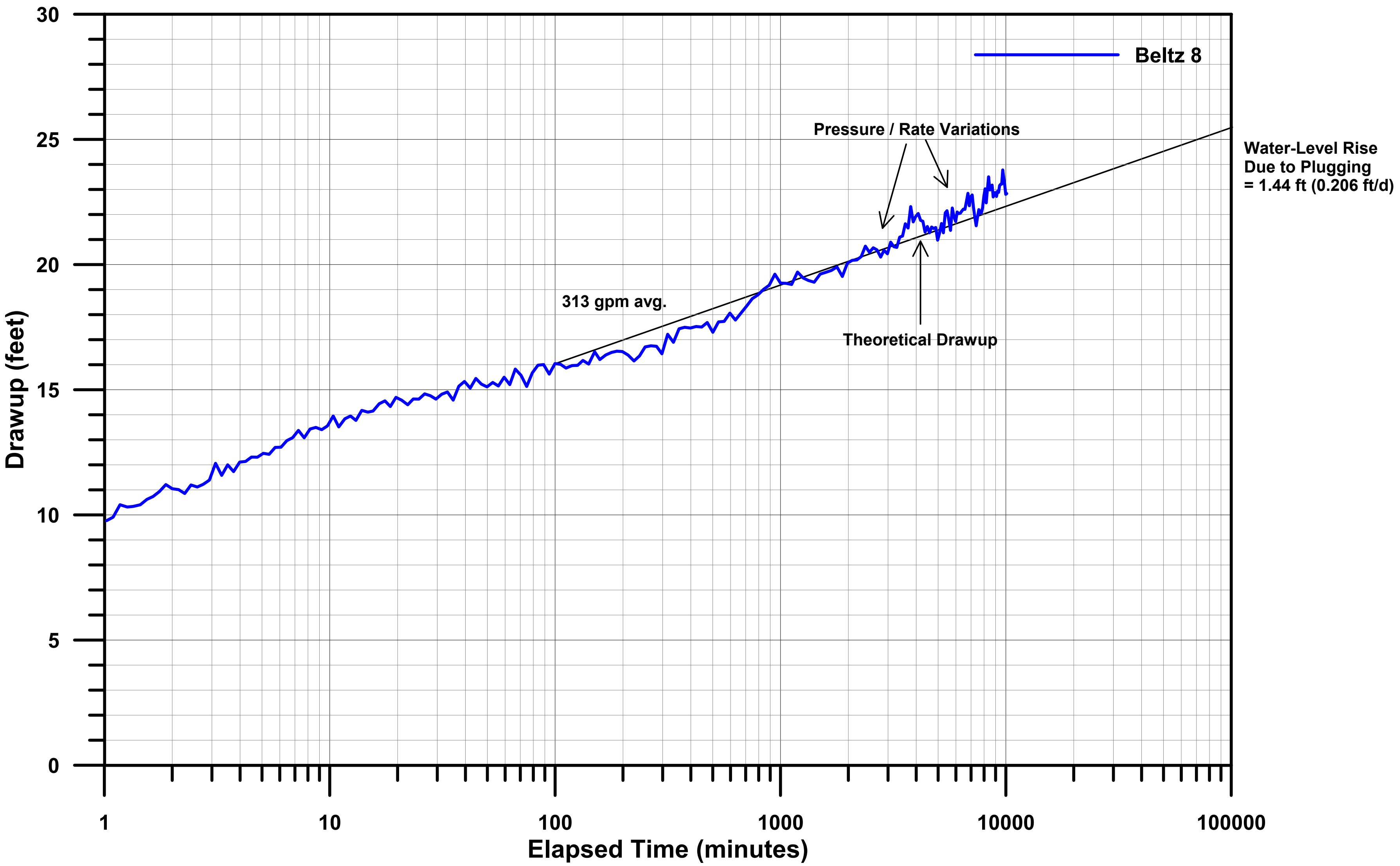


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FIGURE 36. ASR CYCLE 2 - INJECTION PLUGGING RATE ANALYSIS
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Santa Cruz Water Department

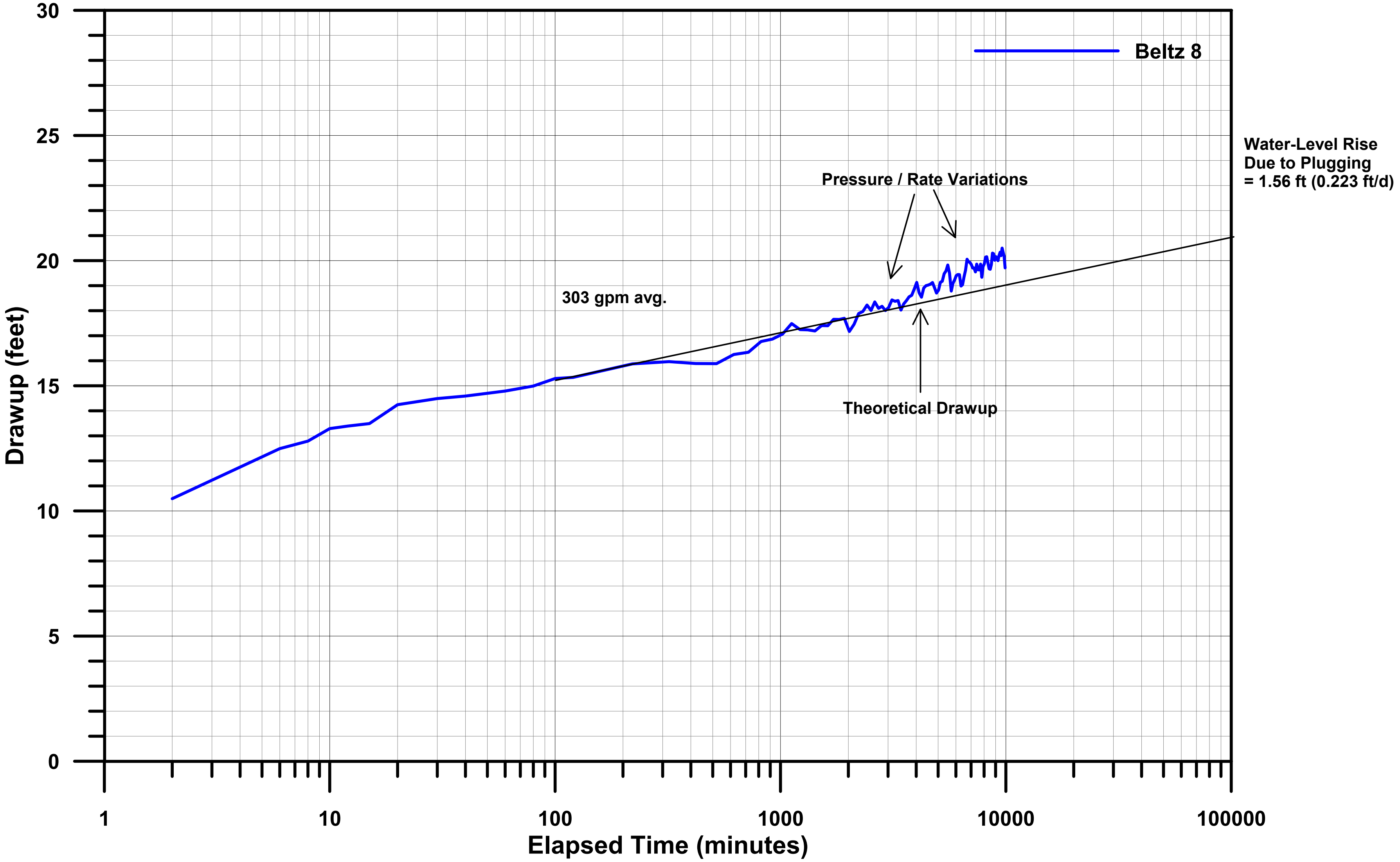

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FIGURE 37. ASR CYCLE 3 - INJECTION PLUGGING RATE ANALYSIS
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

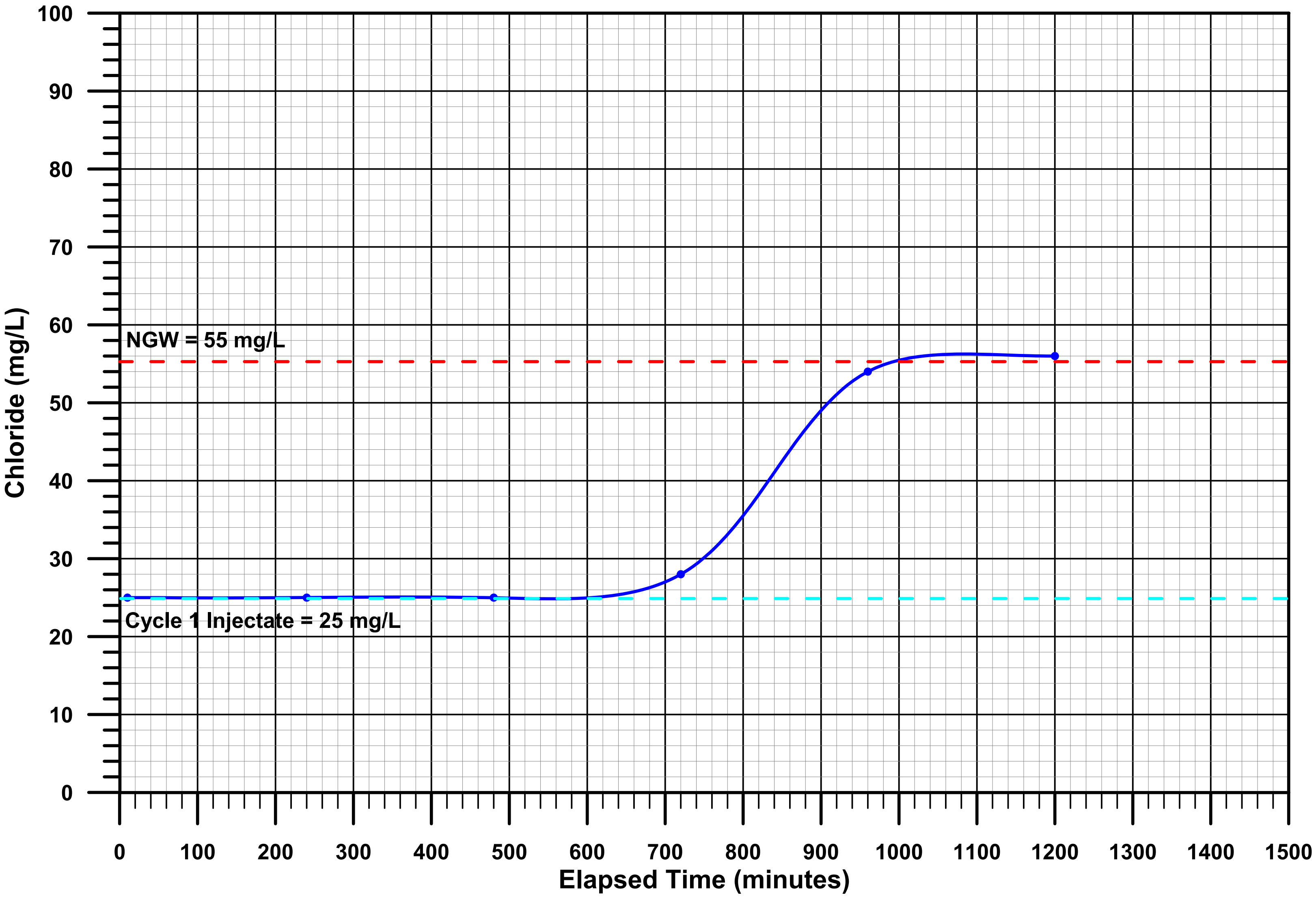

FIGURE 38. ASR CYCLE 1 RECOVERY - CHLORIDE VS. TIME
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

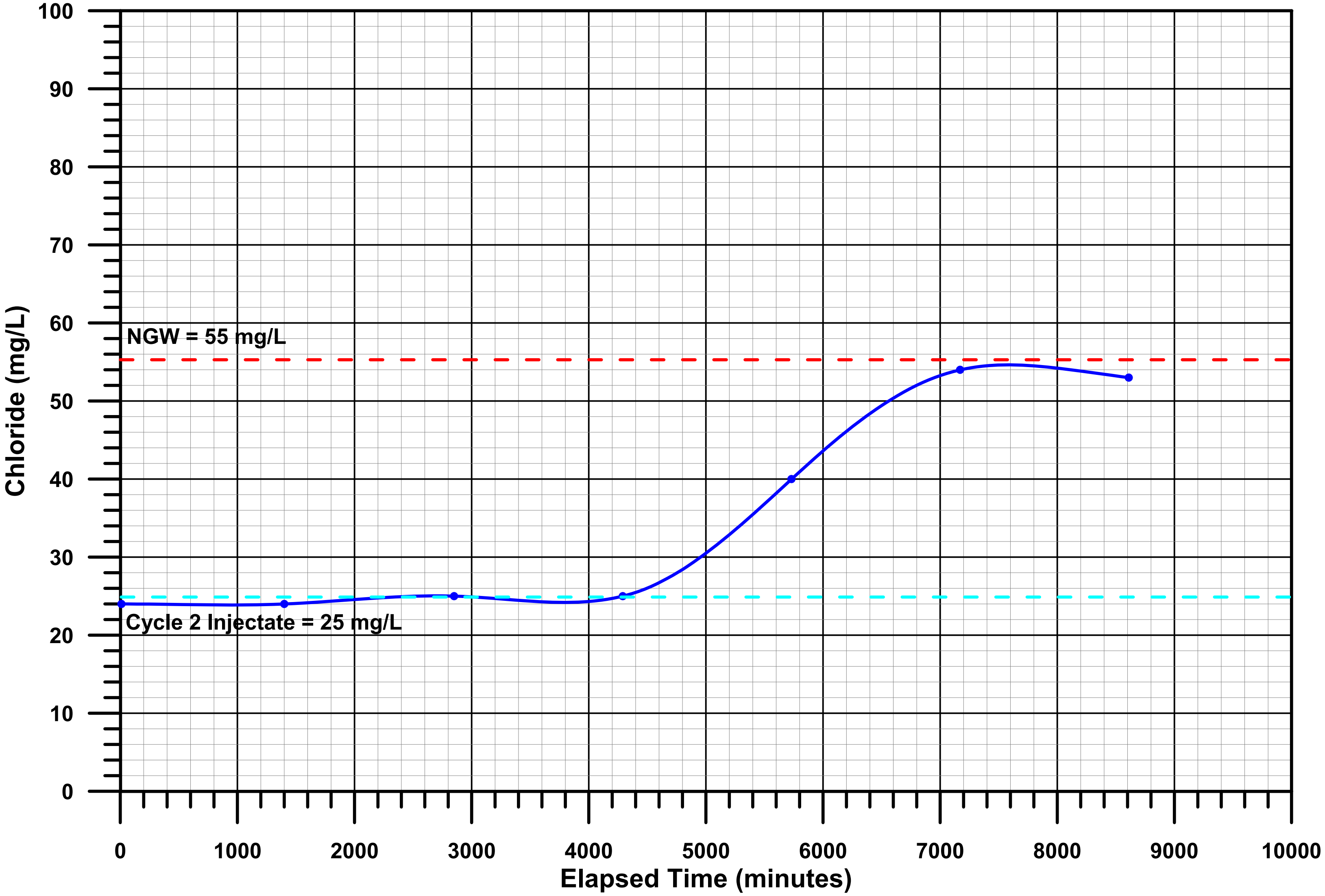

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FIGURE 39. ASR CYCLE 2 RECOVERY - CHLORIDE VS. TIME

Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

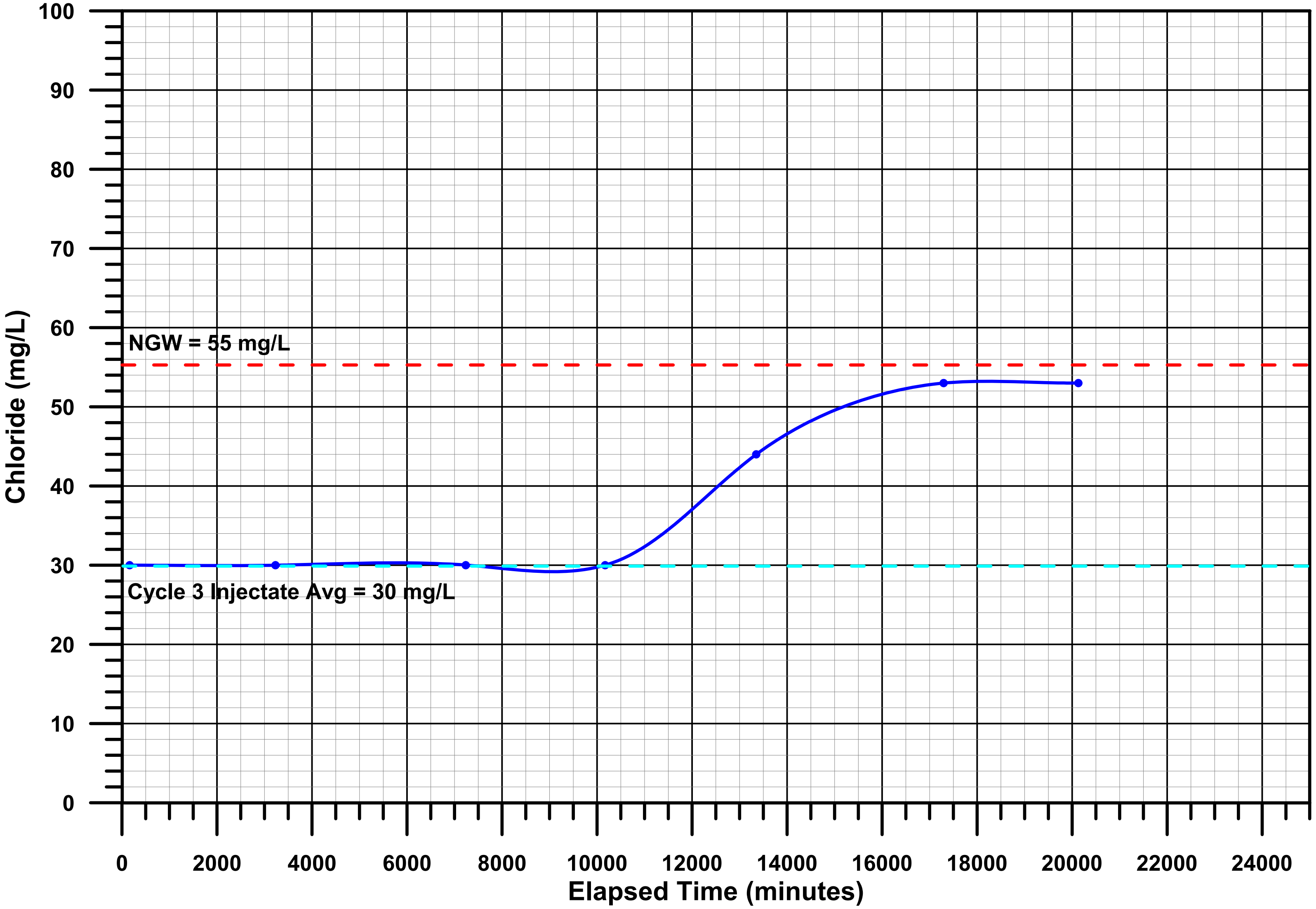

FIGURE 40. ASR CYCLE 3 RECOVERY - CHLORIDE VS. TIME
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

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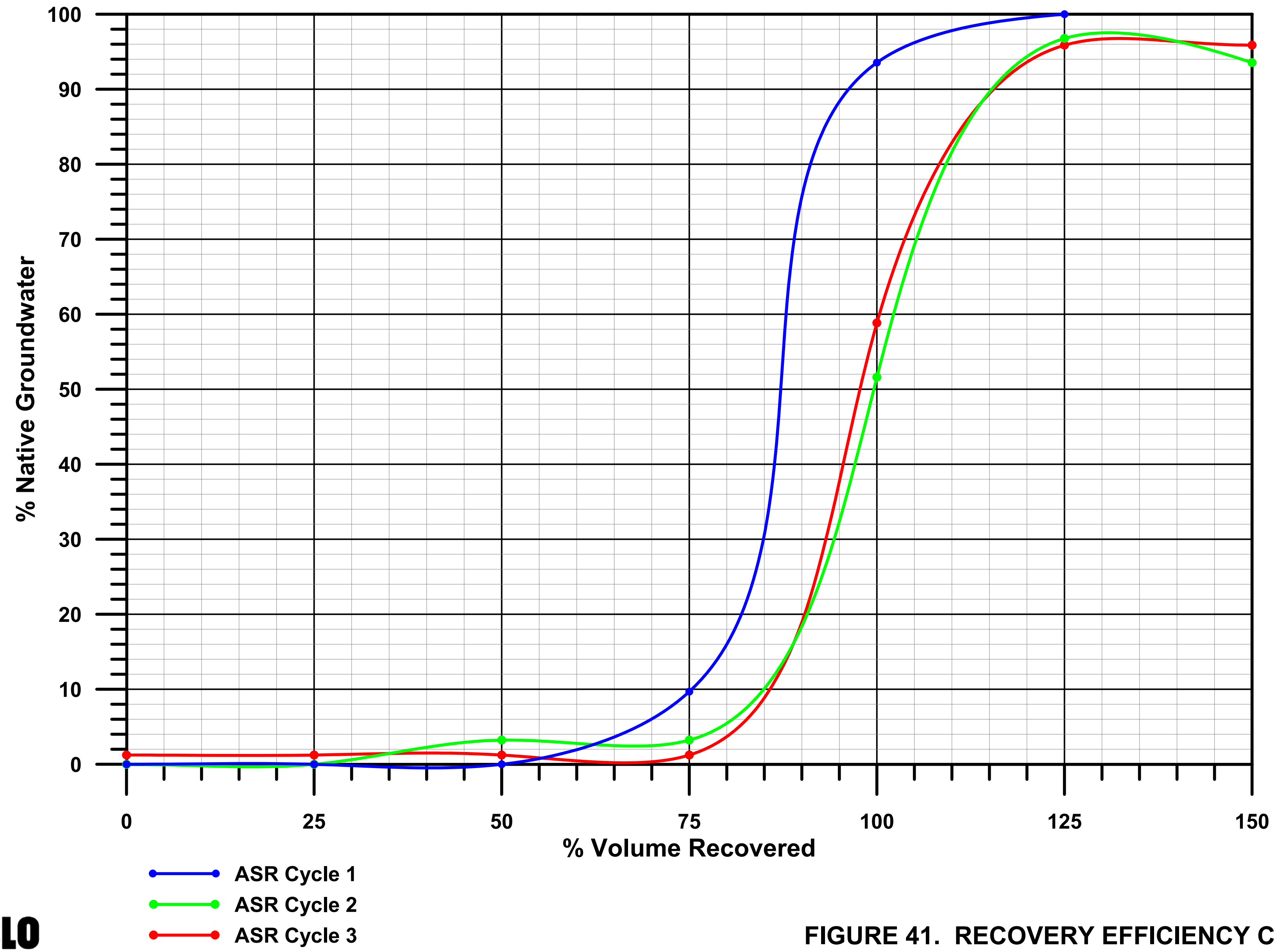

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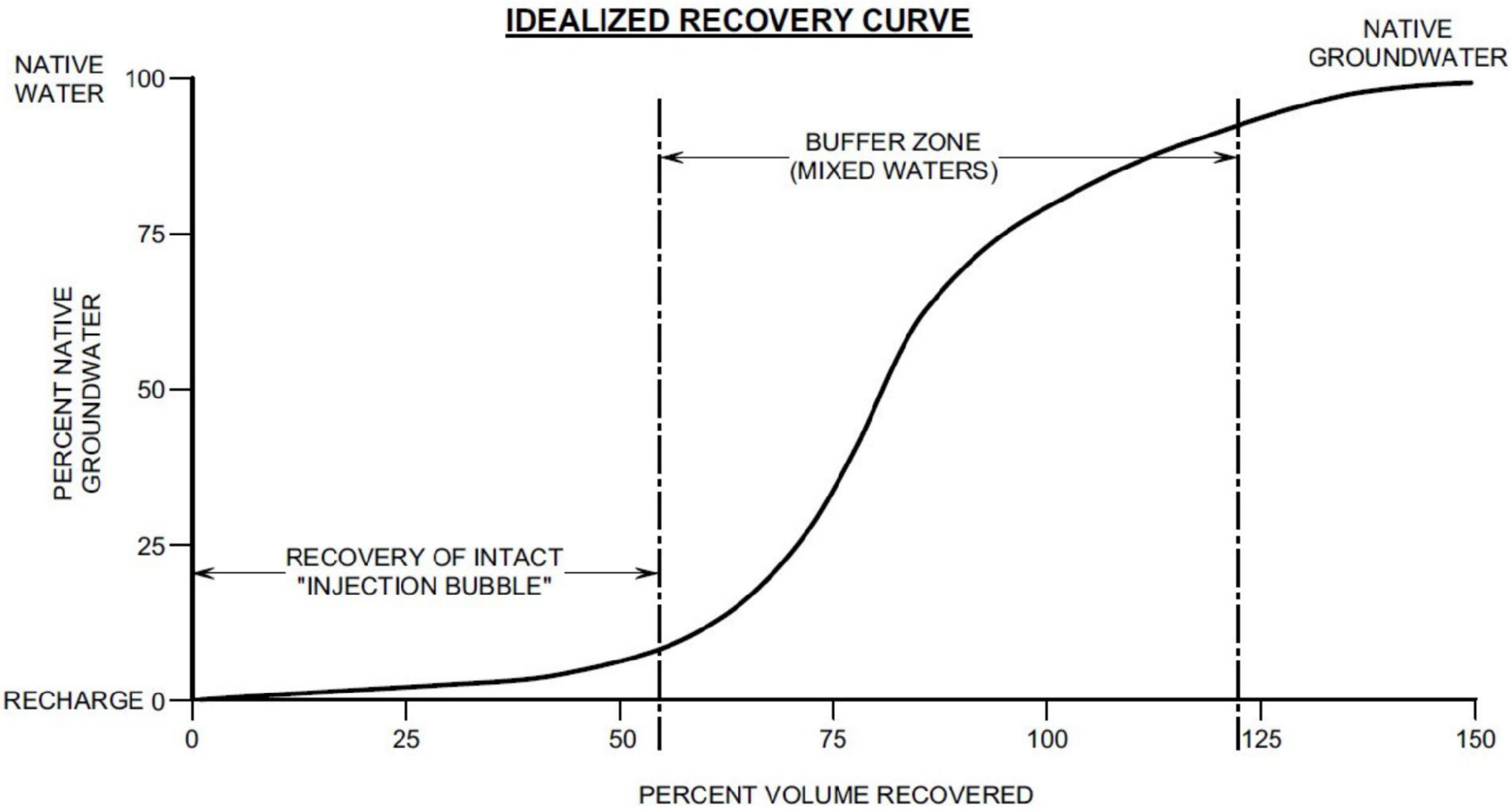
FIGURE 41. RECOVERY EFFICIENCY COMPARISON
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department



Source: Pyne (1996)

FIGURE 42. IDEALIZED RECOVERY EFFICIENCY CURVE
Phase 2 ASR Pilot Test - Beltz 8
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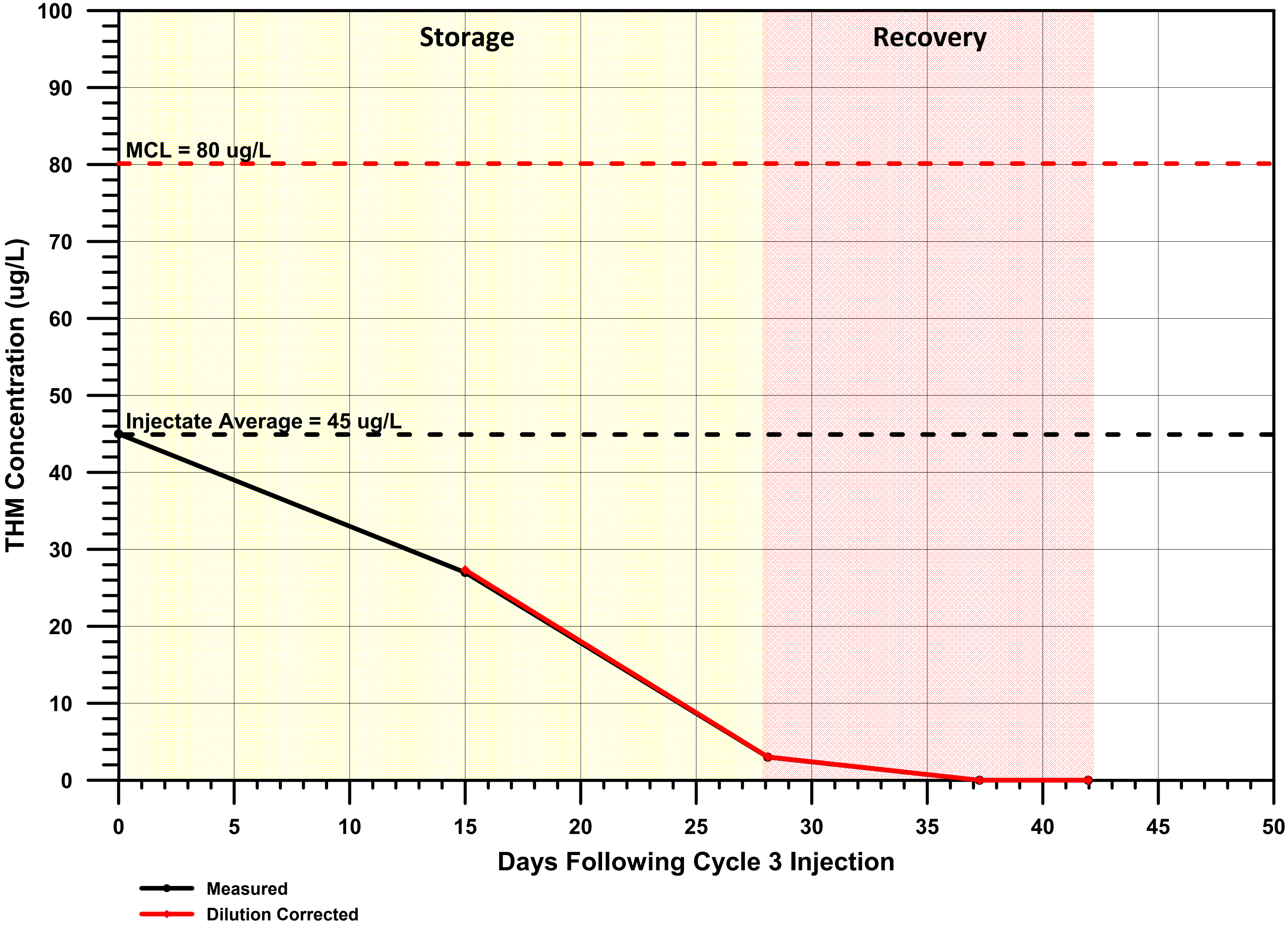

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FIGURE 43. ASR CYCLE 3 THM DATA
Phase 2 ASR Pilot Test - Beltz 8
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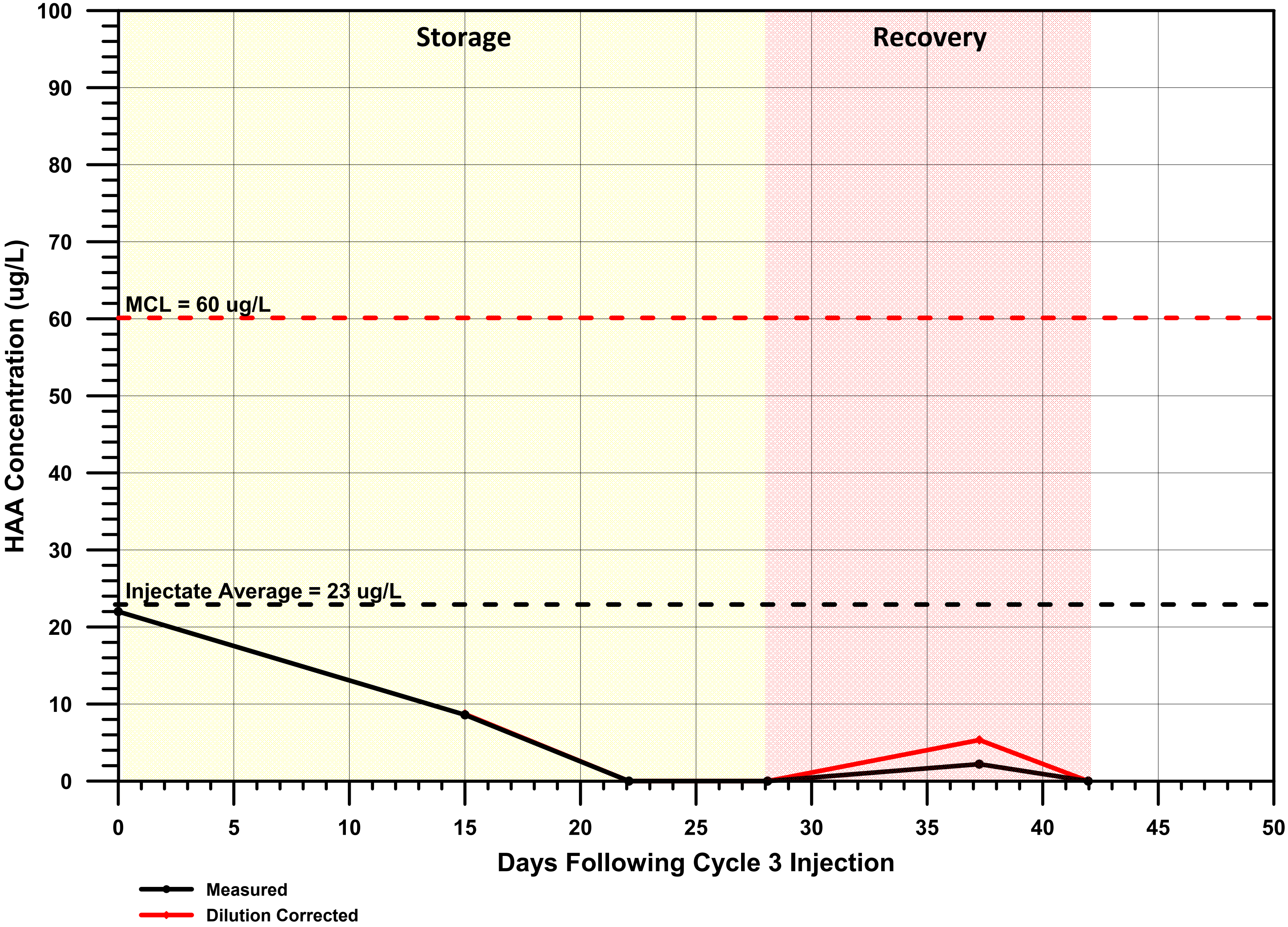

FIGURE 44. ASR CYCLE 3 HAA DATA
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

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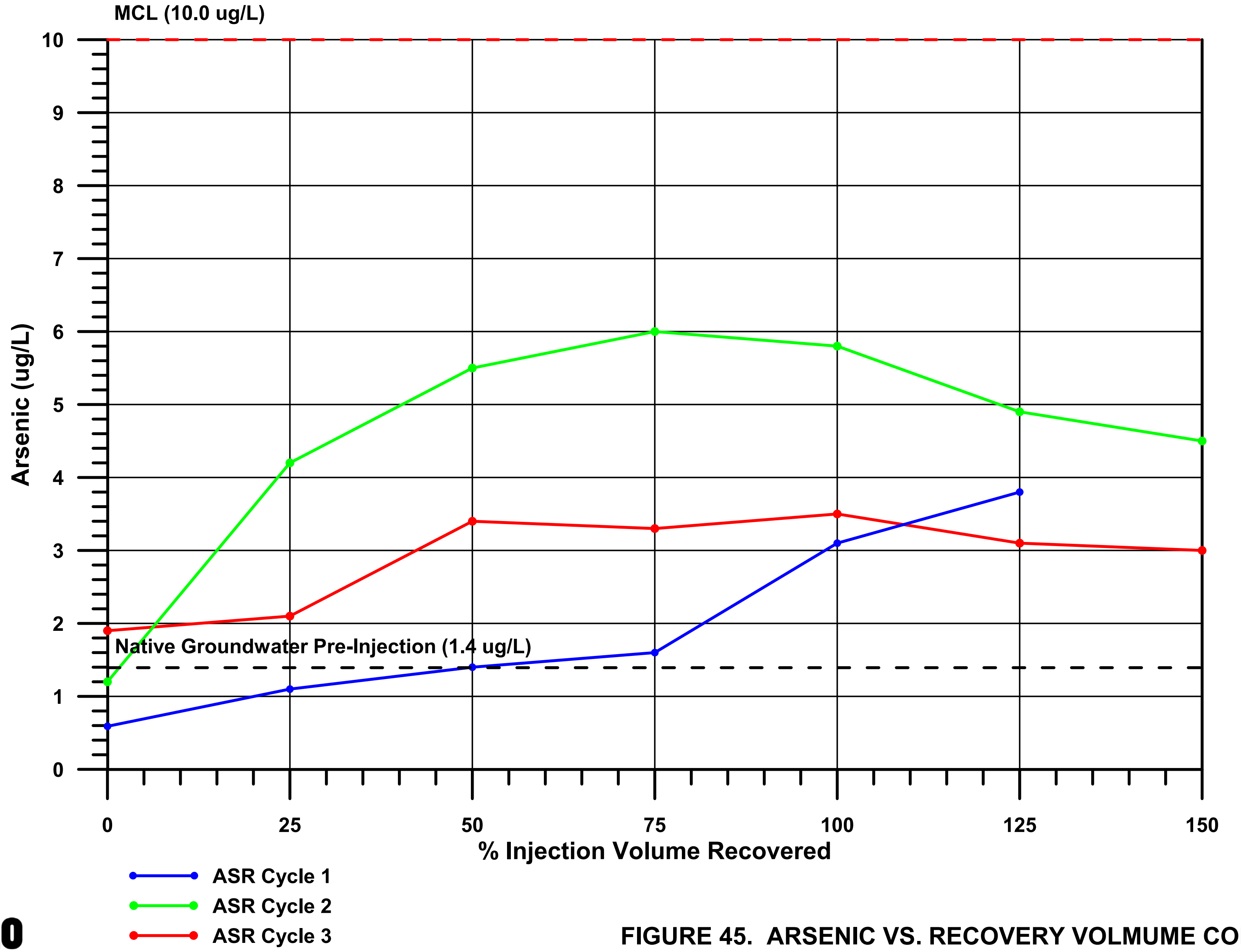

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FIGURE 45. ARSENIC VS. RECOVERY VOLMUME COMPARISON
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

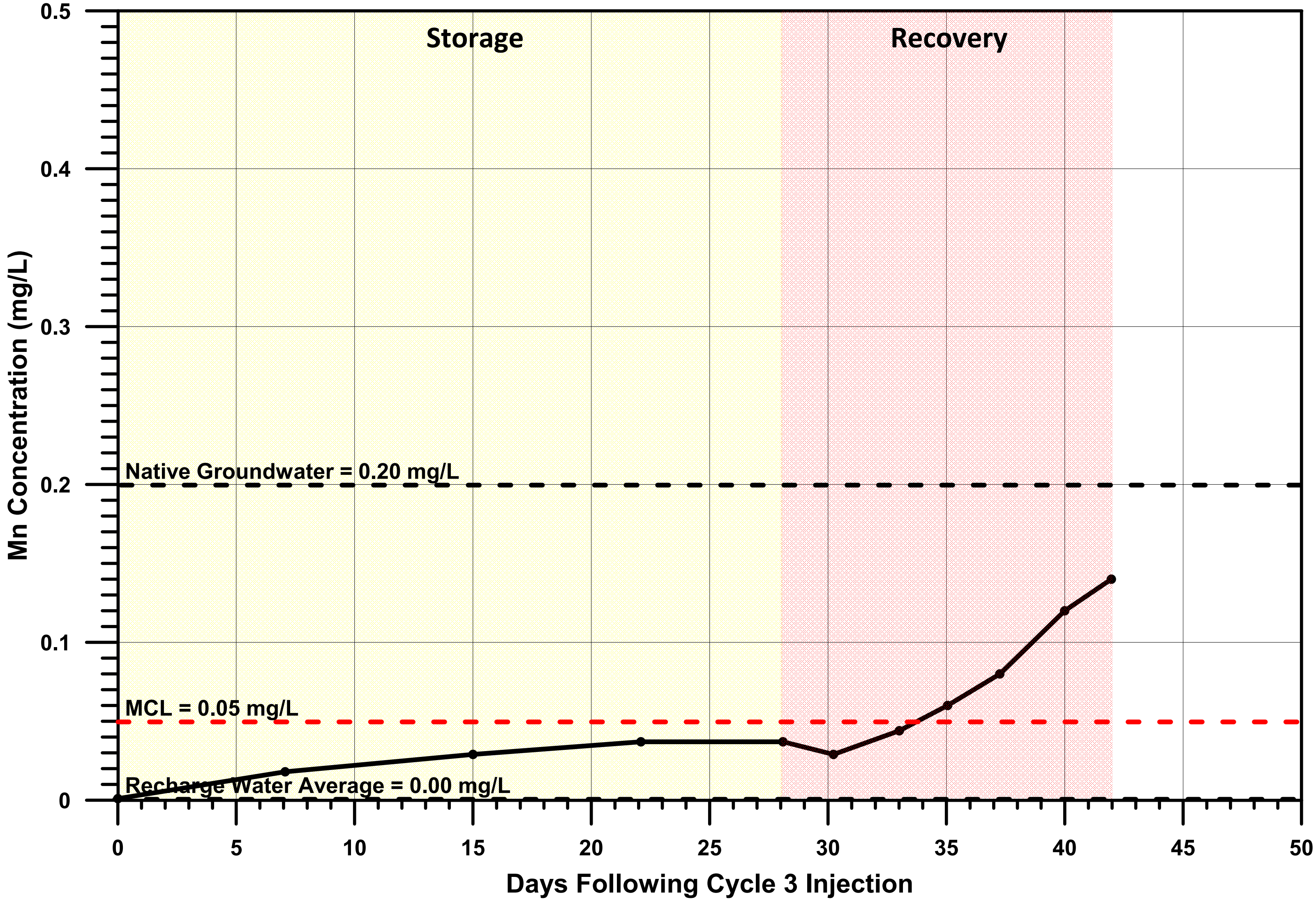

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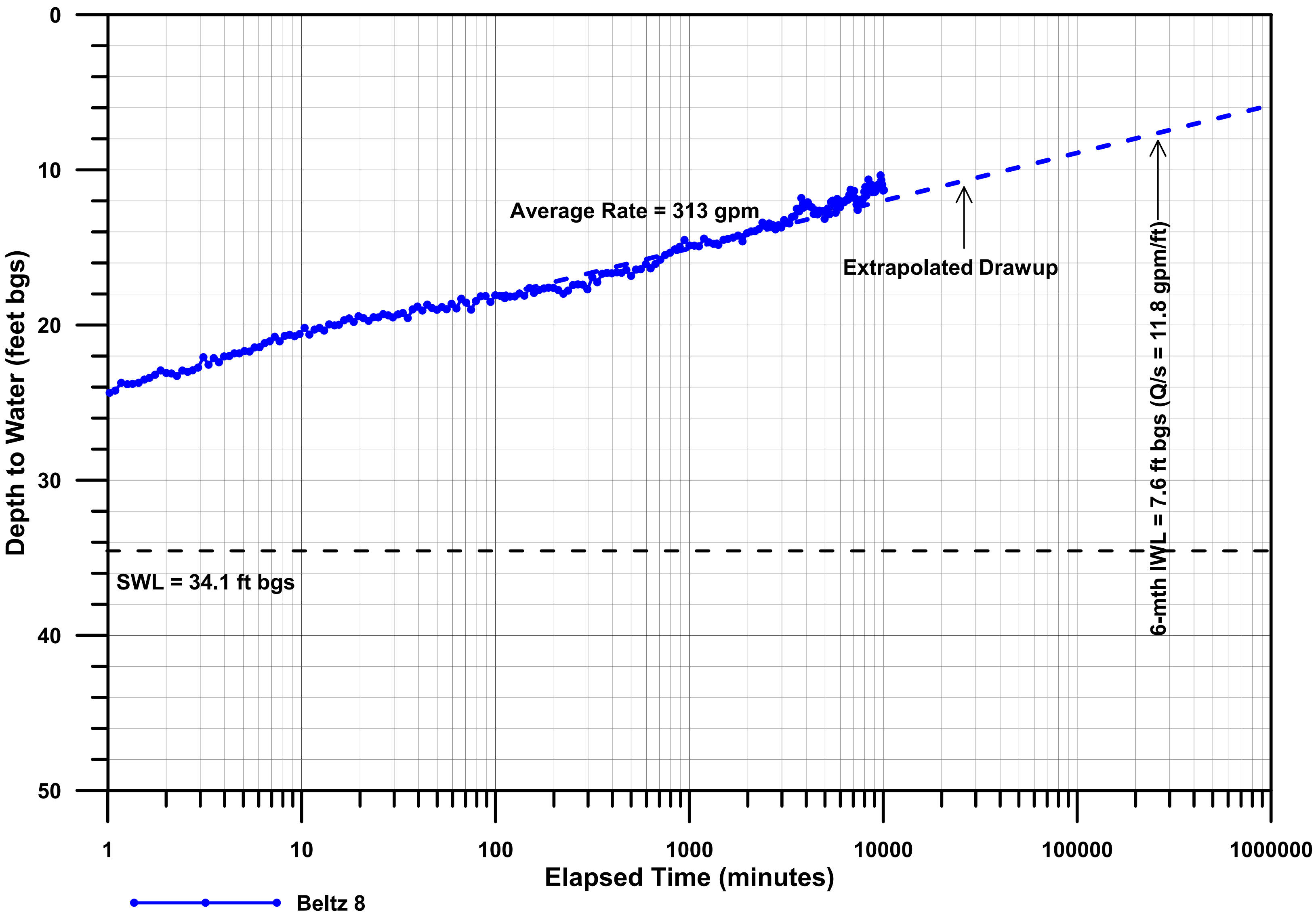
FIGURE 46. ASR CYCLE 3 MANGANESE DATA
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department



PUEBLO water resources

FIGURE 47. ASR CYCLE 2 - INJECTION CAPACITY ANALYSIS
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

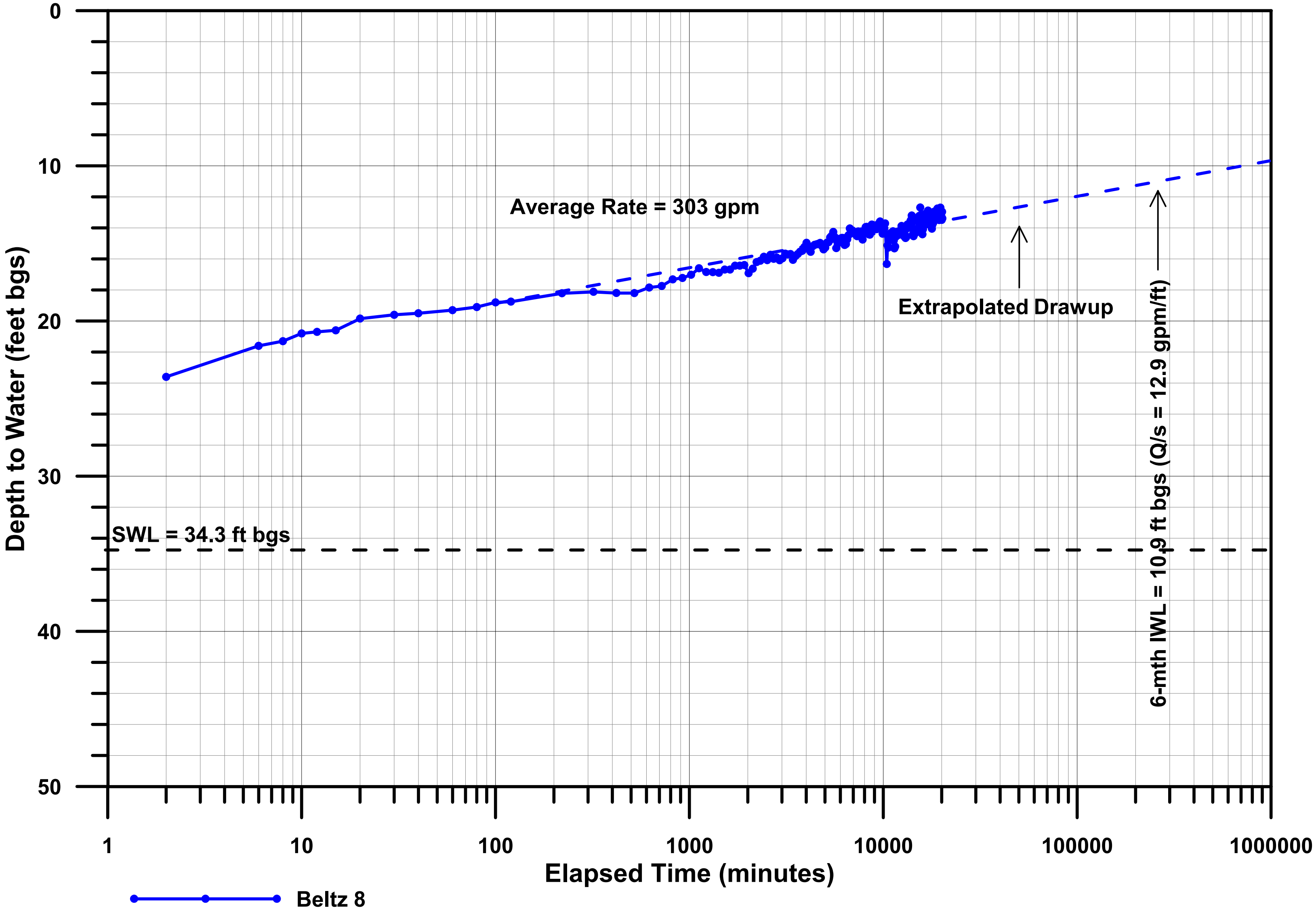


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FIGURE 48. ASR CYCLE 3 - INJECTION CAPACITY ANALYSIS
Phase 2 ASR Pilot Test - Beltz 8
Santa Cruz Water Department

APPENDIX A – WORK PLAN

TECHNICAL MEMORANDUM
Pueblo Water Resources, Inc.
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Ventura, CA 93003 Fax: 805.644.0480

To:	Santa Cruz Water Department	Date:	December 4, 2019
Attention:	Isidro Rivera, P.E. Associate Civil Engineer	Project No:	15-0111
Copy to:			
From:	Robert C. Marks, P.G., C.Hg. Principal Hydrogeologist		
Subject:	Santa Cruz ASR Project – Phase 1 Feasibility Investigation; Task 1.4 - ASR Pilot Test Work Plan for Beltz 8		

INTRODUCTION

Presented in this TM is a detailed Work Plan for implementing an Aquifer Storage and Recovery (ASR) pilot test program at the Santa Cruz Water Department (SCWD) Beltz 8 well. Beltz 8 is located in the Santa Cruz Mid-County Groundwater Basin (MCGB) and is screened in the A Unit of the Purisima Aquifer system. The location of the subject well is shown on **Figure 1** and an As-Built Schematic of the well is shown on **Figure 2**. The overall purpose of the Work Plan is to develop and present the information required to scope, budget, permit and implement an ASR pilot test program at Beltz 8. The Work Plan consists of the following main sections:

- Permitting Requirements
- Site Preparation Details
- ASR Pilot Test Program
- Sampling and Analysis Plan
- Preliminary Project Schedule

BACKGROUND

The SCWD is investigating the feasibility of an ASR project to meet projected shortfalls in City water supplies during extended droughts. The project would involve the diversion of "excess"[1] winter and spring flows from the San Lorenzo River (SLR) via the Tait Street and/or Felton Diversion facilities, which would be treated to potable standards at the Graham Hill Water Treatment Plant (GHWTP), then conveyed through the existing (and/or improved) water distribution system(s) to ASR wells located in the Santa Cruz Mid-County Groundwater Basin (MCGB) and/or the Santa Margarita Groundwater Basin (SMGB) for injection, storage and later recovery when needed.

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[1] "Excess" flows are those flows that exceed SCWD demands and in-stream flow requirements and are within City water rights.

The SCWD's ASR Project is being implemented in phases, as follows:

- Phase 1 – Technical Feasibility Investigation
- Phase 2 – ASR Pilot Testing
- Phase 3 – Permanent Project Design, Permitting, and Implementation

The Phase 1 Technical Feasibility Investigation is near completion (groundwater modeling is ongoing) and Phase 2 ASR Pilot Testing has been successfully implemented at the existing Beltz 12 well (the test program was completed in July 2019). Based on the favorable results of both the Phase 1 Technical Feasibility Investigation and Phase 2 ASR Pilot Testing at Beltz 12, the SCWD desires to further advance the Phase 2 ASR Pilot Testing program to the existing Beltz 8 well.

The overall objective of the Phase 2 pilot testing is to field verify the findings developed from Phase 1 and empirically determine specific hydrogeologic and water quality factors that will allow a technical and economic viability assessment of ASR technology at the Beltz 8 well. If feasible, the data gathered may also be used to complete CEQA documentation for a full scale or permanent ASR project and provide design basis information for the permanent project.

PURPOSE

The previous ASR pilot test was performed at the Beltz 12 well, which is completed in the AA and Tu Units of the Purisima Aquifer system in the MCGB. The primary purpose of the Beltz 8 ASR Pilot Test is to field demonstrate the potential application of ASR in the overlying A Unit of the Purisima Aquifer system, which differs in both hydraulic parameters and mineralogy from the AA and Tu Units. The data will be used to assess both the economic and logistical viability of ASR in the A Unit and will provide the basis for the design, environmental planning, and permitting for a long-term full-scale ASR project. Primary issues to be investigated in the ASR pilot test include the following:

- Determination of well efficiency and specific capacity and injectivity
- Evaluation of injection well plugging rates (both active and residual)
- Determination of optimal rates, frequency, and duration of backflushing to maintain injection capacity
- Determination of long-term sustainable injection rates
- Determination of local aquifer response to injection at Beltz 8
- Monitor ion exchange and redox reactions
- Evaluate water-quality changes during aquifer storage and recovery pumping
- Monitor Disinfection Byproducts (DBPs) Trihalomethanes (THM) and Haloacetic Acid (HAA) ingrowth and degradation during aquifer storage

- Monitor recovery efficiencies (with particular emphasis on manganese concentrations)

FINDINGS

PERMITTING REQUIREMENTS

The State Water Resources Control Board (SWRCB) has adopted general waste discharge requirements for ASR projects that inject drinking water into groundwater (Order No. 2012-0010-DWQ or ASR General Order). The ASR General Order provides a consistent statewide regulatory framework for authorizing both pilot ASR testing and permanent ASR projects, and the Beltz 8 ASR Pilot Test will be permitted under the ASR General Order. Oversight of these regulations is done through the Regional Water Quality Control Boards (RWQCBs) and obtaining coverage under the General ASR Order requires the preparation and submission of a Notice of Intent (NOI) application package to the local RWQCB. The NOI package for the Beltz 8 ASR pilot test program will be modeled on the NOI submitted to the Central Coast RWQCB for the Beltz 12 ASR pilot test, and include the following components:

- NOI application fee
- Complete Form 200 (RWQCB general information form for Waste Discharge Requirements or NPDES Permit)
- Technical Report
- US EPA Underground Injection Control registration
- CEQA compliance documentation

The main body of the NOI package consists of the Technical Report, which would be based largely on the findings developed from the Phase 1 Investigation, including the ASR pilot test Work Plan presented herein. The Beltz 8 well will need to be registered as a Class V Injection Well[2] with the US EPA Underground Injection Control (UIC) Program. This registration is a straight-forward process done via the EPA's on-line UIC Inventory Form.

In addition, the ASR General Order allows that a pilot test may be exempt from provisions of the California Environmental Quality Act (CEQA) under CEQA Guidelines Section 15306, which exempts basic data collection that does not result in a serious or major disturbance to an environmental resource. Accordingly, the City should plan to file a Notice of Categorical Exemption (CE) from CEQA for the ASR pilot test under CEQA Guidelines Section 15306 (including the drilling on an on-site monitoring well).

SITE PREPARATION DETAILS

The Beltz 8 well facility will need some preparatory work performed in order to maximize the potential for a successful the ASR pilot test program, including the following activities:

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[2] A Class V well is used to inject non-hazardous fluids underground.

- Installation of a proximate monitoring well;
- Rehabilitation of the Beltz 8 well, and;
- Installation of various temporary site improvements at the Beltz 8 facility.

Each of these activities are described in further detail in the following sections.

Monitoring Well

A proximate monitoring well that is located within the radius of injected water predicted to surround the subject well (i.e., within the injection "bubble") during the ASR pilot test well and that is completed in the same aquifer zones as the pilot test well is needed for monitoring of both water-level responses and water-quality interactions during the ASR pilot test program. Such a monitoring well is particularly important for the following investigative issues:

- Monitoring of ion exchange and redox reactions;
- Evaluation of water-quality changes during aquifer storage and recovery pumping, and;
- Monitoring of DBPs ingrowth and degradation during aquifer storage.

The existing monitoring well at the Beltz 8 facility is a converted former production well (Beltz 6); however, the screened interval of this existing monitoring well only partially penetrates the aquifer that is screened by Well 8 and, therefore, would not provide adequately representative data for the test program goals. Accordingly, a new monitoring well will need to be drilled at the site prior to initiating the ASR pilot test program and having the following key parameters:

- Located within 80 feet of Beltz 8 (i.e., within the planned radius of injected water influence);
- Completed to a total depth of approximately 190 feet with screens placed between depths of approximately 100 to 180 feet (i.e., matching the Well 8 screened interval);
- Constructed of 2-inch-diameter (minimum) Schedule 40 PVC casing and machine-cut horizontal slot screen;
- Sealed to a depth of approximately 80 feet, and;
- Completed in a grade-level traffic-rated monitoring well vault.

The proposed MW location is shown on **Figure 3** (note: the proposed MW location shown is approximate and may change slightly depending on logistical considerations at the time of drilling but is anticipated to be within 25 feet of the shown location).

Well Rehabilitation

Beltz 8 was drilled in 1998. Following its construction, it displayed a 24-hour specific capacity[3] of approximately 22.8 gpm per foot of drawdown (gpm/ft), and the performance has declined significantly with the recent 24-hour specific capacity at approximately 17.4 gpm/ft. This represents an approximate 25 percent decline in performance. Performing an ASR pilot test at the well with its current performance would be limited in terms of the injection and extraction rates that could be achieved and would not be representative of the potential ASR capacity that the aquifer system at the site is capable of supporting; therefore, the well needs to undergo formal rehabilitation to restore some of the lost performance to maximize the ASR capacity for the pilot test program.

To be effective, the rehabilitation program should consist of both mechanical and chemical well rehabilitation techniques and consist of the following tasks:

1. Performance of 100-minute pre-rehabilitation pumping test (700 gpm)
2. Removal of the existing pump and appurtenances from the well
3. Pre-rehabilitation downhole video surveying
4. Nylon brushing the well screen
5. Bailing the well to bottom
6. Installation of temporary piping, valving and storage tanks to allow for solids settling and acid neutralization of the discharge water
7. Pre-chemical simultaneous air-lift pumping/zone swabbing of the well screen
8. Chemical treatment with combination of hydrochloric and glycolic acids
9. Periodic agitation by "dry" swabbing screen while chemicals remain in well for 48 hours
10. Post-chemical simultaneous air-lift pumping/zone swabbing of the well screen
11. Post-rehabilitation acceptance downhole video surveying
12. Installation of temporary pump and appurtenances (this pump will remain in the well for the ASR pilot test)
13. Well disinfection and flushing
14. Performance of 100-minute post-rehabilitation pumping test (700 gpm)

Project discharges would be routed to the nearest storm drain inlet and maintained in compliance with the existing Statewide NPDES Permit for Drinking Water System Discharges (Order WQ 2014-0194-DWQ, General Order No. CAG140001).

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[3] Specific capacity is the ratio of discharge rate to drawdown, typically expressed in terms of gallons per minute per foot of drawdown (gpm/ft). The value is useful for tracking the performance of a given well over its service life and comparing performance between wells.

It is noted that the Beltz 8 well has not been rehabilitated since its construction nearly 20 years ago and the performance has declined significantly (by approximately 25 percent). Formal well rehabilitation of municipal production wells is typically recommended to be performed every 5 years or when the performance (as measured by specific capacity) has declined by 25 percent from baseline, whichever occurs first. Given these conditions, it is unlikely that rehabilitation will be capable of restoring 100 percent of the lost performance and capacity at this stage of the well's service life. For planning purposes, therefore, it is assumed that rehabilitation will restore 50 percent of the lost capacity. This assumption has been utilized in estimating the injection and extraction capacities for the ASR pilot test program (discussed in a below section).

Site Improvements

Several temporary modifications will be necessary at the Beltz 8 site for implementation of the ASR pilot test, including the following:

- Removal of the existing HP pump assembly and installation of a temporary 30 HP pump and injection drop tubes.
- Connection of temporary injection supply pipeline to the City's distribution system as the source of the injection water (injectate).
- Setup of backflush water and recovered test water pipelines
- Setup of connection to existing on-site reclaim tanks for backflush water solids settling and dichlorination prior to discharge to storm drain

A schematic of the preliminary piping plan is shown in **Figure 4**, which shows the locations of various valves, meters, sampling ports, pressure gauges, etc., in addition to the direction of flows during the recharge and pumping phases of the test program.

Based on the results of the revised site-specific injection capacity analysis for Beltz 8 incorporating an assumed improvement in well performance from well rehabilitation (as noted above), a nominal injection rate of **400 gpm** is recommended for planning purposes. For an injection rate of 400 gpm, a minimum backflush pumping capacity of 800 gpm will be required (i.e., twice the rate of injection) in order to limit well plugging during the test program (refer to the Task 1.2 – Site-Specific Injection Capacity Analysis TM for a discussion of backflushing requirements).

The existing 25 HP pump assembly in Beltz 8 is only rated for approximately 550 gpm @ 100 ft Total Dynamic Head (TDH). The test program will require a pump that is rated for 800 gpm @ 100 ft of TDH for backflushing of the well during the pilot test; therefore, a temporary pump assembly will need to be installed in Beltz 8 with the following general specifications:

1. Removal of the existing 25 HP pump assembly (and cleaned and inspected by the pump contractor).
2. Fabrication of special temporary wellhead seal plate.

3. Installation of temporary submersible pump (Grundfos 800S300-1 [30 HP], or approved equal) set to a depth of approximately 190 ft with a cooling shroud.
4. Installation of three (3) 2-in-dia Sch 40 PVC injection drop tubes. Injection drop tubes shall be F480 flush-threaded set to a depth approximately 80 ft. Special orifice caps for each tube will be provided by PWR for injection flow control.
5. Installation of two (2) 1-in-dia Sch 40 PVC water-level sounding tubes set to a depth of approximately 190 ft.

ASR PILOT TEST PROGRAM

ASR operations generally consist of three steps:

1. Injection of potable-quality drinking water into the aquifer;
2. Storage of the injected/recharged water within the aquifer, and;
3. Recovery of the stored water.

The ASR pilot test program for Beltz 8 presented herein is modeled on the program that was successfully implemented at Beltz 12 but modified for the Beltz 8 site-specific conditions. The structure of the ASR pilot test program includes numerous incremental steps of ASR operations to provide multiple checkpoints in the event that pilot operations deviate significantly from the predicted responses. The program will generally involve three repeated ASR cycles of operations and monitoring, each of larger volume and duration than the preceding cycle, so that if adverse conditions are encountered at any point, the program can be adjusted, if needed.

Summary of ASR Cycles

The ASR pilot test program generally consists of a 1-day hydraulic “pre-test” to establish injection system hydraulics, followed by three (3) repeated cycles of injection-storage-recovery, with each cycle of greater duration and volume. A robust dataset of aquifer response and water quality information will be developed, while minimizing the risk of adverse effects to the well or aquifer system. A summary of the planned ASR cycles is presented in **Table 1** below:

Table 1. Summary of ASR Cycles

ASR Cycle No.	Injection					Storage	Recovery				
	Period (days)	Rate (gpm)	Total Volume (mg)	Total Volume (af)	Radius (ft)	Period (days)	Period (days)	Rate (gpm)	Volume (mg)	Volume (af)	Discharge Location
1	1	400	0.58	1.77	18	2	1	700	1.01	3.09	Storm Drain
2	7	400	4.03	12.4	46	14	6	700	6.05	18.6	Storm Drain
3	30	400	17.3	53.0	96	60	30	400	17.3	53.0	Distribution

Total Active Duration (days):	151
Total Injection Volume (mg):	21.9
Total Recovery Volume (mg):	24.3

As shown, the amount of water injected during each ASR Cycle will vary from approximately 0.6 mg (1.8 af) to 17 mg (53 af), with aquifer storage periods ranging from 2 to 60 days before the water is recovered. Recovery volumes for Cycles 1 and 2 are approximately 150 percent of the previously injected water and will vary from approximately 1 mg (3.1 af) to 7 mg (22 af). The recovery volume for Cycle 3 will be the same as the injected volume (17 mg / 53 af) and will essentially mimic a permanent project typical ASR cycle.

Although no adverse reactions were predicted by the Task 1.3 Geochemical Interaction Analysis[4], or seen during piloting of ASR at Beltz 12, it is planned to discharge recovered water during ASR Cycles 1 and 2 to the storm drain system to allow for the collection and analysis of water-quality data to ensure that no adverse reactions are occurring during aquifer storage that would affect the potability of recovered water. It is our understanding that the water-quality results from Cycles 1 and 2 will need to be provided to the local Department of Drinking Water (DDW) for their review and approval to pump Cycle 3 recovery flows into the SCWD distribution system[5].

Assuming no adverse reactions are observed during ASR Cycles 1 and 2, the temporary test pump and injection drop tubes will be removed from the well (following thorough backflushing of the well) and the permanent pump assembly reinstalled prior to the recovery period of Cycle 3, allowing the well to be operated under normal conditions (which includes manganese treatment prior to distribution). It is also noted that the recovery rate for ASR Cycle 3 is limited to 400 gpm (refer to **Table 1 above**), compared to 700 gpm (approximately 1 mgd) for Cycles 1 and 2. This is due to the capacity of the permanent pump and manganese treatment system at the Beltz 8 facility, which is limited to 400 gpm.

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[4] Assuming GHWTP water is maintained at pH of 7.6 or less to prevent calcite precipitation.

[5] If necessary, Cycle 3 recovery flows can be directed to the storm drain as well

The primary test objectives for each ASR Cycle are summarized below:

ASR Cycle 1

- Establish short-term injection hydraulics
- Monitor short-term ion exchange reactions

ASR Cycle 2

- Measure well plugging rates (active and residual)
- Evaluate backflushing efficacy
- Monitor longer-term ion exchange reactions
- Monitor redox reactions
- Evaluate water chemistry changes during storage
- Monitor recovery efficiency (the percentage of recharged water that is recovered during each cycle)
- Monitor DBPs during recovery
- Define volume of potential "buffer zone" around ASR well

ASR Cycle 3

- Evaluate longer-term well performance and plugging rates
- Monitor injected water quality stability during storage
- Monitor DBP ingrowth/degradation during storage
- Monitor recovered water for re-chlorination and DBP reformation
- Determine economic factors of permanent ASR operations

The total duration of the ASR pilot test program is anticipated to require approximately 6 months and is tentatively scheduled to begin in February 2019 (refer to the preliminary schedule presented in a following section).

Specific procedures for well injection and backflushing during the Beltz 8 ASR Pilot Test Program are outlined below:

Injection Procedures

1. Adjust valving to flush the potable system supply to the storm drain. Set de-chlorination equipment as needed.
2. Initiate system flow to storm drain to flush the distribution system of pipe scale/residue/particulates. Flushing rate should be at least 125 % of maximum ASR injection rate.

3. Perform Silt Density Index (SDI) test on flowing water stream. Record flush meter reading, time, and SDI value.
4. Repeat SDI test after 20-30 minutes. When two successive results of SDI < 3.0 are achieved, injection operations can be initiated.
5. Upon initiation of injection operations for the test program, perform a backflush 24 hours after commencement of injection to ensure material sloughed off system piping from flow reversals in the distribution system is backflushed out of the well.
6. Regularly monitor SDI. If SDI > 5.0, immediately stop injection operations, backflush the well, and flush the distribution system to waste until SDI < 3.0 is restored.

Backflushing Procedures

1. Record all meter readings and water levels.
2. Stop injection flow to well, being careful to avoid both water hammer to the distribution system (i.e., by closing valves to quickly) and prolonged negative pressure/cascading water conditions in the well as practical.
3. Record all meter readings and water levels.
4. Adjust valving to ‘backflush position’, routing well production to the on-site tanks.
5. Start well at backflush rate setpoint (800 gpm) and pump for 15 minutes. Measure and record Turbidity at 1, 2, 5, 10 and 15 minutes of elapsed pumping time. Observe visual water clarity and particulate content and note observations. Turn pump off, noting the minimum ‘off-time’ (restart delay) for the specific pump motor in service.
6. Repeat Step 5 a total of 3 times, or until the discharge water is visually clear and less than 10 NTU within 1 minute of pump start-up.
7. When static water level has stabilized (15-minute minimum), start pump and set flow to normal recovery rate (700 gpm for Cycles 1 and 2, and 400 gpm for Cycle 3). Record 10-minute pumping water level and flow rate, calculate and record 10-minute specific capacity.
8. Record all meter readings and water levels.
9. Adjust valving as needed to next ASR operation (e.g., return to injection, storage, or recovery mode).
10. Following sufficient storage period to allow for solids settling and de-chlorination to meet discharge requirements, drain clear water from tanks to storm drain and ready for next backflushing event.

SAMPLING AND ANALYSIS PLAN

During the Beltz 8 ASR Pilot Test Program, a variety of water-level and water-quality data are to be collected. Water levels in the aquifer system are to be monitored during all phases at the ASR pilot testing well (Beltz 8) as well as several existing, proximate monitoring wells owned by both SCWD and Soquel Creek Water District (SqCWD). In addition, periodic samples of the injected, stored, and recovered waters are to be collected from the Beltz 8 pilot test well and the to-be-constructed Beltz 8 monitoring well (discussed above) and analyzed for a variety of water-quality constituents. The purpose of the Sampling and Analysis Plan (SAP) described below is to identify the locations, sample collection frequency, and parameters to be monitored as part of the ASR pilot test project data collection program.

Project Wells

The Beltz 8 well facility is located in the western portion of the City's service area. Several proximate existing monitoring wells owned both by the SCWD and SqCWD will also be utilized as monitoring wells during the project. The locations of the project wells are shown on **Figure 5** and a summary of project well completion parameters are presented in **Table 2** below:

Groundwater Monitoring Equipment

The equipment required to perform the groundwater monitoring as prescribed in this SAP includes:

- Pressure Transducers/Data Loggers
- Electric Water-Level Sounder
- Sampling Pumps
- Field Water-Quality Monitoring Devices
- Flow-Thru Cell Device(s)
- Sample Containers
- Coolers and Ice

Beltz 8 will be equipped with a temporary 30 HP electric submersible pump. Flow for all process streams will be measured using in-line rate and totalizing flow meters. Sampling ports on the well-head piping allow for the collection of grab samples during recharge and pumping operations. In addition, a submersible sampling pump (Grundfos Redi-Flo2) will be installed in the to-be-constructed on-site Beltz 8 monitoring well and utilized to collect periodic water-quality samples from the aquifer.

Field water-quality monitoring is to be performed using various instruments that allow for the field analysis of a variety of constituents, including but not limited to: chlorine residual, conductivity, dissolved oxygen, pH, temperature, redox/ORP, and Silt Density Index (SDI). The field water-quality monitoring devices are to be routinely calibrated as prescribed in the operating procedures manual for each device.

Table 2. Project Well Construction Summary

Well	Distance from Beltz 8 (ft)	Depth (ft bgs)	Dia (in)	Screen Intervals (ft bgs)	Tp Unit(s) Completed
Beltz 8	--	210	14	100 - 180	A
Beltz 8 MW	50	190	2	100 - 180	A
Beltz 4 MW	945				
shallow		90	2	50 - 80	A (upper?)
deep		135	2	115 - 125	A (lower?)
Beltz 10	1010	362	8	100 - 357	AA
Beltz 9	2120	230	14	110 - 200	A
30th Ave	2385				
shallow		240	2	200 - 240	A
medium		410	2	370 - 410	AA
deep		800	2.5	720 - 800	Tu
Pleasure Pt	2565				
shallow		140	2	110 - 130	A (upper)
medium		240	2	210 - 230	A (lower)
deep		355	2	325 - 345	AA (upper?)
Corcoran Lagoon	2740				
shallow		40	2	30 - 40	A (upper)
medium		100	2	80 - 100	A (lower)
deep		195	2	175 - 195	AA (upper?)
SC-1A*	3670	320	2.5	113 - 320	A
SC-22 *	3675				
shallow		240	2	150 - 230	A
medium		500	2	460 - 490	AA (upper)
deep		705	2	640 - 700	AA (lower)
SC-13*	3745	820	2	760 - 770	AA/A
Moran Lake	4025				
shallow		170	2	130 - 170	A (upper)
medium		225	2	205 - 225	A (lower)
deep		295	2	255 - 295	AA (upper?)
Soquel Pt	4190				
SP-3		130	2	110 - 130	A (upper)
SP-2		270	2	250 - 270	AA (lower)
SP-1		330	2	310 - 330	AA (upper?)

Notes:

Tp - Purisima Formation

* - SqCWD monitoring well

The pilot test well, as well as the monitoring wells listed in **Table 2**, will be instrumented with dedicated pressure/level transducers and dataloggers[6]. Reference-point elevations will be established by existing survey records for the wells. Static water-levels will be manually measured with an electric sounder on a monthly basis (minimum) and the transducers calibrated accordingly. The transducers are to be programmed with the reference static water-level and the appropriate data-collection intervals.

Purging and Sampling

During injection periods, samples of the recharge water will be collected directly at the Beltz 8 wellhead while active injection is occurring. During storage periods, the well will be periodically purged and sampled per the below Sampling Schedule. During recovery periods, the well pump will be operating, therefore sample purging is continuous and sustained.

The sampling pumps will be used to purge a volume equivalent to a minimum of three (3) casing volumes from each well (Beltz 8 and Beltz 8 MW) prior to sampling. Purge water from the pilot well during backflushing and sampling is to be discharged to holding tanks on site (existing Reclaim tank) for surge suppression and analysis prior to discharge to the on-site storm drain system. Water produced by the well during Cycles 1 and 2 recovery operations will also be discharged to the storm drain. The water-quality data collected during Cycles 1 and 2 are intended to demonstrate the potability of recovered water - assuming the results are favorable, Cycle 3 recovery operations will pump into the distribution system (i.e., to minimize “wasting” of water during the pilot test program).

During purging and prior to sampling, field water-quality parameters of temperature, pH and specific conductance are to be monitored. Stabilization of these water-quality parameters will indicate when collection of a representative sample is allowable.

Laboratory Program

A complete list of constituents and constituent “groups” to be monitored as part of the Beltz 8 ASR Pilot Test Project for injected, stored, and recovered waters is presented in **Table 3** below:

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[6] Most of the project monitoring wells have existing water level transducers / dataloggers programmed on hourly data collection intervals, which will be maintained and utilized during the pilot test; Beltz 8 and the on-site monitoring well will have supplemental instrumentation installed by PWR and programmed with variable data collection intervals (i.e., depending on the phase of testing and particular well).

Table 3. Analytic Testing Program Constituent Summary

Parameter	Location of Analysis	Method	Unit	PQL	Field Parameters	Geo-chemical	Disinfection By-Products	Supple-mental
Group ID					**F-1**	**G-1**	**DBPs**	**S-1**
Field Parameters								
Cl Residual	on-site	Hach	mg/L	0.05	x			
Diss O2	on-site	Hach	mg/L	0.2	x			
EC	on-site	EPA 120.1	umho/cm	10	x			
ORP	on-site	USGS	mV	10	x			
pH	on-site	EPA 150.1	Std Units	0.01	x			
SDI	on-site		Std Units	0.01	x			
Temperature	on-site	SM 2550	°C	0.5	x			
Turbidity	on-site	Hach 2100Q	NTU	0.1	x			
General Mineral Analysis								
Alkalinity (Total)	Lab	SM2320B	mg/L	5		x		x
Ca	Lab	EPA 200.7	mg/L	0.03		x		x
Cl	Lab	EPA 300.0	mg/L	0.5		x		x
EC	Lab	EPA 120.1	umho/cm	10		x		x
F	Lab	EPA 300.0	mg/L	0.1		x		
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		x		x
Fe (Total)	Lab	EPA 200.8	mg/L	0.05		x		x
K	Lab	EPA 200.8	mg/L	1		x		x
MBAS	Lab	SM 5540C	mg/L	0.05		x		
Mg	Lab	EPA 200.8	mg/L	0.5		x		x
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		x		x
Mn (Total)	Lab	EPA 200.9	mg/L	0.05		x		x
Na	Lab	EPA 200.7	mg/L	0.05		x		x
NH3	Lab	EPA 350.1	mg/L	0.05		x		
NO2	Lab	EPA 300.0	mg/L	0.1		x		x
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1		x		x
P (Total)	Lab		mg/L	0.001		x		
pH	Lab	EPA 150.1	Std Units	0.01		x		x
SiO2	Lab	EPA 370.1	mg/L	2		x		
SO4	Lab	EPA 300.0	mg/L	0.5		x		x
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		x		
TDS	Lab	SM2540C	mg/L	5		x		x
TKN	Lab	EPA 351.2	mg/L	0.2		x		

Table 3. Analytic Testing Program Constituent Summary (con't)

Parameter	Location of Analysis	Method	Unit	PQL	Field Parameters	Geo-chemical	Disinfection By-Products	Supple-mental
Group ID					**F-1**	**G-1**	**DBPs**	**S-1**
Inorganic Trace Metals								
Ag	Lab	EPA 200.8	ug/L	10		x		
Al	Lab	EPA 200.8	ug/L	10		x		
As	Lab	EPA 200.8	ug/L	1		x		x
B	Lab	EPA 200.8	ug/L	50		x		
Ba	Lab	EPA 200.7	ug/L	1		x		
Be	Lab	EPA 200.8	ug/L	1		x		
Br	Lab	EPA 200.9	ug/L	100		x		x
Cd	Lab	EPA 200.8	ug/L	1		x		
Co	Lab	EPA 200.8	ug/L	1		x		
Cr	Lab	EPA 200.8	ug/L	10		x		
Cu	Lab	EPA 200.8	ug/L	5		x		
Hg	Lab	EPA 200.8	ug/L	0.025		x		x
I	Lab	EPA 200.8	ug/L	100		x		
Li	Lab	EPA 200.7	ug/L	1		x		
Mo	Lab	EPA 200.8	ug/L	5		x		
Ni	Lab	EPA 200.8	ug/L	1		x		
Pb	Lab	EPA 200.8	ug/L	1		x		
Sb	Lab	EPA 200.8	ug/L	1		x		
Se	Lab	EPA 200.8	ug/L	5		x		
Sr (Total)	Lab	EPA 200.7	ug/L	1		x		
Sr 86/Sr 87 (ratio)	Lab	EPA 200.8	ug/L	0.1 (ratio acuracy)		x		
Tl	Lab	EPA 200.8	ug/L	1		x		
U	Lab	EPA 200.8	ug/L	0.5		x		
V	Lab	EPA 200.8	ug/L	1		x		
Zn	Lab	EPA 200.8	ug/L	10		x		
Bio / Organics								
Coliform	Lab		CFU	<1		x		
HAA5's	Lab	EPA 552.2	ug/L	1			x	
HPCs	Lab	SM9215B	CFU	<1		x		
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1			x	
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1			x	
TTHM's	Lab	EPA 502.2	ug/L	1			x	
Miscellaneous								
CH4	Lab	RSK-175	ug/L	5		x		
Gross Alpha	Lab	EPA 900.0	pCi/L			x		
Color	Lab	SM2120B	Color Units	3		x		
Hardness	Lab	SM2340B	mg/L	10		x		
Tu	Lab	EPA 180.1	NTU	0.1		x		
TSS	Lab	EPA 160.2	mg/L	1		x		

Notes:

F-1 parameters to be measured concurrently with collection of G-1, DBP and S-1 samples.

Sampling Schedule

The planned sample constituent group frequencies for each source for the injection, storage, and recovery periods for each ASR Cycle are summarized below.

Baseline. Prior to Cycle 1 injection, samples will be collected from Beltz 8 and the to-be-constructed on-site monitoring well (MW) and analyzed for F-1, G-1 and DBPs Group parameters to establish baseline conditions.

ASR Cycle 1. The sampling schedule for Cycle 1 is presented in **Table 4** below:

Table 4. Sampling Schedule – ASR Cycle 1

Analyte Group	Injection		Storage		Recovery	
	Injectate	MW	Beltz 8	MW	Beltz 8	MW
F-1	Once	--	@end	--	@ 25, 50, 75, 100, 125 & 150%	--
G-1	Once	--	@end	--	@ 50 and 100%	--
DBP	Once	--	@end	--	@ 100%	--
S-1	--	--	--	--	@ 25, 75, 125, & 150%	--

As shown, the full suite of parameters (F-1, G-1, and DBPs) will be collected of the injectate once during the 1-day injection period of Cycle 1. One sample of the stored water will be collected from Beltz 8 at the end of the 2-day storage period. During recovery pumping, G-1 samples will be collected at 50 and 100 **percent recovery of the injection volume**, supplemented with the shorter S-1 group at 25, 75, 125 and 150 percent. No samples are planned to be collected from the on-site monitoring well during Cycle 1 due to the limited volume of injection not anticipated to be sufficient to arrive at the well during the cycle.

ASR Cycle 2. The sampling schedule for Cycle 2 is presented in **Table 5** below:

Table 5. Sampling Schedule – ASR Cycle 2

Analyte Group	Injection		Storage		Recovery	
	Injectate	MW	Beltz 8	MW	Beltz 8	MW
F-1	Once	--	Weekly	@end	@ 0, 25, 50, 75, 100, 125 & 150%	@end
G-1	Once	--	Weekly	@end	@ 0, 50 and 100%	@end
DBP	Once	--	Weekly	@end	@ 0 & 100%	@end
S-1	--	--	--	--	@ 25, 75, 125, & 150%	--

As shown, the sampling schedule for Cycle 2 is similar in scope to Cycle 1 but expanded somewhat and also includes some limited sampling of the on-site monitoring well. During the 1-week injection period, again only one sample is needed. During the 2-week storage period, two samples will be collected from Beltz 8 and one sample collected from the on-site monitoring well at the end of the period. During recovery pumping, samples will be collected from Beltz 8 at similar percent recovery points as described above for Cycle 1, with one sample collected from the on-site monitoring well at the end of the period.

ASR Cycle 3. The sampling schedule for Cycle 3 is presented in **Table 6** below:

Table 6. Sampling Schedule – ASR Cycle 3

Analyte Group	Injection		Storage		Recovery	
	Injectate	**MW**	**Beltz 8**	**MW**	**Beltz 8**	**MW**
F-1	Weekly	Weekly	Weekly	Weekly	@0, 25, 50, 75, & 100%	Weekly
G-1	Once	Once	Once	Once	@ 0, 50 and 100%	@ 0, 50 and 100%
DBP	Weekly	Weekly	Weekly	Weekly	@0, 25, 50, 75, & 100%	Weekly
S-1	Weekly	Weekly	Weekly	Weekly	@ 25 & 75%	Weekly

As shown, the sampling schedule for Cycle 3 is the most intensive. This is due to both the extended duration and larger volumes of injection and recovery during Cycle 3. In particular, it is anticipated that the injected water will fully envelope the on-site monitoring well during the injection period; therefore, sampling at this monitoring well is more relevant during Cycle 3 than the previous cycles. During the 30-day injection period, weekly samples will be collected from both Beltz 8 and the monitoring well for the F-1, DBP and S-1 groups, with one sample of the full G-1 suite collected. A similar schedule is planned for the 60-day storage period. During the 30-day recovery period, samples will be collected from Beltz 8 at similar percent recovery levels as the previous cycles, with weekly samples collected from the on-site monitoring well.

PRELIMINARY PROJECT SCHEDULE

A preliminary schedule for the Beltz 8 ASR Pilot Test Program is presented in **Table 7** below:

Table 7. Preliminary Project Schedule

Task / Activity	Time Period	Duration (months)
CEQA and Permitting	Nov 2019 - Jan 2019	3
Monitoring Well Drilling	Jan 2020	0.75
Well Rehabilitation	Jan - Feb 2020	1
Site Preparation	Feb 2020	0.25
ASR Cycles	Mar 2020 - Aug 2020	6
Data Analysis and Reporting	Sep 2020 - Oct 2020	2
	Total:	**12**

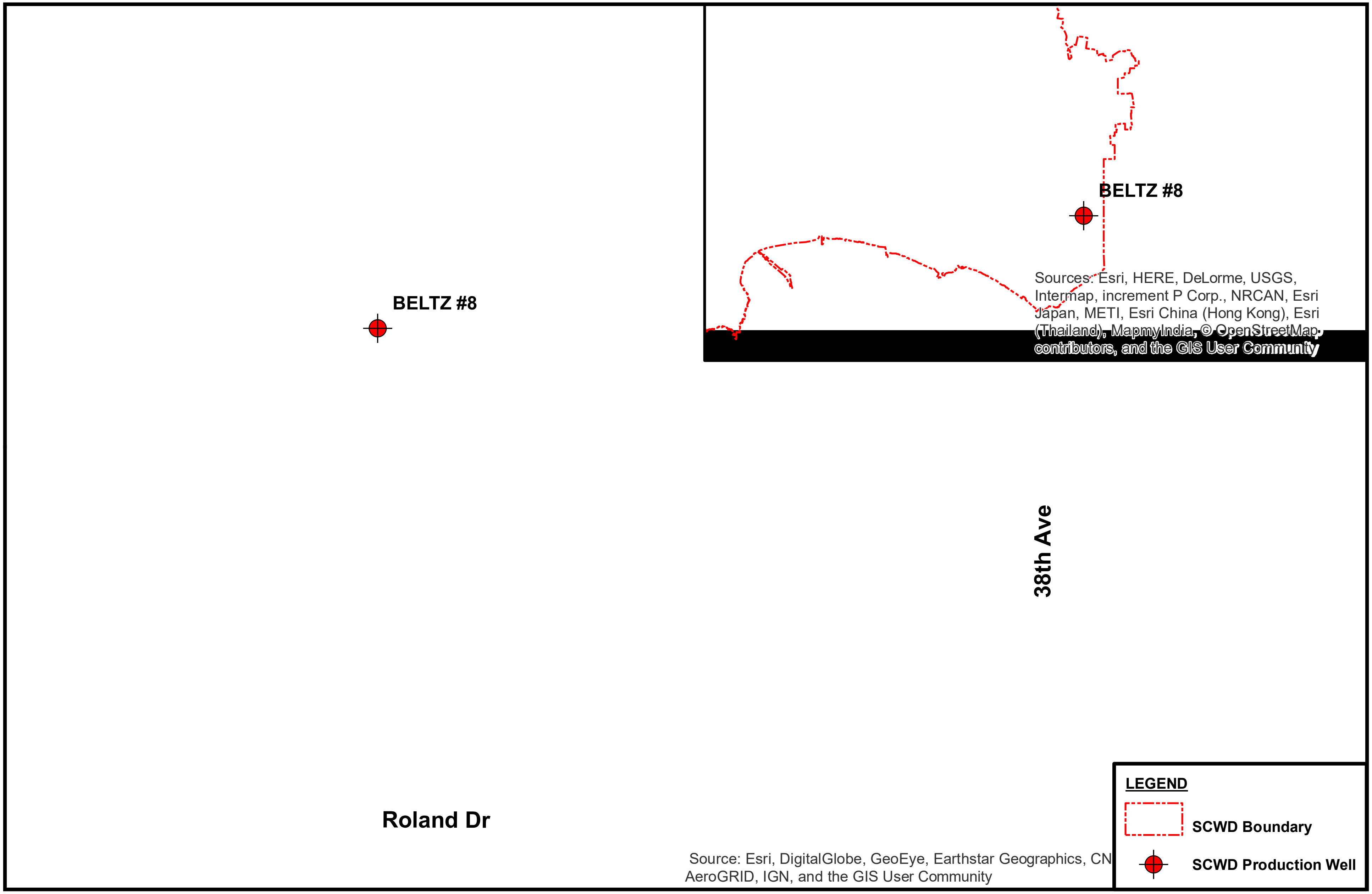
As shown, the ASR cycles are planned to be implemented during the winter/spring of the 2020 water year when excess SLR flows are anticipated to be available (i.e., through the month of May 2020). There is an estimated 4 months of CEQA/permitting and site preparatory work (including monitoring well drilling and well rehabilitation) to be completed prior to implementing the test program; therefore, this work will need to be initiated no later than November 2019. Data analysis, reporting and project completion are anticipated by October of 2020, for a total project duration of approximately 1 year.

CLOSURE

This memorandum has been prepared exclusively for the City of Santa Cruz Water Department for the specific application to the City of Santa Cruz ASR Feasibility – Phase 1 Investigation. The findings and conclusions presented herein were prepared in accordance with generally accepted hydrogeologic practices. No other warranty, express or implied, is made.

FIGURES

December 2019
Project No. 15-0111



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CN AeroGRID, IGN, and the GIS User Community

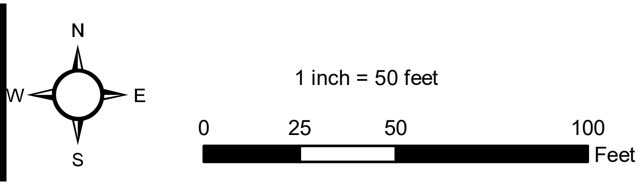
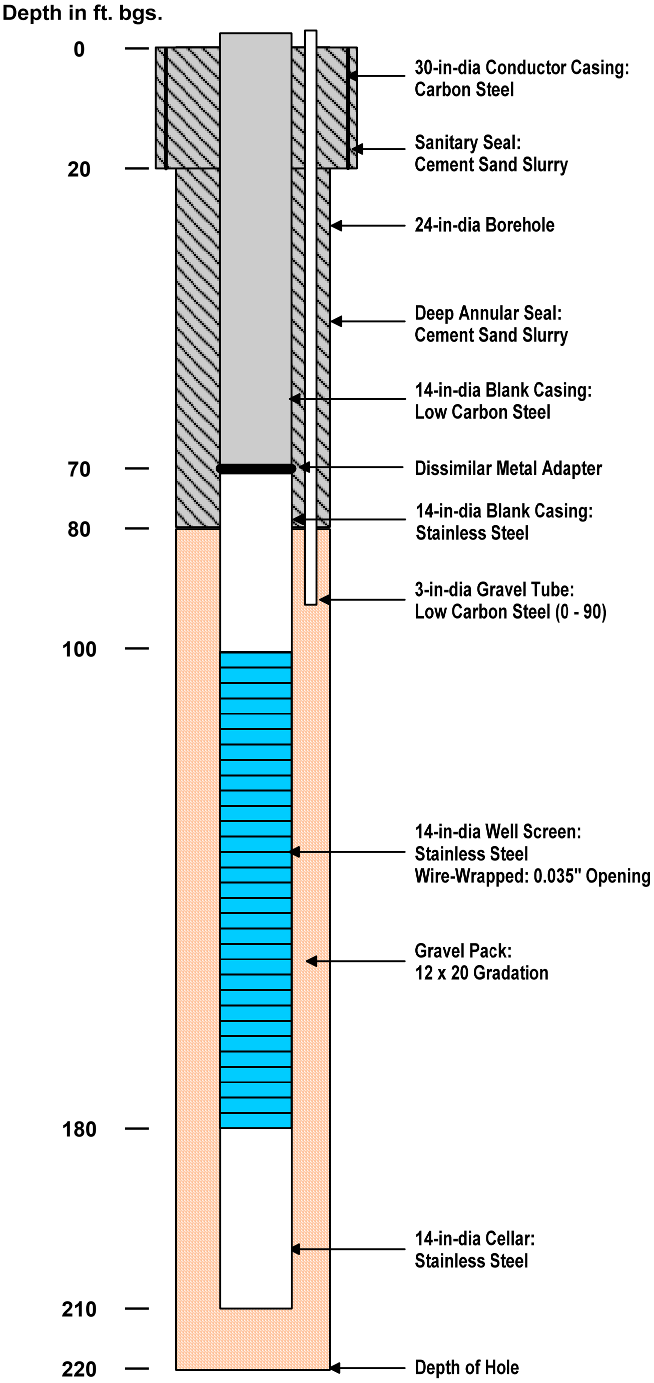


FIGURE 1. SITE LOCATION MAP
ASR Pilot Test Work Plan - Beltz 8
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department

December 2019
Project No. 15-0111



NOT TO SCALE

FIGURE 2. AS-BUILT WELL SCHEMATIC
ASR Pilot Test Work Plan - Beltz 8
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department

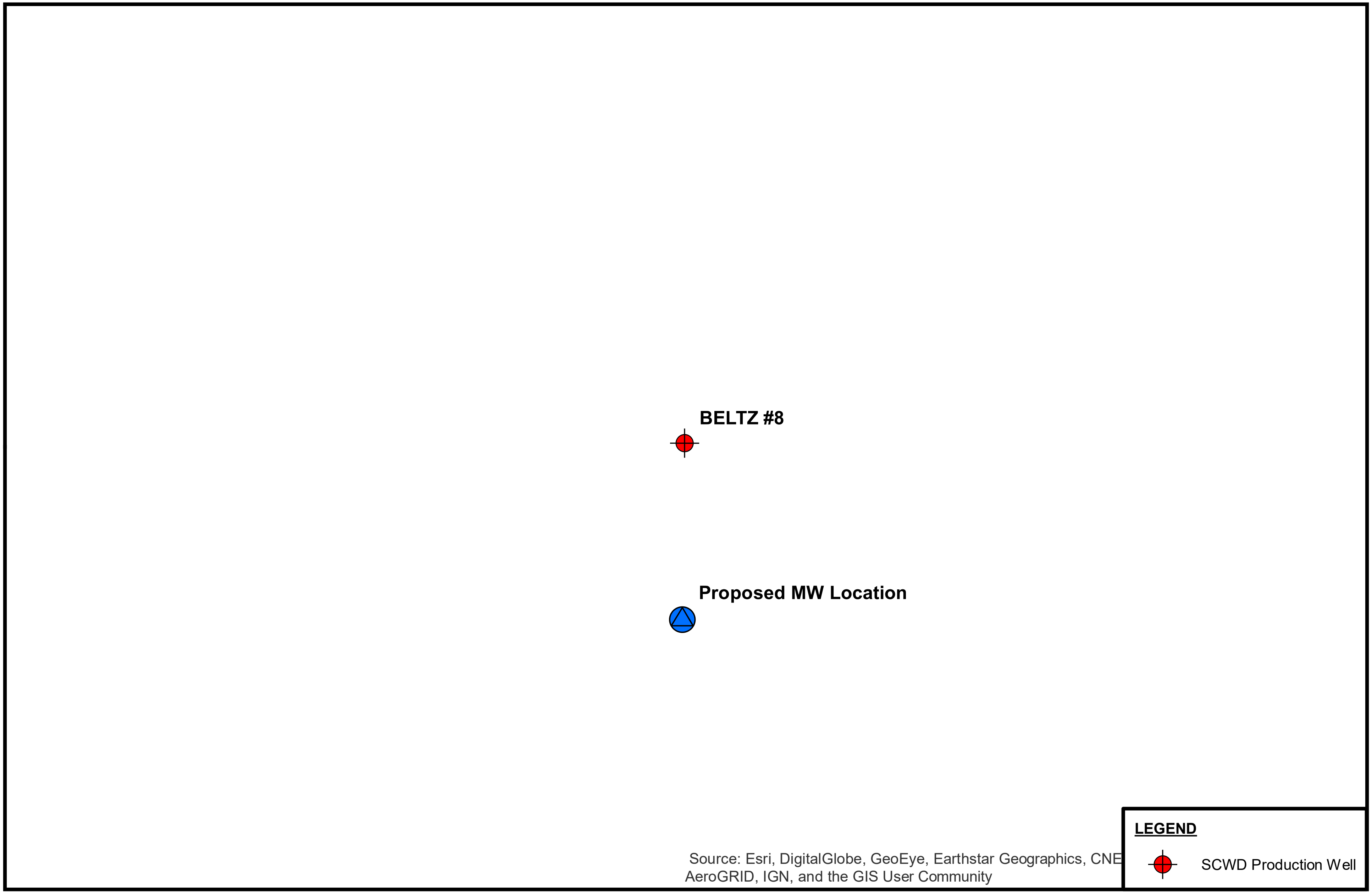
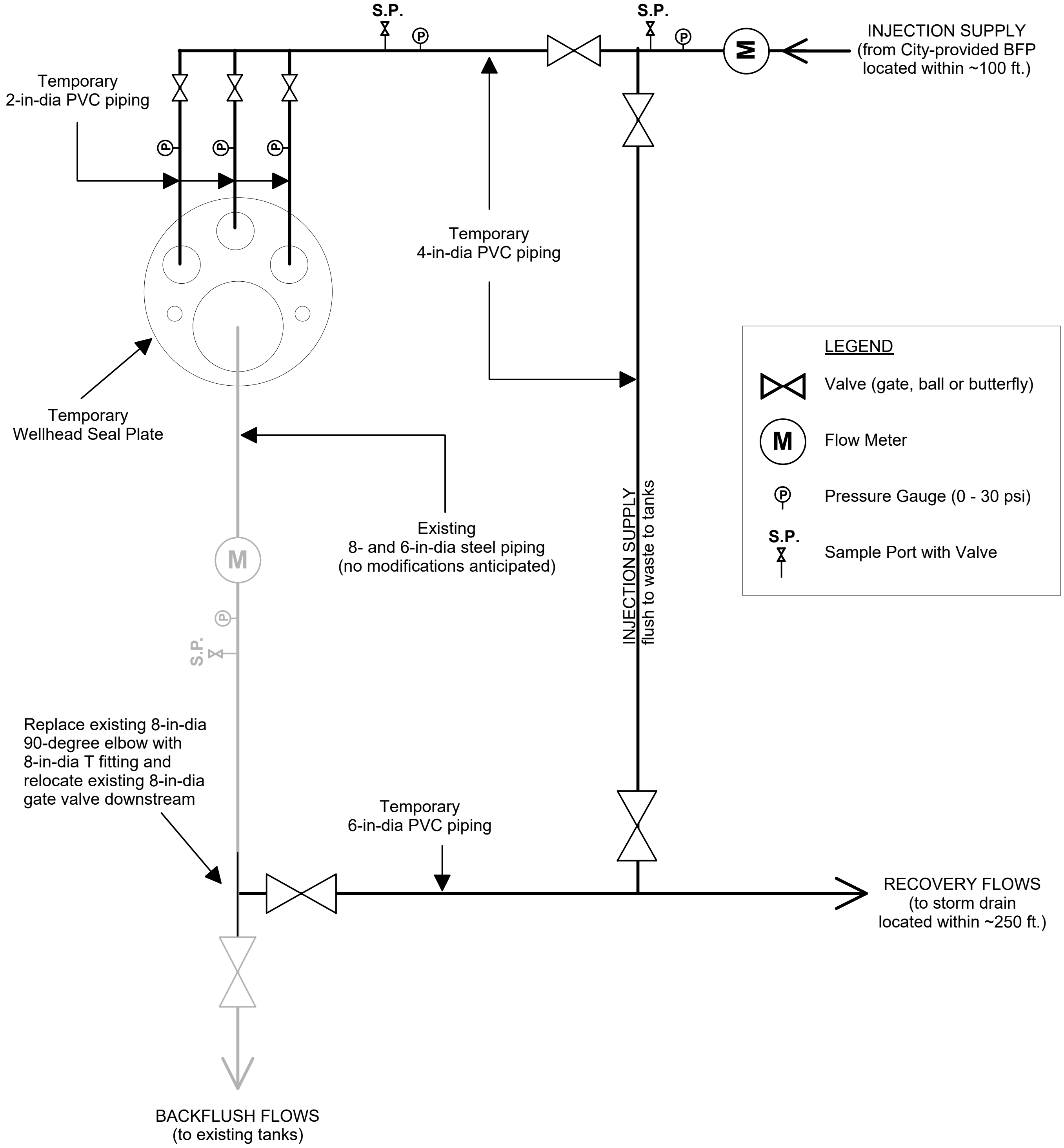


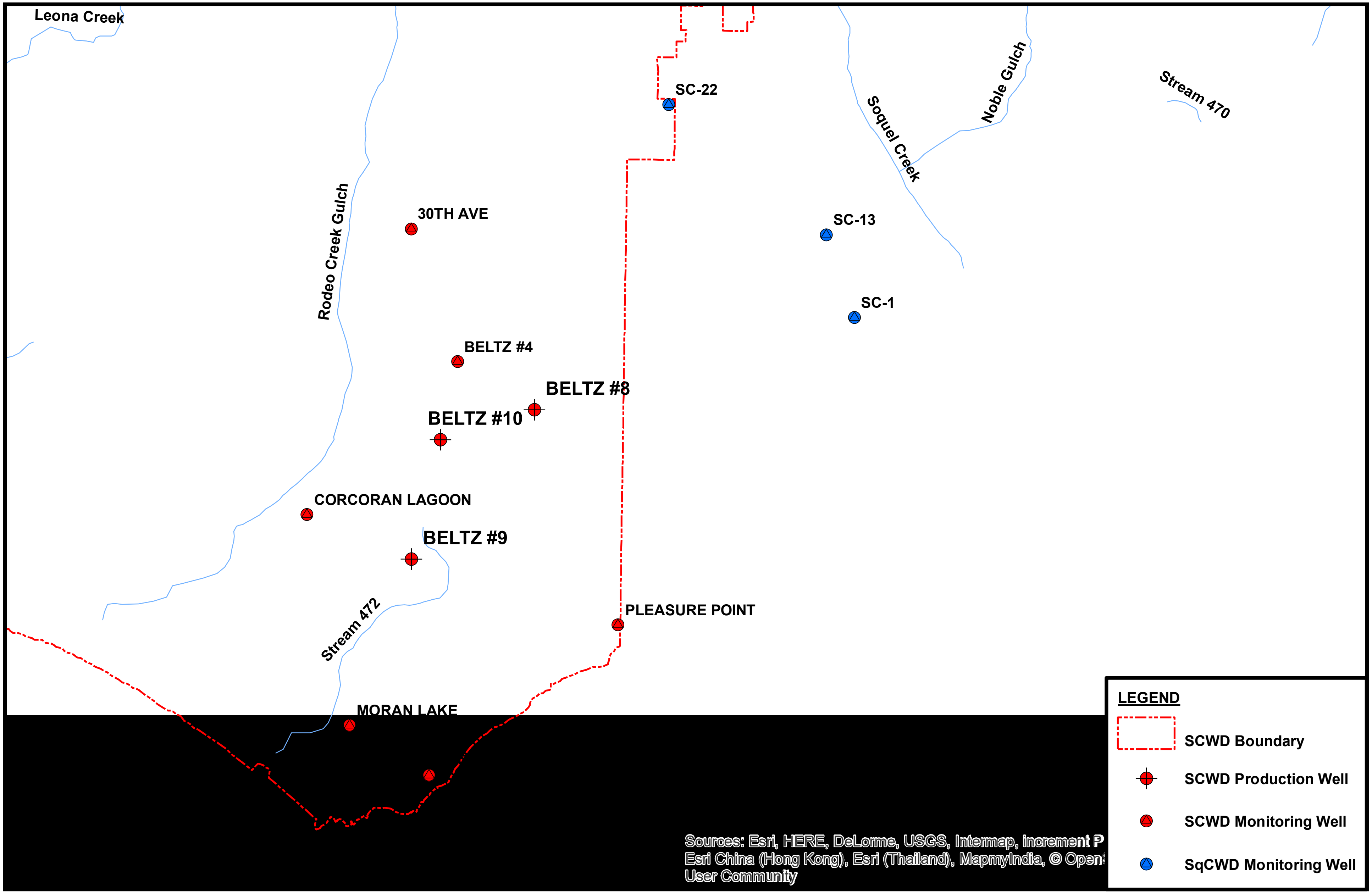
FIGURE 3. BELTZ 8 MW LOCATION MAP
ASR Pilot Test Work Plan - Beltz 8
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department



Note: existing piping is shown in grey and temorary piping is shown in **black**

PUEBLO
water resources

FIGURE 4. PRELIMINARY PIPING SCHEMATIC
ASR Pilot Test Work Plan - Beltz 8
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department



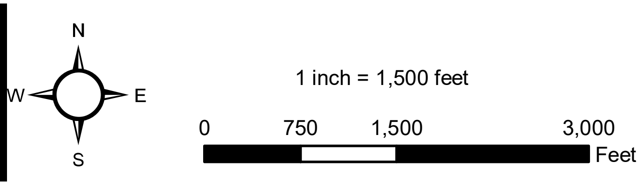


FIGURE 5. WELL LOCATION MAP
ASR Pilot Test Work Plan - Beltz 12
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department

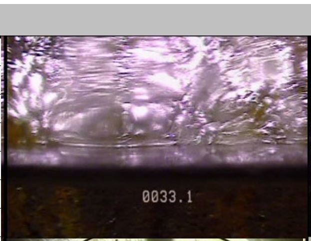
APPENDIX B – VIDEO SURVEY REPORTS

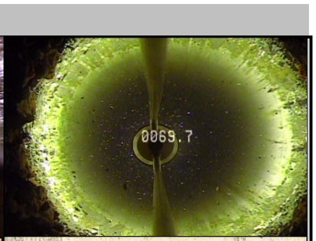
Newman Well Surveys

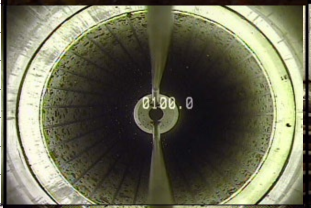
Video Survey Report

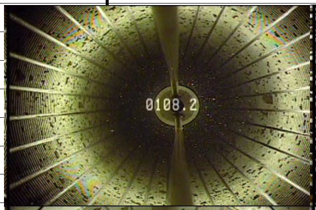
Company:	Zim Industries, Inc.	**Date:**	2-Mar-20
Well:	SCWD Beltz #8	**Run No.**	One
Field:	Santa Cruz	**Job Ticket:**	75091
State:	California	**Total Depth:**	208.4 ft
		Water Level:	33.1 ft
Location:	1035 38th Ave.	**Elevation:**	48.0 ft
	Santa Cruz, CA.	lat 36.966933°	lon -121.968366°
Zero Datum:	Top of casing	**Tool Zero:**	Side view lens (Add 2 ft. to downward view)
Reason for Survey:	General Inspection		

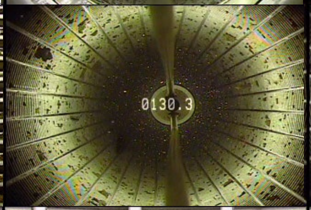
Depth	Remarks
0.0 ft	13 ½" Steel casing.
33.1 ft	Water level.
102.3 ft	Perforation screen begins, continues to 184.5 ft.
208.4 ft	Total depth.

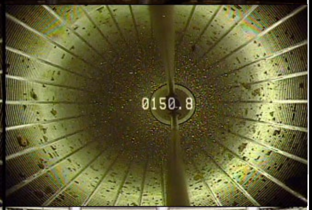


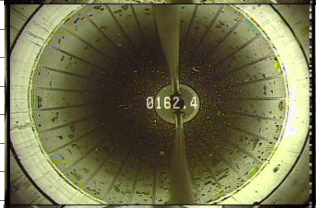


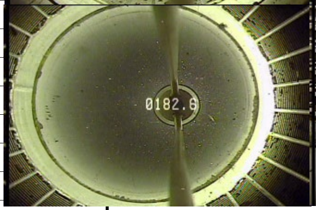












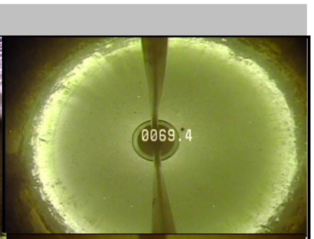
Notes: No casing damage seen.

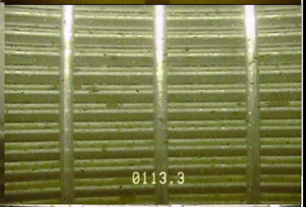
Newman Well Surveys

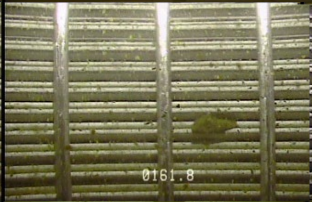
Video Survey Report

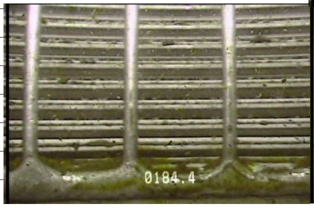
Company:	Zim Industries, Inc.	**Date:**	11-Mar-20
Well:	SCWD Beltz #8 Run #2	**Run No.**	Two
Field:	Santa Cruz	**Job Ticket:**	76005
State:	California	**Total Depth:**	209.0 ft
		Water Level:	33.2 ft
Location:	1035 38th Ave.	**Elevation:**	48.0 ft
	Santa Cruz, CA.	lat 36.966933°	lon -121.968366°
Zero Datum:	Top of casing	**Tool Zero:**	Side view lens (Add 2 ft. to downward view)
Reason for Survey:	General Inspection		

Depth	Remarks
0.0 ft	13 ½" Steel casing.
33.2 ft	Water level.
102.3 ft	Perforation screen begins, continues to 184.5 ft.
209.0 ft	Total depth.









Notes: No casing damage seen.

APPENDIX C – FIELD DATA SHEETS

INJECTION TESTING DATA

PUEBLO
water resources

Project: Santa Cruz ASR Ph 2 - Beltz 8
Project No.: 15-0113
Well: Beltz 8
Test: Cycle 1 Injection

Sheet No. 1 of 2

Date/Time	ET (min)	Rate (gpm)	Totalizers			Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj ~~(ft3)~~ gal	BFP-1 (ft3)	BFP-2 (ft3)	Line	Head	0.75	1.25	1.50"			
3/20/20 9^{30}	0	—	$14912\boxed{18}$	21642	36191	90	—	—	—	—	34.4	0	Start Inj. open 1.50" Tube
	1	180						—	—	20			100 gals/33 Secs
	2							—					open 1.25" Tube
	4	285						—	20	10	23.6		100 gal/21 secs. Adj Q ↑
	6							—	20	14	21.7		" / 21 "
	8							—	20	16			" / 21 "
	10	300				36		—	20	20	20.9		" / 20 secs No Adj
	12					36		—	20	20			" / 20
	15	300				36		—	20	20	20.1		" / 20 secs
	20	300				36	33	—	20	20	20.1		/ 20
10^{00}	30	300	$14993\boxed{00}$			36	33	—	20	20	19.9		/ 20 (268 gpm Avg)
	40	300				36	34	—	20	20	19.4		
	50							—	—	21			
10^{30}	60	300	$15081\boxed{50}$			36	34	—	21	21	19.3		(295 gpm Avg)
	70	305					34	-	24	22	18.8		Adj Q ↑
	80	305				36	34	—	24	22	18.7		
11^{00}	90							—	24	22	18.5		
11^{10}	100	305	$15202\boxed{15}$			36	34	-	24	22	18.3	16.1	SPI: t_0 = 44 secs (302 Avg)
													t_5 = 51 $\boxed{=1.78}$
													t_{10} = 56
													t_{15} = 60

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 8
Project No.: 15-0113
Well: Beltz 8
Test: Cycle 1 Injection

Sheet No. 2 of 2

Date/Time	ET (min)	Rate (gpm)	Totalizers			Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj (gal)	BFP-1 (ft3)	BFP-2 (ft3)	Line	Head	0.75	1.25	1.50"			
11^{30}	120	305	15			32	30	–	24	22	18.3		Note! Changed Line & Head gages
12^{00}	150		$15354\boxed{25}$			32	32	–	24	22	17.9		(0-200 → 0-100 psi)
12^{30}	180												
13^{00}	210												
13^{30}	240												
14^{00}	270	305	$15720\boxed{75}$			33	33	–	24	22	17.6		305 gpm Avg. No Adj
14^{30}	300					33	33	–	24	22			
15^{30}	360	305	$15997\boxed{10}$			34	34	–	26	23	17.1		307 Avg SDI: $t_0 = 43$ sec
16^{30}	420	305	$16182\boxed{70}$	28220	47331	34	34	–	26	23	17.0	17.4	$t_5 = 55$ = 3.08
													$t_{10} = 67$
19^{30}	600	305											$t_{15} = 80$
19^{35}	605		$16757\boxed{15}$			34	34	–	26	24	16.5		No Adj
3/21 8^{30}	1380	325	$19244\boxed{85}$			38	38	–	30	28	15.1		100 gals/18.5 secs
8^{45}									27	26			SDI: $t_0 = 41$ sec
9^{30}	1440	315	$19435\boxed{95}$			36	36		28	26	15.1	19.3	STOP, close $t_5 = 51$ = 2.59
													9^{33} off $t_{10} = 59$
9^{33}		0	$19442\boxed{10}$	44838	76115								$t_{15} = 67$

24-hr Q/s =
314 gpm / 19.3 ft
= 16.3 gpm/ft

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 - Beltz 8

Project No: 15-0113

Well: Beltz 8

Date: 3/23/20

Test/Data Set I.D.: Cycle 1 Recovery

Observer: RCM

Reference Pt: Top of Casing

Static Water Level (ft): 33.8

Pump Setting (ft): ~190

Well Depth (ft): ~210

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
10^{00}	0	0	33.8	–	Totalizer = 451988$\boxed{000}$ gals
	1	560		–	
	2	555	57.7	–	22.4 psi B.Pres
	4	555	58.4	–	22.1 psi
	6	553	59.2	–	Adj Q ↑
	8	555		–	
10^{10}	10	544		–	Totalizer = 451994$\boxed{000}$ 21.4 psi
	15	555	60.4	–	21.2
10^{20}	20	553	60.9	–	21.1 psi. Adj Q ↑
10^{30}	30	553	61.1	–	Adj Q ↑
	40	552	61.2	–	Adj Q ↑
	50	555	62.1	–	20.5 psi B. Pres. No Adj.
11^{00}	60	555	62.1	–	
	70	553	62.4	–	Adj Q ↑
	80	–	–	–	
11^{30}	90	553	62.5	–	20.4 psi. Adj Q ↑
	100	555	62.7	–	11^{45} Totalizer = 452046$\boxed{000}$ gals = $\boxed{\text{552 gpm Avg}}$
12^{00}	120	554	62.8	–	No Adj
13^{00}	180	–	–	–	
14^{00}	240	552	63.4	–	20.1 psi, Adj Q ↑
15^{00}	300	553	63.9	–	19.7 psi Adj Q ↑
16^{00}	360	555	64.3	–	Totalizer = 452187$\boxed{000}$ No Adj

Notes: 553 gpm Avg

Sheet 1 of 2

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 – Beltz 8

Project No: 15-0113

Well: Beltz 8

Date: 3/23 – 24/20

Test/Data Set I.D.: Cycle 1 Recovery

Observer: RCM

Reference Pt: Top of Casing

Static Water Level (ft): 33.8

Pump Setting (ft): ~190

Well Depth (ft): ~210

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
17^{00}	420	553	64.5	–	19.6 psi B. Pres. Adj Q ↑
18^{00}	480	555	64.6	–	19.4 psi No adj
22^{00}	720	553	64.9	–	19.3 psi. Adj Q ↑
2^{00}	960	553	64.9	–	19.3 psi. Adj Q ↑
6^{00}	1200	553	65.2	–	19.2 psi Adj Q ↑
					9^{30} T = 19.59°C, EC = 634, pH = 7.08, ORP = 74 mV
10^{00}	1440	553	65.4	–	STOP DO = 0.00, Tu = 0.17
					Totalizer = 452785000 gals
					553 gpm / 31.6 ft
					Q/s = 17.5 gpm/ft

Notes:

Sheet 2 of 2

PUEBLO water resources

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 8
Project No.: 15-0113
Well: Beltz 8
Test: ASR Cycle 2 Injection

Sheet No. 1 of 2

Date/Time	ET (min)	Rate (gpm)	Totalizers			Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj (gal)	BFP-1 (ft3)	BFP-2 (ft3)	Line	Head	0.75	1.25	1.50"			
3/25 10^{00}	0	–	19538$\boxed{06}$	45345	76936	84	84	–	–	–	35.6	–	Restart XO Log cycle
	1					36	36	–	16	14	24.9		
	2	285											100 gals/21 secs, Adj Q ↑
	4							–	18	16	23.3		a/a a/a
	6	300				34	34	–	20	18	22.3		100 gals/20 secs
	8										22.5		
	10	300	19565$\boxed{00}$					–	20	18	21.9	13.7	Adj Q ↑
	15	300				34	34	–	20	20	21.5		" "
	20	305				33	33	–	22	20	21.1		No adj
10^{30}	30	305				33	33	–	22	20	20.4		"
	40	305						–	22	20	20.6		"
	50	305				33	33	–	22	20	20.5		"
11^{00}	60										20.2		
	70												
	80	305				33	33	–	22	21	20.1		
11^{30}	90					33	33	–	22	21	19.6		SDI: t_0 = 40 secs
11^{40}	100	305				34	34	–	23	22	20.1	15.5	t_5 = 51
12^{00}	120	305	19897$\boxed{05}$			34	34	–	22	22	19.6		t_{10} = 60 2.80
								–	21	21			t_{15} = 69
16^{15}	375	305	20677$\boxed{10}$			36	36	–	24	24	17.9		305 gpm Avg
3/26 9^{00}	1380	315				40	38	–	26	25	15.9		Sys pres. up. No adj
10^{00}	1440	315	24056$\boxed{70}$	68677	116998	38	38	–	26	25	16.0	19.6	314 gpm Avg MW DTW = 23.9'
													pH = 7.45 EC = 391 SDI:
13^{45}	1665	315				40	38	–	26	26	15.4		t_0 = 42 secs
													t_5 = – = 2.93
3/27 8^{30}	2790	305	28306$\boxed{90}$			38	36	–	26	24	14.9		pH = 7.36 EC = 387 t_{10} = 66
10^{00}	2880		28583$\boxed{10}$								14.7		SDI: t_0 = 43 secs t_{15} = 75
													t_5 = 57
16^{15}	3255	305	29745$\boxed{30}$			38	38	–	26	25	14.6		Adj Q ↑ t_{10} = 66 = 2.74
									26	26			t_{15} = 73

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 8
Project No.: 15-0113
Well: Beltz 8
Test: ASR Cycle 2 Injection

Sheet No. 2 of 2

Date/Time	ET (min)	Rate (gpm)	Totalizers			Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj (gal)	BFP-1 (ft3)	BFP-2 (ft3)	Line	Head	0.75	1.25	1.50"			
3/28			~~33~~										
9^{30}	4290	315	33076$\boxed{80}$			40	40	-	28	28	13.8	21.8	pH = 7.52, EC = 395 µS
9^{50}		305							26	26			SDI: t_0 = 43 secs
													t_5 = 56
													t_{10} = 69 $\boxed{=3.08}$
													t_{15} = 80
													Sys pres up - Adj Q ↓
													316 gpm Avg for test
													321 " " " overnight
3/29 10^{00}	5760	305	37625$\boxed{50}$			38	38	-	24	24	13.8	21.8	pH = 7.57, EC = 393 µS
													SDI: t_0 = 43 secs
													t_5 = 55 $\boxed{=2.69}$
													t_{10} = 65
													t_{15} = 72
3/30 9^{00}	7140	305	41947$\boxed{60}$			41	40	-	26	26	13.5	22.1	pH = 7.53, EC = 397 µS
													SDI: t_0 = 41 secs
													t_5 = 52 $\boxed{=2.76}$
													t_{10} = 61
													t_{15} = 70
3/31 9^{00}	8580	305	46390$\boxed{30}$			42	40	-	27	27	12.7	22.9	pH = 7.47, EC = 402 µS
													SDI: t_0 = 41 secs
													t_5 = 51 $\boxed{=2.53}$
													t_{10} = 58
													t_{15} = 66
4/1 9^{00}	10020	305	50894$\boxed{50}$			38	38	-	24	24	12.8	22.8	pH = 7.52, EC = 405 µS
													SDI: t_0 = 40 secs
													t_5 = 49
10^{00}	10080		51077$\boxed{05}$	206593	358054						12.8	22.8	OFF t_{10} = 57 $\boxed{=2.56}$
													t_{15} = 65

Total vol = 3,153,898 gals
313 gpm Avg

PUMPING TEST DATA

PUEBLO
water resources

Client: City of SC

Project: ASR Ph 2- Beltz 8

Project No: 15-0113

Well: Beltz 8

Date: 4/15 -21/20

Test/Data Set I.D.: Cycle 2 Recovery

Observer: Rcm

Reference Pt: Top of Casing

Static Water Level (ft): 33.5

Pump Setting (ft): ~190

Well Depth (ft): ~210

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
11^{00}	0	–	33.5	–	Totalizer = 452,826 $\boxed{000}$ gals
	1	590	59.3	–	
	2	557	58.0	–	22.3 psi B. Pres.
	4	555	58.8	–	22.1 psi
	6	555	59.4	–	21.8 psi
	8	555	59.8	–	21.7 psi
11^{10}	10	555	59.9	–	Totalizer = 452,832 $\boxed{000}$ gals
	12	555	60.3	–	21.4 psi
	15	554	60.2	–	21.3 psi
	20	552	60.8	–	Adj Q ↑
11^{30}	30	554	61.4	–	Adj Q ↑
	40	555	61.3	–	20.9 psi B. Pres
	50	553	61.7	–	20.8 psi. Adj Q ↑
12^{00}	60	555	61.9	–	
	70	555	62.2	–	20.5 psi B. Pres
	80	554	62.1	–	
12^{30}	90	552	62.2	–	20.6 psi. Adj Q ↑
12^{40}	100	555	62.6	–	Totalizer = 452,882 $\boxed{000}$ gals
14^{00}	360	552	63.0	–	20.2 psi. Adj Q ↑
16^{00}	300	552	63.7	–	Totalizer = 452,993 $\boxed{000}$ gals. Adj Q ↑
				–	
				–	

Notes: 0-10 mins gradually adjust Q to maintain ~555 gpm

Sheet 1 of 2

PUMPING TEST DATA

PUEBLO
water resources

Client: City of SC
Project: ASR ph 2 - Beltz 8
Project No: 15-0113

Well: Beltz 8
Date: 4/15 - 21/20
Test/Data Set I.D.: Cycle 2 Recovery
Observer: RCM

Reference Pt: Top of Casing
Static Water Level (ft): 33.5
Pump Setting (ft): ~190
Well Depth (ft): ~210

	Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
4/16	8^{30}	1290	547	65.4	–	Totalizer = 453535 $\boxed{000}$ gal, 19.5 psi
					–	Adj Q ↑ (550 gpm Avg)
	11^{00}	1440	553	65.9	–	Totalizer = 453617 $\boxed{000}$ gal, 17.5 psi
					–	Adj Q ↑
	14^{00}	1620	553	66.3	–	
					–	
	17^{00}	1980	553	66.5	–	Adj Q ↑
4/17					–	
	10^{00}	2820	550	67.1	–	17.3 psi B. Pres. Adj Q ↑
					–	
	15^{00}	3120	553	67.4	–	17.0 psi, Totalizer = 454544 $\boxed{000}$ gals
					–	(551 gpm Avg)
4/18					–	
	10^{30}	4290	554	68.1	–	Totalizer = 455192 $\boxed{000}$ 16.6 psi
					–	No Adj
					–	
4/19	10^{00}	5700	554	68.1	–	Totalizer = 455971 $\boxed{000}$, 16.6 psi
					–	(552 test Avg, 553 past 24-hrs). No Adj
					–	
4/20	10^{00}	7140	551	68.3	–	Totalizer = 456765 $\boxed{000}$, 16.5 psi, Adj Q ↑
4/21					–	
	11^{00}	8640	553	68.7	–	STOP, Totalizer = 457594 $\boxed{000}$ gal

Notes:

$\boxed{\text{552 gpm Avg}}$

Sheet 2 of 2

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 8
Project No.: 15-0113
Well: Beltz 8
Test: Cycle 3a - Injection

Sheet No. 1 of 5

Date/Time	ET (min)	Rate (gpm)	Totalizers			Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj (gal)	BFP-1 (ft3)	BFP-2 (ft3)	Line	Head	0.75	1.25	1.50"			
4/6/21 10^{20}	0	—	2$\boxed{700}$	374364	27310	85	85	–	–	–	35.84	—	open 1.5" DT
	1												
	2										25.1		open 1.25" DT
	4	300											
	6							–	12	10	23.1		
	8	~300									22.8		
	10	^300						–	12	10	22.3	13.5	Adj Q ↑ slightly
	12										22.2		
	15	~295									22.1		Adj Q ↑
	20	~305				21	20	–	15	12	21.3		
10^{50}	30	305									21.1		
	40	305									21.0		(#2 = 87 gpm) #1 = 224 } 311 gpm
	50												
11^{20}	60					22	20	-	16	13	20.8		SDI: t_0 = 24 secs
	70												t_5 = 30
	80	305							15	13	20.6		t_{10} = 35 $\boxed{= 2.76}$
11^{50}	90										20.5		t_{15} = 41
12^{00}	100	305	32$\boxed{960}$								20.3	15.5	
12^{20}	120										20.2		303 gpm Avg $\boxed{Q/s = 19.6 \text{ gpm/ft}}$
	150												
13^{20}	180	305				22	20	-	16	14	20.1		SDI: t_0 = 24 secs
	210										20.1		t_5 = 32
14^{20}	240	305				24	22	—	16	14	19.9		t_{10} = 36 $\boxed{= 2.76}$
14^{50}	270										19.8		t_{15} = 41
15^{20}	300												
15^{50}	330	305				24	22	—	16	14	19.7		
16^{20}	360										19.8		SDI: t_0 = 24 secs
17^{20}	420	300	131$\boxed{305}$			22	20	-	15	13	19.9		t_5 = 31
													t_{10} = 35 = $\boxed{2.67}$
20^{20}	600	300	185$\boxed{100}$			22	20	-	15	12	19.8	16.0	t_{15} = 40

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 8
Project No.: 15-0113
Well: Beltz 8
Test: Cycle 3a - Injection

Sheet No. 2 of 5

Date/Time	ET (min)	Rate (gpm)	Totalizers			Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj (gal)	BFP-1 (ft3)	BFP-2 (ft3)	Line	Head	0.75	1.25	1.50"			
4/7 7^{20}	1260	305	388 $\boxed{120}$			24	22	-	16	14	18.9	16.9	SDI: t_0 = 25 secs 307 Avg t_5 = 31 t_{10} = 34 $\boxed{\approx 2.50}$ t_{15} = 40
17^{35}		305	575 $\boxed{880}$			24	22	-	16	14	18.6	17.2	SDI t_0 = 24 secs pH =7.41 EC =423 t_5 = 31 t_{10} = 35 $\boxed{\approx 2.46}$ t_{15} = 38
4/8 9^{20}	2820	305	863 $\boxed{420}$			24	22	-	16	14	18.1	17.7	$\boxed{\text{305 gpm Avg}}$ SDI: t_0 = 24 secs pH = 7.41 EC = 402 t_5 = – t_{10} = 33 $\boxed{\approx 2.22}$ t_{15} = 36
14^{20}	3120	305	954 $\boxed{200}$			24	22	–	16	14	17.7	18.1	SDI: t_0 = 24 secs pH = 7.45 EC = 397 t_5 = – t_{10} = 33 $\boxed{\approx 2.34}$ t_{15} = 37
4/9 9^{20}	4260	300	1299 $\boxed{950}$			22	20	–	16	13	17.5	18.3	303 gpm 24-hr Avg. Adj Q ↑
9^{40}	4280	305				24	22	-	16	14	17.3	18.5	SDI: t_0 = 25 secs pH = 7.46 EC = 408 t_5 = 29 t_{10} = 33 $\boxed{\approx 2.16}$ t_{15} = 37

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 8
Project No.: 15-0113
Well: Beltz 8
Test: Cycle 3a - Injection

Sheet No. 3 of 5

Date/Time	ET (min)	Rate (gpm)	Totalizers			Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj (gal)	BFP-1 (ft3)	BFP-2 (ft3)	Line	Head	0.75	1.25	1.50"			
4/9 16^{40}	[illegible]	305	1434$\boxed{340}$			24	22	-	17	15	17.0	18.8	SDI: t_0 = 24 secs pH = | t_5 = 31 7.48 | t_{10} = 35 = $\boxed{2.67}$ EC = | t_{15} = 40 402 us
4/10 10^{20}	5760	300	1758$\boxed{520}$			24	22	-	16	14	16.9	18.9	SDI: t_0 = 24 secs pH = | t_5 = 29 7.56 | t_{10} = 32 = $\boxed{2.10}$ EC = | t_{15} = 35 408 us
4/11 10^{20}	7200	300	2197$\boxed{520}$			24	22	-	16	14	16.4	19.4	SDI: t_0 = 24 secs pH = | t_5 = 29 7.51 | t_{10} = 33 = $\boxed{2.34}$ EC = | t_{15} = 37 409 us
4/12 18^{20}	8640	305	2633$\boxed{870}$			24	22	-	17	15	16.0	19.8	Adj. Q ↑
11^{40}		305				26	24	-	18	16			SDI: t_0 = 25 secs pH = | t_5 = 32 7.48 | t_{10} = 43 = $\boxed{3.52}$ EC = | t_{15} = 53 408 us
16^{20}	9000	305	2744$\boxed{380}$			26	24	-	18	16	15.6	20.2	SDI: t_0 = 24 secs pH = | t_5 = 30 7.50 | t_{10} = 34 = $\boxed{2.56}$ EC = | t_{15} = 39 403 us

PUEBLO water resources

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 8
Project No.: 15-0113
Well: Beltz 8
Test: Cycle 3a - Injection

Sheet No. 4 of 5

Date/Time	ET (min)	Rate (gpm)	Totalizers			Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj (gal)	BFP-1 (ft3)	BFP-2 (ft3)	Line	Head	0.75	1.25	1.50"			
4/13 10^{20}	10080	300	3074 390			24	22	–	16	14	16.0	19.8	SDI: t_0 = 25 secs pH = 7.59 t_5 = 30 t_{10} = 33 = 2.16 EC = 408 µs t_{15} = 37
13^{20}	10260	305	3135 460			26	24	–	17	15	15.5	20.3	STOP Inj → Backflush (see field obs Rpt)
15^{40}	10400	~305				24	22	–	16	14			Resume Inj.
17^{05}	10485	305	3161 980			26	24	–	17	15	17.2	18.6	
4/14 9^{00}	11440	300	3455 090			24	22	–	16	14	16.8	19.0	SDI: t_0 = 24 secs pH = 7.53 t_5 = 29
14^{05}	11745	305	3547 360			26	24	–	17	15	16.2		t_{10} = 32 EC = 405 µs. t_{15} = 35 = 2.09 ~14^{10} Adj; Q ↑
4/15 9^{00}	13185	295	3896 230			24	22	–	15	13	16.6	19.2	24-hr Avg Q = 306 gpm, Adj; Q ↑ SDI: t_0 = 24 secs
14^{05}	13490	305	3987 740			26	24	–	18	16	15.9	19.9	pH = 7.57 t_5 = 30
15^{05}	13550	309	4006 260										t_{10} = 33 EC = 403 µs t_{15} = 36 = 2.22
4/16 9^{00}	14320	295	4337 530			24	22	–	15	13	16.4		Adj; Q ↑ SDI: t_0 = 24 secs pH = 7.58 t_5 = 30 t_{10} = 35 = 2.46 EC = 404 µs t_{15} = 38

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 8
Project No.: 15-0113
Well: Beltz 8
Test: Cycle 3a - Injection

Sheet No. 5 of 5

Date/Time	ET (min)	Rate (gpm)	Totalizers			Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj (gal)	BFP-1 (ft3)	BFP-2 (ft3)	Line	Head	0.75	1.25	1.50"			
4/16 17:00		305	4480$\boxed{720}$			26	24	–	16	14	15.9	19.9	
4/17 10:00	15820	300	4794$\boxed{480}$			24	22	–	16	14	16.0	19.8	SDI: t_0 = 24 secs. Adj Q ↑ pH = t_5 = 30 7.60 t_{10} = 34 EC = t_{15} = 37 = $\boxed{2.34}$ 400 uS
4/18 10:00	17260	300	5234$\boxed{980}$			25	23	–	17	15	15.6	20.2	SDI: t_0 = 24 secs pH = t_5 = 30 7.59 t_{10} = 34 = $\boxed{2.34}$ EC = t_{15} = 37 408 uS
4/19 10:00	18700	305	5672$\boxed{220}$			25	23	–	17	15	15.3	20.5	SDI: t_0 = 25 secs. Adj Q ↑ pH = t_5 = 31 7.56 t_{10} = 35 = $\boxed{2.39}$ EC = t_{15} = 39 408 uS
4/20 10:00	20140	305	6111$\boxed{340}$			26	24	–	17	15	14.9		SDI: t_0 = 24 secs pH = t_5 = 30 7.63 t_{10} = 34 = $\boxed{2.22}$ EC = t_{15} = 36 414
13:20	20160		6117$\boxed{770}$	437102	217747.49								stop Injection 303 gpm Avg

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 - Beltz 8

Project No: 15-0113

Well: Beltz 8

Date: 5/18/21 — 6/1/21

Test/Data Set I.D.: Cycle 5a Recovery

Observer: RCM

Reference Pt: Top of Casing

Static Water Level (ft): 34.7

Pump Setting (ft): ~190

Well Depth (ft): ~210

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
10^{00}	0	–	34.7		Totalizer = 36,472,722 gals
	1		55.4		
	2	470	54.8		
	4	450	55.4		40.7 psi, 60 Hz
	6		55.1		
	8		55.8		
10^{10}	10	450	56.0		Totalizer = 36477276 gals
	12		56.6		
	15		56.5		
	20		56.6		
10^{30}	30		57.1		
	40		56.9		
	50		57.5		
11^{00}	60	449	57.8		Adj Q ↑ slightly
	70	451	58.1		
	80		–		
11^{30}	90		58.4		
11^{40}	100		58.5		
12^{00}	120	450	58.7		
12^{30}	150		58.8		
13^{00}	180		–		
14^{00}	240		59.3		

Notes:

Sheet 1 of 3

PUMPING TEST DATA

PUEBLO
water resources

Client: City of SC
Project: ASR Ph 2- Beltz 8
Project No: 15-0113

Well: Beltz 8
Date: 5/18/21 — 6/1/21
Test/Data Set I.D.: Cycle 3a Recovery
Observer: RCM

Reference Pt: Top of Casing
Static Water Level (ft): 34.7
Pump Setting (ft): ~190
Well Depth (ft): ~210

	Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
	15^{00}	300	450	59.5		
	17^{00}	420	450	59.9		Totalizer = 36661965 gals (451 gpm Avg)
5/19	9^{00}	1380	449	61.3		Totalizer = 37094216 gals. Adj Q ↑
						Q/s = 450/26.6 = 16.9 gpm/ft
	17^{00}	1860	451	61.9		Totalizer = 37310744 gals.
5/20						
	9^{00}	2820	451	62.6		Totalizer = 37744181 gals (451 gpm Avg)
						37.5 psi B.Pres.
	16^{00}	3240	450	62.8		Totalizer = 37933384 gals. Adj Q ↑
5/21						
	10^{00}	4320	451	63.2		Totalizer = 38420545 gals
5/22						
	10^{00}	5760	450	63.7		Totalizer = 39068877 gals Adj Q ↑
5/23						
	10^{00}	7200	451	64.4		Totalizer = 39719107 gals
5/24						
	10^{30}	8670	450	64.5		Totalizer = 40382199 gals Adj. Q ↑
						36.7 psi B.Pres
5/25	10^{00}	10080	451	64.7		Totalizer = 41018342 gals

Notes:

1410

Sheet 2 of 3

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 - Beltz 8

Project No: 15-0113

Well: Beltz 8

Date: 5/18/21 — 6/1/21

Test/Data Set I.D.: Cycle 3a Recovery

Observer: RCM

Reference Pt: Top of Casing

Static Water Level (ft): 34.7

Pump Setting (ft): ~190

Well Depth (ft): ~210

	Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
5/26	10^{00}	11520	450	64.9		Totalizer = 41667807 gals. Adj Q ↑
5/27	10^{05}	12965	451	65.2		Totalizer = 42320556 gals
5/28	10^{00}	14400	450	65.2		Totalizer = 42967740 gals Adj Q ↑
5/29	9^{20}	15800	451	65.3		Totalizer = 43599958 gals
5/30	10^{00}	17280	450	65.4		Totalizer = 44267682 gals Adj Q ↑
5/31	9^{30}	18690	451	65.5		Totalizer = 44904137 gals 36.2 psi B. Pres.
6/1	10^{00}	20160	451	65.7		STOP Totalizer end = 45,567,367 gal Avg Q = 451.1 gpm

Notes:

Sheet 3 of 3

APPENDIX D – WATER-QUALITY LABORATORY REPORTS

available for download here:

https://pueblo-water.sharefile.com/d-s462b44a8d1bd4bcda561952665c8eb95

APPENDIX E – GEOCHEMICAL INTERACTION ANALYSIS TECHNICAL MEMORANDA

TECHNICAL MEMORANDUM
Pueblo Water Resources, Inc.
4478 Market St., Suite 705 Tel: 805.644.0470
Ventura, CA 93003 Fax: 805.644.0480

To:	Santa Cruz Water Department	Date:	February 20, 2021
Attention:	Leah VanDerMatten, P.E.	Project No:	15-0113
Copy to:			
From:	Robert C. Marks, P.G., C.Hg. Principal Hydrogeologist		
Subject:	Santa Cruz ASR Project – Phase 2 Feasibility Investigation; Beltz 8 ASR Pilot Test – Interim Geochemical Interaction Evaluation		

INTRODUCTION

The purpose of this Technical Memorandum (TM) is to retransmit the subject geochemical interaction evaluation performed by Dr. Richard Glanzman and to provide Pueblo Water Resources, Inc. (PWR) high-level interpretation of the key findings. The geochemical interaction evaluation was performed on the results of Aquifer Storage and Recovery (ASR) Pilot Test Cycles 1 and 2 implemented at the Santa Cruz Water Department's (SCWD) Beltz 8 well during the period during the period March 13 through April 21, 2020.

During ASR Cycles 1 and 2, arsenic concentrations in the recovered waters were shown to have been elevated relative to pre-injection concentrations in the native groundwater, indicating that potentially adverse geochemical reactions between the injected water, native groundwater and/or aquifer minerals were occurring at the site. Although the arsenic concentrations in the recovered waters did not exceed the drinking water standard Maximum Contaminant Level (MCL) for arsenic of 10 micrograms per liter (ug/L), peaking at a concentration of 6.0 ug/L, the increase relative to the baseline concentration of 1.4 ug/L (an approximate four-fold increase) was of sufficient concern for the ASR pilot test program to be suspended, and a geochemical interaction evaluation of the ASR Cycle 1 and 2 results was performed before continuing ASR operations at the site.

FINDINGS

The geochemical interaction analysis performed by Dr. Richard Glanzman (a subconsultant to PWR) is documented in the attached TM dated October 1, 2020. There is a lot of highly technical and relevant information presented in it, which will not be repeated here; however, we believe the key findings for advancing the Beltz 8 ASR Pilot Test Program are as follows:

1. The source of arsenic is mobilization from pyrite (FeS_2) minerals present in the geologic matrix throughout the target aquifer at the site (the A Unit of the Purisima Aquifer system). Pyrite formed under low oxidizing aquifer conditions typically

accumulates other metals and metalloids that are in solution during its formation, and arsenic is a common metal accumulated by pyrite formation.

2. The mechanism of arsenic release is oxidation of pyrite by the injection source water. The injection source water is treated surface water containing relatively high levels of dissolved oxygen and is carrying a chlorine residual, factors which result in a high Oxidation-Reduction Potential (ORP) of the water. When pyrite is exposed to oxidizing recharge water, it releases dissolved iron, sulfuric acid and the accumulated metals such as arsenic; however, a subsequent part of the geochemical reaction is that dissolved iron released from pyrite into the groundwater becomes oxidized to iron oxyhydroxide. Iron oxyhydroxide is one of the most efficient adsorption media for removing arsenic from groundwater. In other words, the geochemical reaction sequence that is occurring results in an initial release of arsenic into the groundwater, followed by subsequent adsorption after some period of time.

3. It is impossible to predict through geochemical modeling the anticipated arsenic concentrations in the stored and recovered waters, because there is no way to know how much of the pyrite in the aquifer geologic matrix is exposed to injected water without performing in-situ ASR pilot testing; however, based on analysis of the empirically-derived data from the results of ASR Cycles 1 and 2, and an understanding of the geochemical mechanism for arsenic release and subsequent adsorption, it is considered unlikely that continued ASR operations at the site will result in the arsenic concentration increasing above the MCL of 10 ug/L (it can be expected to get as high as about 7.5 ug/L based on the results to date).

Given these findings, we recommend proceeding with ASR Cycle 3 at the site to further investigate arsenic behavior at the site and validate the findings of the geochemical interaction evaluation; however, we do not recommend that the entire volume of Cycle 3 recovery water be placed into the distribution system as originally planned due to the potential risk that arsenic may exceed the MCL without further testing; therefore, we recommend that the original ASR Cycle 3 program be bifurcated into two separate ASR Cycles (e.g., Cycles 3a and 3b) in order to both develop the additional data needed for the arsenic investigation and mitigate the risk that water exceeding the MCL be pumped into the distribution system. Accordingly, a revised Work Plan for ASR Cycle 3 has been developed and is presented in a separate TM[1].

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[1] Pueblo Water Resources, Inc., *Santa Cruz ASR Project – Phase 2 Feasibility Investigation; Revised ASR Pilot Test Work Plan for Beltz 8 – ASR Cycle 3*, prepared for Santa Cruz Water Department, dated February 20, 2021.

CLOSURE

This memorandum has been prepared exclusively for the City of Santa Cruz Water Department for the specific application to the City of Santa Cruz ASR Feasibility – Phase 2 Investigation at the Beltz 8 Well. The findings and conclusions presented herein were prepared in accordance with generally accepted hydrogeologic practices. No other warranty, express or implied, is made

TECHNICAL MEMORANDUM

To: Robert Marks/Pueblo Water Resources/Ventura,CA

From: Dick Glanzman/Glanzman Geochemical LLC/Lakewood, CO

Date: October 1, 2020

Subject: Preliminary Report on the Geochemistry of Beltz 8 Groundwater at City of Santa Cruz ASR Project Site

INTRODUCTION

Beltz 8 and Beltz 9 are two potential ASR well locations in the relatively shallow Plio-Pleistocene-aged Purisima Formation aquifer (the well locations are shown on the attached project map). The two well locations have similar aquifer characteristics and groundwater chemistry and the Beltz 8 well site was chosen for the initial ASR pilot test in the aquifer. Two of three initial ASR pilot test cycles were performed at the Beltz 8 ASR well site in the March 18, 2020 to April 21, 2020 time period. Both cycles documented increases in the arsenic concentrations in recovered water concentrations, but did not exceed the 10 µg/L drinking water standard. However, this increase in arsenic concentrations resulted in a decision to temporarily halt the third pilot test until the quality of the recovered water chemistry could be evaluated and potential for recovered water quality issues could be estimated. This preliminary geochemical report is one of the evaluations and estimates performed to respond to that concern.

This preliminary report discusses the results of these tests at the Beltz 8 well, its associated MW (located approximately 35 feet from Beltz 8 at the site) and potential differences between the Beltz 8 and Beltz 9 well locations. Analytical data for 17 groundwater samples collected from the Beltz 8 ASR well and four groundwater samples from the nearby MW are listed in Tables 1 and 2, respectively. The extensive analytical suite has mostly an excellent mass balance estimated error of less than 5 percent and only one sample with a still acceptable 9 percent estimated error.

The following sections include discussions on the Purisima Formation characteristics of the aquifer sediments, followed by a discussion of the groundwater chemistry that includes a discussion of the current and historical arsenic and manganese concentrations of the Beltz 8 groundwater and recovered recharge water from the two preliminary ASR pilot test cycles.

AQUIFER CHARACTERISTICS

The Beltz 8 ASR well is a 14-inch diameter well drilled to a depth of 210 feet in the Plio-Pleistocene-aged Purisima Formation aquifer. The well is screened between 100 and 180 feet deep through very dark gray to black-colored, predominately fine-grained, but includes some coarse-grained, micaceous, silty sand and sandstone. The lithologic log indicates that the sediments also contains some brown rock fragments.

Four 20-foot depth interval samples collected while drilling the adjacent two-inch diameter MW were sent to the Mineralogy Incorporated laboratory to determine the aquifer characteristics at the Beltz 8 well site (100-120, 120-140, 140-160 and 160-180 feet, respectively). Analytical methods for this characterization included sieve analysis for grain-size, X-ray Diffraction (XRD), mineralogy, X-ray Fluorescence (XRF), chemistry, Cation Exchange Capacity (CEC), Acid Insoluble Residue Analysis, and both Thin Section petrography and Scanning Electron Microscopy (SEM) images to determine the mineralogical associations and pore structure. The results and descriptions of this characterization were reported in Mineralogy, Inc. (2020, attached for reference).

Essentially the same aquifer characterization was performed on three depth intervals (60-80, 80-100 and 100-120 feet depth intervals) on Purisima Formation aquifer sediments of the SC-22 well used to characterize the A Unit of the Purisima Formation aquifer system, which both the Beltz 9 and Tannery potential ASR wells are completed in (Mineralogy, Inc. 2017). The SC-22 well is 3,675 feet from the Beltz 8 well while the Beltz 9 well is 2,120 feet from the Beltz 8 well (Robert Marks, personal communication, 2020). Characterization results were summarized in Glanzman (2017) along with Beltz 9 groundwater chemistry used for comparison purposes in this report.

Grain-Size

The sieved samples are dominated by 35.5 to 43.89 (100-120 foot sample) percent 0.3 millimeter (mm) grain-size. The deepest two depth intervals contain about 10 percent of the larger grain-sizes between 0.7mm and 2.0 mm while the shallowest two depth intervals contain less than 1.5 percent of this larger grain-size.

XRD Mineralogy

The sediment mineralogy is dominated by the sodium-rich plagioclase mineral, oligoclase, increases from 34 percent in the deepest depth interval to 38 percent in the shallowest. Volcanic glass (obsidian, amorphous silica) is second in abundance ranging between 20 and 24 percent while quartz (crystalline silica) is third, ranging between 19 and 22 percent. The prevalence of this black volcanic glass makes this aquifer unusual. Quartz is usually the most abundant mineral in most aquifers. The potassium feldspar mineral, orthoclase, comprises a very consistent 5 to 6 percent of the total mineral composition. The swelling smectite clay is essentially as abundant as the orthoclase but with a range between 5.5 to 6 percent in shallower two depth intervals and slightly less 4 to 5 percent in the deeper two depth intervals. This small increase in the shallower depths probably reflects higher conversion of volcanic glass and plagioclase to smectite in the shallower depths compared to a lesser conversion at deeper depths. The clinopyroxene mineral, augite, comprises 3 percent.

Calcite comprises 1 to 4 percent. The two deepest samples contain 3 to 4 percent calcite while the shallowest two contain only 1 to 2.5 percent. This small amount of calcite is unusual in a relatively shallow aquifer and it is important because calcite is typically the mineral that controls the pH where pyrite is being actively oxidized. This low calcite percentage is confirmed by the high acid insoluble residue of 96 to 98 percent. This test indicates only 2 to 4 percent total carbonate (includes dolomite) is present in the sediments. Preferential oxidation of pyrite in the shallower two depth intervals may be responsible for the lower calcite concentrations in the two shallower depth intervals.

Pyrite (iron sulfide) and magnetite (iron oxide) individually comprise 1.5 to 2.5 percent of the aquifer sediment. The two deepest samples contain 2 to 2.5 percent pyrite while the shallowest two contain only 1.5 percent pyrite. This proportionality is similar to that of the calcite supporting the above supposition that pyrite is being more readily oxidized in the shallower than the deeper part of the aquifer sediments.

The zeolite mineral heulandites, the two clays, kaolinite and chlorite, along with illite/mica each occur in trace amounts of less than 0.5 percent. This mica percentage is surprisingly low compared to the visual micacous description of the aquifer sediments in the lithological description of the cuttings during collection of these sediments.

These Beltz 8 sediment samples contain a significantly lower abundance of volcanic glass and lower abundance of most crystalline minerals, but higher quartz and plagioclase while about the same pyrite abundance compared to those of the SC-22 (used for the Beltz 9 analysis) sediment samples.

Cation Exchange Capacity

The cation exchange capacity (CEC) of the dominantly smectite clays in the sediments ranges from a low 10 milliequivalents per gram (meq/g) in the shallowest depth interval (100 to 120 feet) to 20.5 meq/g in the second shallowest depth interval (120 to 140 feet). Intermediate CEC values of 16.5 and 17.6 meq/g occur in the two deeper depth intervals (140 to 160 and 160 to 180 feet, respectively). Calcium and sodium ions make up 89 to 93 percent of the exchangeable cations leaving the remainder to magnesium and potassium, respectively. Surprisingly, the shallow, lowest CEC, depth interval sample has sodium>>>calcium>>magnesium>potassium distribution of exchangeable ions while the other three depth intervals have a calcium>>>sodium>>magnesium>potassium distribution. The ionic distribution usually mimics the dominant cation distribution in the groundwater, but that is not the case in groundwater from this well. Calcium is the dominant cation in all groundwater and recovered water from this well.

The CEC of the SC-22 sediments is similar to that of the Beltz 8 CEC in this shift in calcium and sodium dominance in the shallowest sediments relative to that of the deeper sediments. The shallowest depth interval CEC was about the same, but the two deeper depth intervals had significantly higher CEC values of 45 and 32 meq/100 gram, respectively, probably reflecting the higher proportion of volcanic glass (31 to 36 percent) in the SC-22 sediments compared to that of the Beltz 8 sediments (20 to 24 percent).

There is no apparent explanation for the sodium dominance of exchangeable ions in the shallowest depth sediments and a calcium dominance of the three deeper sediments.

XRF Chemistry

The XRF chemistry essentially reflects the mineralogy composition of the sediments. However, the chemistry of the sediments would have been considered typical of alluvial sediments if the mineralogy was not available. For example, the 64 to 65 percent silica (SiO_2) concentration is by far the highest of all the elements and would have been interpreted as being present as quartz rather than the more abundant oligoclase and volcanic glass in these sediments. The silica concentration slightly, but consistently decreases with depth supporting the supposition that oxidation of pyrite similarly decreases with depth.

Alumia (Al_2O_3) is second in abundance ranging between 13.8 to 14.5 percent. Similar to silica, alumina slightly decreases with depth also supporting the supposition that oxidation of pyrite decreases with depth.

Similar to silica and alumina, the calcium concentration, third in abundance, decreases with depth with the two shallower depth samples containing 3.1 and 3.7 percent while the two deeper depths containing 4.5 and 4.8 percent. Calcium better defines a more active oxidation of pyrite in the shallower two depth intervals than the deeper two depth intervals. Calcium is usually dominantly present as calcite in aquifer sediments, but it is dominantly present in the plagioclase mineral oligoclase in these sediments.

Iron, fourth in abundance, increases only slightly with depth (3.5 to 3.6 percent). The iron concentration poorly reflects the oxidation of pyrite because it is predominately present in volcanic glass, augite, hornblende and magnetite, minerals that are less soluble than calcite. These four minerals are also essentially responsible for the dark color of the bulk sediments.

Sodium, dominantly present in the plagioclase mineral oligoclase, is fifth in abundance with a relatively consistent concentration ranging between 2.2 and 2.5 percent. Similarly, potassium, sixth in abundance, has a consistent 2 percent concentration dominantly present in orthoclase and mica Magnesium, seventh in abundance and dominantly present in augite and hornblende, has a relatively consistent range between 1.1 and 1.2 percent. All the remaining constituents are present in concentrations equal to and mostly less than 0.5 percent.

The sulfur concentration ranges between 0.688 to 0.721 percent in shallower three depth interval samples increasing to 0.911 percent in the deepest sample. Assuming all of the sulfur is associated with iron to form pyrite, the sediments in the 100 to 160 foot depth-interval would contain 1.3 percent pyrite while the 160 to180 foot depth-interval would contain 1.7 percent. These percentages are close to the 1.5 percent semi-quantitative XRD value for the 100 to 140 foot depth-interval and the 2 percent value for the 160 to 180 foot depth-interval. The slightly elevated 2.5 percent XRD value for the 140 to 160 foot depth-interval compared to the 1.3 percent XRF value probably indicates a greater degree of pyrite heterogeneity in this depth-interval.

Oxides of titanium (TiO_2), phosphorus (P_2O_5) and barium (BaO) have concentrations of about 0.5, 0.3 and 0.1 percent (5,000, 3,000, and 1,000 mg/kg), respectively. Elemental concentrations of manganese (Mn) strontium (Sr), zirononium (Zr) and rubidium (Rb) have concentrations of about 600 to 700, 600, 90 to 130, and 70 to 90 mg/kg, respectively.

The arsenic concentration was not detectable in either the Beltz 8 or SC-22 XRF chemistry.

The silica, alumina and iron oxide percentages in the Beltz 8 sediments are about 5 percent lower than those in the SC-22 sediments. Both the manganese oxide and sulfur concentrations in the SC-22 sediment samples are considerably higher than those in the Beltz 8 sediment.

The manganese oxide concentrations in the SC-22 sediments are about twice the concentrations reported for the Beltz 8 sediments. This suggests that the manganese concentration in the native groundwater at SC-22 would be about twice that of the native groundwater from the Beltz 8 well. The total and dissolved manganese concentrations in native groundwater from the Beltz 9 well are 0.190 and 0.180 mg/L while they are 0.095 and 0.100 mg/L in the native groundwater from Beltz 8, indicating that manganese oxide concentrations in Beltz 9 sediments are also likely greater than at Beltz 8.

The sulfur concentrations in the SC-22 sediments is particularly higher in the three depth interval samples from the well than the four depth interval samples from Beltz 8. The shallowest sample (60 to 80 feet) contained 0.58 percent sulfur, intermediate sample (80 to 100 feet) contained an elevated 2.6 percent and the deepest sample (100 to 120 feet) contained 1.3 percent. The intermediate sample also contained one percent gypsum (calcium-sulfate) while the deepest sample contained a trace (less than 0.5 percent). Correcting for the gypsum, the three depth intervals contain an estimated 1.08, 4.6 and 2.4 percent pyrite. The 4.6 percent pyrite concentration in the intermediate depth interval sediments contain significantly higher pyrite than either the XRF and the XRD pyrite concentrations in the Beltz 8 sediments (1.5 to .2.5 percent). The deepest depth interval sediments contain essentially the same amount of pyrite as that of the anomalously high XRD pyrite (2.5 percent) in the Beltz 8 (140 to 160 foot depth interval sample). These higher sulfur/pyrite concentrations suggest that the sulfate concentrations would be significantly higher in the Beltz 9 native groundwater than in the Beltz 8 groundwater. However the sulfate concentration of both groundwaters is exactly the same at 130 mg/L. This suggests that the pyrite in the Beltz 9 sediments is considerably shielded from the oxidation that occurs in the Beltz 8 sediments. In other words, there is significantly less pyrite exposure to the groundwater in the Beltz 9 sediments.

Neither the Beltz 8 nor the SC-22 XRF data reported a detectable arsenic concentration in the sediment samples. This is unusual because the arsenic detection limit was 10 µg/L in the recent past and given the dissolved arsenic concentration in both the native groundwater from both the Beltz 8 well, and particularly the MW and recovered water, contained detectable arsenic concentrations that would suggest a higher than 10 µg/L concentration in the Beltz 8 sediments. It is possible that the arsenic in the Beltz 8 sediments is restricted to pyrite cement that occurs in narrow coatings of particles dispersed within the sediments that are not sufficiently exposed to the x-ray beam to be detectable.

GROUNDWATER GEOCHEMISTRY

Analytical data for 17 groundwater samples collected from the Beltz 8 ASR well and four groundwater samples from the nearby Monitoring Well (MW) are listed in Tables 1 and 2, respectively. The extensive suite of parameters analyzed for the pilot tests is mostly of excellent mass balance estimated error of less than 5 percent and only one sample with a still acceptable 9 percent estimated error.

Arsenic, manganese and iron concentrations are of primary concern with regard to drinking water standards and therefore discussed prior to the overall groundwater geochemical characteristics.

Arsenic, Manganese and Iron

Arsenic, manganese and iron are the only parameters that equal or exceed their individual drinking water standards in groundwater from Beltz 8 ASR well and the associated MW.

Arsenic

Historical arsenic concentrations in 10 groundwater samples from the Beltz 8 well between November 7, 2001 and November 7, 2018 averaged 2.8 µg/L and ranged between 1.9 and 7.0 µg/L. These data indicate that arsenic was and continues to be naturally and variably present in groundwater from this well. An arsenic source is present in the sediments that impacts the groundwater from the Beltz 8 well and the MW. The native groundwater sample from the MW on March 18, 2020 contained 29 µg/L. However, the three subsequent samples on April 15 and April 21, 2020 from the MW contained significantly lower arsenic concentrations of 6.5, 7.4 and 5.4 µg/L. The MW is a two-inch diameter well and therefore developed using air-purging. Air-purging injects a significantly higher amount of atmospheric oxygen than that available in recharge water injected into the aquifer sediments. This air injection significantly oxidizes more of the iron-sulfide mineral pyrite around the well bore than recharge water.

Pyrite Arsenic Source and Iron Oxyhydroxide Adsorption

Pyrite precipitated under low oxidizing aquifer conditions typically accumulates other metals and metalloids that are in solution during its precipitation. When this pyrite is exposed to oxidizing recharge water it releases dissolved iron, sulfuric acid and these sorbed metals and metalloids. Arsenic is one of the most strongly accumulated of these associated elements. Therefore, when the pyrite in the aquifer is oxidized, arsenic is one of the most common anions mobilized during pyrite oxidation. However, the dissolved iron released into the oxidized groundwater becomes oxidized to iron oxyhydroxide initially precipitated as a colloid that then slowly flocculates and coats the aquifer sediment particles surrounding and downgradient of the oxidizing pyrite. Iron oxyhydroxide is one of the most efficient adsorption media for removing arsenic from groundwater in both its colloid, flocculated and coated forms. Iron oxyhydroxide colloids in groundwater near the well bore commonly contain highly elevated arsenic concentrations (tens of µg/L) and is likely the source of the initial native groundwater sample from the MW sent to the laboratory on March 18, 2020. The lower arsenic concentration of groundwater from the subsequent groundwater pumped from the MW probably reflect the more typical arsenic concentrations of the aquifer as demonstrated by the arsenic concentration in the recovered water from the two ASR cycles from Beltz 8.

The pilot tests are designed to demonstrate the characteristics of the arsenic concentration readily released from oxidation and dissolution of pyrite exposed to the oxidizing recharge water (primarily Cycle 1). The arsenic concentrations subsequently released by a larger volume of recharge water chemically interacting with the aquifer mineralogy and mixing with the native groundwater during both the recharge and recovery processes are primarily demonstrated by Cycle 2. Finally, the relative amount of exposed pyrite releasing and sorbing arsenic would be demonstrated in a significantly larger volume of the aquifer in Cycle 3.

Historical arsenic concentrations in 10 groundwater samples from the Beltz 9 well on the same dates as the Beltz 8 well were non-detect in 9 of the 10 samples and only 1.4 µg/L in the single sample with detectable arsenic. Given the characteristics of the aquifer and groundwater chemistry at the Beltz 9 well, the pyrite in the aquifer at that well location is apparently minimally exposed to oxidation in groundwater.

Pilot Test Results from Cycle 1 and Cycle 2

Figure 1 shows the arsenic concentration of recovered recharged water and native groundwater brought back through the volume of aquifer that received the recharged water during Cycle 1 and 2 of the ASR pilot tests.

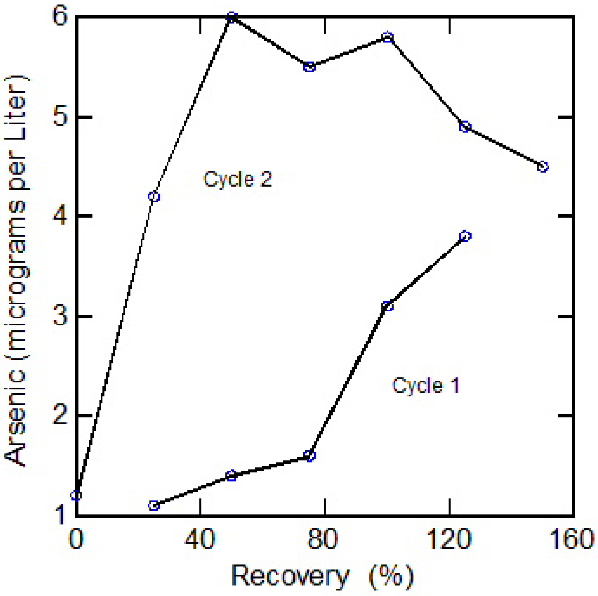

Figure 1. Arsenic concentration in recovered water from Beltz 8 ASR well pilot testing.

The percentage of recovered recharged water volume is on the x-axis and the arsenic concentration of each sample is on the y-axis. Cycle 1 was recharge for one day, stored for two days and then recovered for one day. Cycle 2 was recharged for one week, stored for 2 weeks and then recovered for one week.

Cycle 1

Cycle 1 data clearly indicates that arsenic is being relatively rapidly released from the oxidation of pyrite. The arsenic concentration increased in the recovery of both the recharge water and the native groundwater displaced by the recharge water (125 percent sample). The recharge water contained less than one µg/L in the first sample of recovered water representing the last recharged water of Cycle 1 is not plotted on the graph. However, projecting the three nearly linear 25, 50 and 75 percent recovery samples in a linear equation indicates that the initial sample likely contained 0.87 µg/L arsenic with 98 percent confidence. The 25, 50 and 75 percent recovery samples increase from 1.1 to 1.6 µg/L arsenic, basically the pre-ASR natural groundwater arsenic concentration (1.4 ug/L). However, the 100 and 125 percent recovery samples indicate a nearly linear increase in arsenic concentration from 3.1 to 3.8 µg/L, respectively. These last two samples contain significantly higher arsenic concentration from oxidation and dissolution of pyrite has been added to the 1.4 µg/L contained in the native groundwater suggesting that the arsenic concentration may increase with a higher volume.

Cycle 2

Cycle 2 indicates a more complex condition occurring with an increase in recharge volume. The major ion chemistry described in the following sections indicates that the initial sample through the 75 percent recovered recharge water sample is recharged water. The 125 and 150 percent recovered water samples are Beltz 8 native groundwater. The 100 percent recovered sample is a mixture of about 20 percent recharge water and 80 percent native groundwater. This is proportionately similar to Cycle 2 pilot test characteristics of other successful ASR pilot test results in alluvial aquifer sediments.

The initial 1.2µg/L arsenic concentration in the Cycle 2 recovery sample represents arsenic dissolution following one week of recharge and two weeks storage after the last sample was collected from Cycle 1. This arsenic concentration is very close to that of the natural groundwater arsenic concentration of 1.4 µg/L. Arsenic rapidly increased to 4.2µg/L at 25 percent recovery and 6 µg/L at 50 percent recovery but then formed essentially a plateau of about 5.5 to 5.8 µg/L at 75 to 100 percent recovery. The arsenic concentration then further decreases at 125 and 150 percent recovery to 4.9 and 4.5 µg/L, respectively. The major ion chemistry of the 125 and 150 percent recovery sample groundwater is essentially the native groundwater. Assuming linearity, the arsenic concentration in the recovered water reached a high of 6.3 µg/L in recovered recharge water at about 41 percent recovery. Again, assuming linearity, the arsenic concentration is predicted to decrease to the natural groundwater concentration of 1.4 µg/L after about 370 percent recovery.

The arsenic concentration is likely to be present as dissolved arsenic ions with minimal sorption to iron oxyhydroxide coating on aquifer sediments through the recovered 50 percent sample. Arsenic concentrations in the 75 to 150 percent recovered water samples indicate increasing sorption to colloidal/flocculates of iron oxyhyroxide in the 75 and 100 percent recovery samples. Adsorption to iron oxyhydroxide coatings may also have minimally impacted the 75 and 100 percent recovered water, but increasingly impacted the recovered native groundwater in 100 to 150 percent recovery samples. Cycle 2 suggests that increasing the volume and storage time is likely to result in lower concentrations of both arsenic and iron oxyhydroxide (total iron) in the recovered water.

These characteristics of the Cycle 2 pilot test bode well for the Cycle 3 and subsequent ASR recharge. The results of the Cycle 2 pilot test indicate that subsequent ASR recharge is unlikely to produce an arsenic concentration that exceeds the drinking water standard in the recovered water from the Beltz 8 ASR well.

Monitoring Well

The initial groundwater sample from the MW on March 18, 2020 contained 29 µg/L of arsenic, considerably exceeding the 10 µg/L drinking water standard. This sample likely reflects the airlifting development within this two inch diameter MW. Airlifting results in the injection of atmospheric oxygen into the groundwater near the wellbore that considerably increases the oxidation of pyrite present in the aquifer sediments. This conclusion is supported by the three additional samples collected from the MW on April 12, 2020 and April 21, 2020. The arsenic concentrations ranging between 5.4 to 7.4 µg/L suggesting an average of about 6.2 µg/L or about the same as the highest arsenic concentration in the Cycle 2 recovered water from the ASR well. However, the 7.4 µg/L suggests that the recharge water may increase to this concentration without being recovered through a volume of aquifer conditioned by the recharge water. Alternatively, the groundwater samples may be reflecting a mixing of native groundwater and the groundwater impacted by air lifting.

The MW groundwater chemistry supports the conclusion reached based on the Cycles 1 and 2 pilot test results.

Manganese

The manganese concentration in the Beltz 8 native groundwater of 0.1 mg/L exceeds the 0.05 mg/L secondary aesthetic drinking water standard. Manganese concentrations in 58 historical native groundwater samples collected between November 7, 2001 and August 29, 2019 averaged 0.18 mg/L and ranged between 0.018 and 0.25 mg/L. The sample results for manganese in the 75 percent recovery of the recharge water volume in both cycles is less than the drinking water standard. The 100 and 125 percent recovery samples in Cycle 1 contained 0.8 mg/L (0.93 mg/L) and 0.09 mg/L (0.079 mg/L) manganese (total manganese concentrations), respectively while all the manganese concentrations in the 75 percent and less recovery were less than 0.05 mg/L. Similarly, 100, 125 and 150 percent recovery in Cycle 2 contained 0.07 mg/L (0.063 mg/L). 0.08 mg/L (0.085 mg/L), and 0.9 mg/L (0.1 mg/L) dissolved manganese (total manganese) concentrations, respectively. All manganese concentrations in the 75 percent and lower percentage recovery samples contained less than 0.05 mg/L drinking water standard.

Cycles 1 and2 pilot test data consistently indicate that 75 percent of the recharge water can be recovered with both dissolved and total manganese concentrations less than the 0.05 mg/L drinking water standard. The relative consistency of the manganese concentrations in the same recovery percentages in both a one day and 7 day recharge volumes is remarkable. It suggests that the manganese in the aquifer is produced by macro- and micro-pore volume exchange at a remarkably similar rate or manganese originated from an upgradient source and moves in the aquifer almost like the unreactive chloride ion in the groundwater. Cycle 3 may indicate that the latter condition is the case. If this is the case, repeated ASR cycles may increase the recovery percentage of recharge water that does not exceed the drinking water standard.

Iron

The dissolved iron concentration in all water samples in the Beltz 8 analytical data on Table 1 is well within the drinking water standard of 0.3 mg/L. Iron concentrations in 58 historical native groundwater samples collected between November 7, 2001 and August 29, 2019 averaged 1.50 mg/L and ranged between non-detect and 1.99 mg/L. As expected, both the recharge water samples had non-detectable dissolved and total iron. Only the two 75 percent recovery samples contained detectable dissolved iron concentrations essentially the detection limit. The total iron concentration of all samples, except the stored water containing 0.31 mg/L (barely over the drinking water standard), are below the drinking water standard. The total iron concentration of the native groundwater is reported to be 0.18 mg/L. All the recovered water samples have a very low, but detectable total iron concentration.

The difference in the dissolved and total iron in the samples suggests that a relatively minor but ubiquitous amount of pyrite is being oxidized in the aquifer forming a variable amount of flocculated iron hydroxide colloid in the groundwater. This would be consistent with the proposed source of arsenic concentrations in the groundwater and recovered recharge water samples.

The total iron concentration in the MW native groundwater of 0.34 mg/L and the two samples collected on April 21, 2020, containing 0.56 and 0.87mg/L, exceed the drinking water standard for iron. Only the dissolved iron concentration of the native groundwater is equal to the drinking water standard. The dissolved iron of the other three groundwater samples are well within the drinking water standard. These relationships are consistent with the proposed oxidizing pyrite source of both arsenic and iron in the Beltz 8 analytical data.

Groundwater Geochemical Characteristics

The native groundwater from the Beltz 8 ASR well is a calcium-bicarbonate-sulfate water chemistry type with a temperature of 19.37 degrees Celsius (°C), total dissolved solids (TDS) of 470 mg/L, a very slightly acidic field pH of 6.98 but slightly basic laboratory pH of 7.3 and an oxidized oxidation-reduction-potential (ORP) of plus 53.4 millivolts (mv). The increase in laboratory pH compared to the field pH is a typical result of the evolution of carbon dioxide gas from the groundwater sample between sample collection and analysis. Adding 240 mv to correct the ORP to Eh, the groundwater had an Eh of 293 mv. The ORP and Eh values are common values for an oxidized groundwater from a relatively shallow alluvial aquifer. However the zero mg/L dissolved oxygen (DO) is not and suggests that the oxidation of pyrite is sufficient to consume the DO originally present in the groundwater.

The MW native groundwater is a calcium-sodium-bicarbonate-sulfate water chemistry type but with a slightly higher temperature of 20.21 °C, the same TDS, a more alkaline field and laboratory pH of 7.55 and 7.8 respectively, and nearly the same DO (0.02) and lower ORP value of minus 88 mv (Eh of plus 152 mv). These differences in the Beltz 8 and MW groundwater pH and ORP likely reflect the development of the MW by airlifting.

The native groundwater from the Beltz 9 well is also a calcium-bicarbonate-sulfate water chemistry type, but one degree cooler (18.3 °C) than Beltz 8 groundwater even though the wells have similar depths. The TDS is the same, but the field pH of 7.94 and laboratory pH of 8.3 are considerably more alkaline than those of the Beltz 8 groundwater. The DO of 1.9 mg/L and Eh of 138 mv indicates an oxidized groundwater. These pH, DO and Eh values indicate that there is minimal active pyrite oxidation in native groundwater interacting with the sediments occurring at the Beltz 9 well location.

Silica and Aluminum

The silica concentration of the Beltz 8 groundwater of 61 mg/L and Beltz 9 groundwater of 71 mg/L are highly elevated compared to typical groundwater that contains between about 8 and 10 mg/L. The elevated silica concentration results from the dissolution of volcanic glass content of the sediments. Beltz 8 contains 20 to 24 percent volcanic glass compared to the 31 to 36 percent in the SC-22 sediments. Chemical reactions between water and volcanic glass result in significantly increase the silica concentration of the water and usually a significantly increase in the pH. The higher content of volcanic glass in the SC-22 sediments than the Beltz 8 sediments is likely responsible for the differences in the silica concentration and pH values of the two native groundwater. Pyrite oxidation in sediments of the Beltz 8 sediments also contributes to the lower pH of the Beltz 8 native groundwater.

Aluminum was less than 0.010 mg/L in all groundwater samples. It is assimilated with silica in the precipitation of smectite clay as part of volcanic glass and plagioclase feldspar dissolution.

Major Ions

Figure 2 is a trilinear diagram that illustrates the relationships of major ion chemistry for the Beltz 8 native groundwater, recharge water and recovered water for the first two preliminary ASR pilot tests and the MW groundwater.

Unlike most other ASR projects, the major ion chemistry of all of these source waters are remarkably similar as documented in all three parts of the trilinear diagram. On the central diamond part of the trilinear diagram, the two recharge water calcium-bicarbonate waters form a small pair beneath and to the right of the larger cluster of the Beltz 8 native calcium-bicarbonate-sulfate groundwater with less than six to seven percent difference. The native groundwater of the MW and the second groundwater sample collected from the MW on April 21, 2020 with the highest sodium percentage are offset about 9 percent to the lower left of the Beltz 8 native groundwater and recovered waters.

The trilinear diagram indicates that, with one exception, the recovered water from the two pilot test cycles are either the raw water or the native groundwater within analytical accuracy and precision of the laboratory analysis. The one exception is the April 19, 2020 sample of Cycle 2 that appears to be a mixture of about 80 percent Beltz 8 native groundwater and 20 to 30 percent recharge water. This distribution is shown not only the percentages but also the concentrations of all the major ions. Figure 3 shows the chloride concentrations of both recovery Cycles 1 and 2 showing the essentially same distribution as the trilinear diagram.

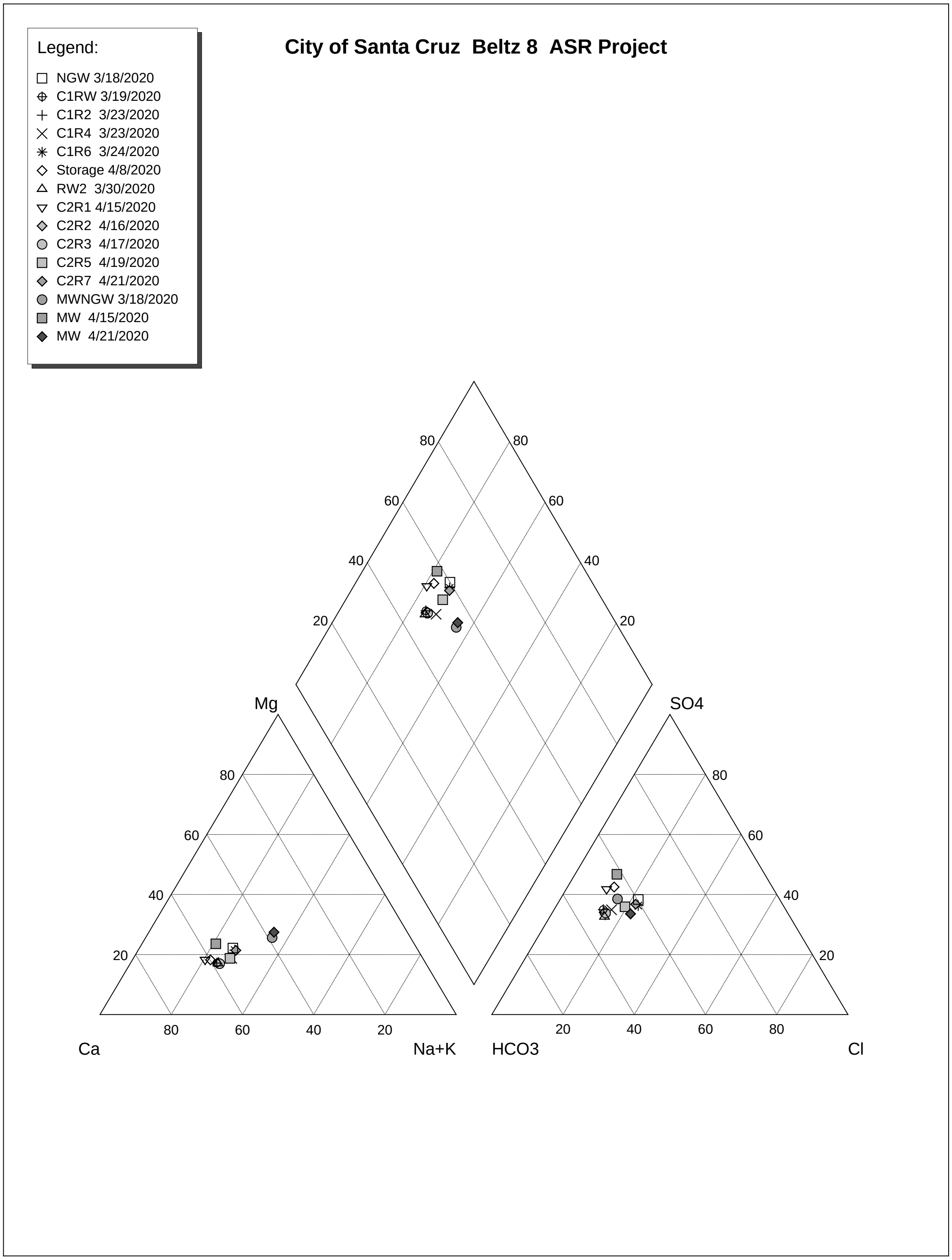

Figure 2. Trilinear diagram showing the major ion relationships for the Beltz 8 ASR Project pilot testing.

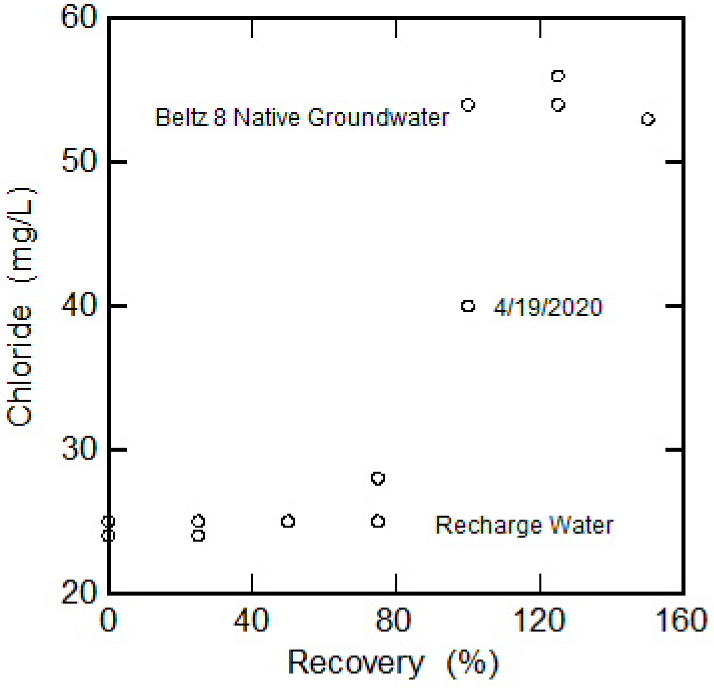

Figure 3. Chloride concentrations of recovered water from ASR pilot test Cycles 1 and 2.

What this means is that there is virtually no chemical reactions occurring with either the mixture of the recharge water with the Beltz 8 native groundwater or their contact with the aquifer mineralogy sufficiently strong to change the major ion chemistry during the time period of the two cycles. A similar concentration distribution is likely to occur in the third cycle even with its much longer contact time. In other words, the changes in the arsenic, manganese and iron concentrations resulting from pyrite oxidation is such a minor chemical reaction it is not shown by the major ion chemistry.

Although the Beltz 9 native groundwater is not plotted on the trilinear diagram of Figure 2, it plots very near that of the Beltz 8 groundwater. This is documented in Figure 1 of the 2017 report (Glanzman, 2017). Similar to these two cycles at Beltz 8, it is not possible to predict the recovered water chemistry of preliminary ASR pilot tests because the amount of pyrite exposed to recharge water in the aquifer at that well is not known without the pilot testing. However, given that the groundwater chemistry, TDS and that the sulfate concentration of the Beltz 9 native groundwater is the same as the Beltz 8 native groundwater plus that the Beltz 9 groundwater is more alkaline than the Beltz 8 groundwater, the pilot test results from Beltz 9 may be similar to these from Beltz 8. Alternately, if the apparent shielding of a significant amount of the pyrite is sustained during the pilot testing of Beltz 9, the arsenic concentration would be significantly lower than those documented in the two pilot tests at Beltz 8.

Thermodynamic Equilibrium Modeling

Thermodynamic equilibrium modeling estimates that the groundwater from the Beltz 8 ASR well is in equilibrium with respect to amorphous silica, plagioclase, swelling smectite clay and dolomite. It is undersaturated with respect to calcite and supersaturated with respect to iron oxyhydroxide.

Groundwater is rarely in equilibrium with respect to amorphous silica. The silica concentration of groundwater is usually much lower at less than about 10 mg/L where quartz is a dominant mineral in the aquifer and between 10 and 20 mg/L where silica and plagioclase feldspar are dominant in the aquifer. The volcanic glass in the aquifer mineralogy is predominantly responsible for the amorphous silica equilibrium as the glass is converted to smectite clay. Plagioclase is also converted to smectite clay but silica is in equilibrium with respect to cristobalite when plagioclase is the dominant precursor of smectite clay and volcanic glass is not present in the aquifer sediments.

The alteration of the significantly higher volcanic glass concentrations at the Beltz 9 well location to smectite clay may be a major factor in the significantly higher pH (7.9) of the Beltz 9 groundwater than that of the Beltz 8 native groundwater (6.98). This higher pH and precipitation of amorphous silica in the groundwater at the Beltz 9 well location may form a cover over pyrite in the aquifer mineralogy thereby limiting exposure of the pyrite to oxidation at that well location.

Groundwater is usually in equilibrium with respect to calcite since the kinetics of its precipitation are rapid. The 6.98 pH of this groundwater would have to be at least as high as 7.2 for calcite to be in equilibrium with this groundwater chemistry. Calcite is in equilibrium with the groundwater geochemistry of the raw water with a pH of 7.31 and the MW with a pH of 7.55. The pH of the Beltz 8 groundwater increases to the 7.2 to 7.4 range in the recovered water. It is possible that this lower pH is reflecting the oxidation of pyrite near the well bore as the well sits idle thereby resulting in this lower pH of the initial sampling of the well to document the native groundwater chemistry.

Iron oxyhydroxide is supersaturated in the Beltz 8 groundwater and all recovered water chemistry. This verifies the consistent low total iron and lack of dissolved iron in almost all the groundwater analyses. A nearly non-detect dissolved iron of 0.02 mg/L in the 75 percent recovery sample in both Cycles 1 and 2 supports the oxidation of pyrite near the wellbore of Beltz 8. The total iron is probably present as iron oxyhydroxide colloids in the groundwater and recovered water.

Nitrogen

Nitrate-nitrogen was not detected in the native groundwater from Beltz 8,but the recharge water contained 0.2 mg/L. Recovered recharge water (0 to 100 percent) from Cycle 1 contained 0.12 to 0.14 mg/L, but the recovered native groundwater (125 to 150 percent) did not contain any detectable nitrate-nitrogen. However, there were no detected nitrate-nitrogen concentrations in any of the recovered water from Cycle 2 (0 to 150 percent). Oxidizing pyrite converts nitrate-nitrogen to nitrogen gas over the longer time period of Cycle 2 compared to Cycle 1.

None of the four samples from the MW contained detectable nitrate-nitrogen and, similar to the Beltz 8 native groundwater, the Beltz 9 native groundwater did not contain detectable nitrate-nitrogen.

Ammonia-nitrogen is present at a very low 0.05 mg/L in the Beltz 8 native groundwater and 0.06 mg/L in the 125 percent recovered water sample, but in no other recovered water sample. Only the April 15, 2020 groundwater sample from the MW contained a detectable ammonia-nitrogen concentration (0.06 mg/L). The Beltz 9 native groundwater contains a similar very low ammonia-nitrogen of 0.079 mg/L.

Total Kjeldahl nitrogen (TKN) of 0.24 mg/L was reported to be present in the initial recovered water from Cycle 1 and a respectable 2.3 mg/L in the 125 percent recovered water in Cycle 1. TKN was not detected in the recharge water nor any other recovered water in Cycles 1 and 2. It was also not detected in any of the four samples from the MW. However, it was detected at 0.12 mg/L in the Beltz 9 native groundwater.

Since TKN is the sum of ammonia-nitrogen and organic nitrogen, the organic-nitrogen can be calculated by subtracting the ammonia-nitrogen from the TKN. This subtraction results in an organic-nitrogen on 0.24 and 2.24 mg/L in the two samples from Cycle 1 of the Beltz 8 well and 0.038 mg/L in the Beltz 9 native groundwater. The lack of supporting detectable concentrations of either TKN or ammonia-nitrogen suggests that the reported concentrations of both may well be either introduced during the well development, sampling process or be analytical errors. However, the heterotrophic plate count data suggests relatively elevated colony forming units in the Beltz 8 native groundwater and recovered water from both pilot test cycles as well as MW groundwater.

Total Phosphorus

Total phosphorus (TP) as phosphorus detected concentrations range between 0.1 to 0.2 mg/L with one non-detect concentration in the Beltz 8 groundwater and recovered water. The Beltz 8 native groundwater contained 0.11 mg/L and the recharge water contained 0.19 and 0.20 mg/L effectively marking two end members of this restricted TP range. The three MW groundwaters contained one non-detect and the other two containing 0.17 and 0.4 mg/L. The Beltz 9 native groundwater contains 0.14 mg/L. This very restricted range indicates that TP is essentially present as a non-reacting ion.

Trace Metals

A broad suite of 24 trace metals were analyzed with very low detection limits. Detections present are at very low concentrations and, for those that are regulated, well below their respective regulatory drinking water standards.

Gross Alpha

Gross alpha is a measure of alpha decay products generated by the decay of uranium and thorium. Since all uranium determinations yielded non-detectable concentrations in the groundwater, the gross alpha activity values would be expected to be similarly low and that is the case. The Beltz 8 native groundwater is reported to contain 6.4 picocuries per Liter (pCi/L) that is well within the 15 pCi/L gross alpha drinking water standard. The two raw water gross alpha values are 3.6 pCi/L and non-detect, respectively. Recovered water ranged between 4.2 and 8.5 pCi/L and therefore within the drinking water standard. The MW native groundwater is reported to contain 14 pCi/L that approaches the standard while the two additional groundwaters reported a non-detect and 13 pCi/L, respectively.

Organic Carbon

The total organic carbon (TOC) and the dissolved organic carbon (DOC) concentrations both have a low restricted range between 0.43 and 1.9 mg/L with the Beltz 8 native groundwater containing the lowest concentration and the recharge water, the highest concentration of the range, respectively. The TOC concentration is always slightly lower than the DOC and may be mislabeled. The MW native groundwater has an elevated TOC and DOC of 7.6 and 8.3 mg/L, respectively, that is probably an artifact of the airlift development of the well. The other two TOC and DOC concentrations range between 0.45 and 1.5 mg/L; are essentially the same as the Beltz 8 groundwater and recovered water range. The Beltz 9 native groundwater contains 0.46 and 0.54 mg/L, respectively.

Methane

Very low levels of methane are reported to be present in not only Beltz 8 native groundwater (0.37 µg/L) but also in the recharge water (0.22 and 0.34 µg/L) and recovered water (0.31 to 0.58 µg/L). Furthermore, it is also present in the MW native groundwater (0.25 µg/L) and the two additional groundwater samples from the well (0.12 and 0.88 µg/L). The ubiquitous occurrence of these less than 1 µg/L methane concentrations in these three disparate sources suggest that these values either represent a background methane distribution for this area or represent a laboratory generated values.

Bacteria

Heterotrophic Plate Count (HPC) and coliform bacteria tests were performed on both recharge water samples, Beltz 8 native groundwater, most of the recovered water samples and three of the four MW groundwater samples. HPC tests are essentially a screening test for the presence of bacteria, yeasts and molds potentially present in water. Most of those forms present in the HPC tests are not considered harmful but coliform bacteria that are included in the HPC test results can be harmful. Fortunately, none of the coliform bacteria results except for the MW groundwaters indicated detectable amounts of colony forming units (CFU). The MW native ground water collected March 18, 2020 is reported to contain 180 CFU while the April 15, 2020 and April 21, 2020 samples contained 110 and 1CFU, respectively. The MW native groundwater sample contained 1,900 CFU on the HPC tests while the other two MW groundwater samples contained 3,200 and 59 CFU, respectively.

The Beltz 8 native groundwater contained 150 CFU in the HPC tests while the two recharge water samples contained a very low 4 CFU in the March 19, 2020 sample and less than 1 CFU in the March 30, 2020 sample. HPC at zero percent recovery on Cycle 1 was 2,300 CFU and 590 CFU in the 125 percent recovery sample. The stored water between Cycles 1 and 2 and the zero percent recovery sample on Cycle 2 both had a very high HPC of greater than 5,700 CFU. The HPC values dropped to 3,100 and 3,600 CFU on the 50 and 100 percent recovery samples.

There is no apparent explanation for the elevated HPC values since neither the Beltz 8 native groundwater nor the recharge water contain the highly elevated HPC values reported for the recovered water. The aquifer sediments do not have an elevated organic matter nor elevated nutrients (nitrogen and phosphorus ions and compounds) that are usually associated with elevated HPC. The elevated TOC and DOC of the MW native groundwater suggests that the HPC may be associated with the recharge process rather than a presence within the aquifer sediments.

Disinfection Byproducts

The two recharge water Halo Acetic Acids (HAAC5) concentrations prior to Cycles 1 and 2 were 33 and 24 µg/L, respectively, well within the 60 µg/L drinking water standard for HAAC5. Individual HAAC5 byproducts rapidly react with the aquifer mineralogy and thereby are not usually present in most recovered water. Only the stored water following recharge and prior to recovery and the initial zero percent recovery samples contained detectable HAAC5 concentrations of 19 and 12 µg/L. All of the other recovered waters were non-detect.

The two recharge waters total trihalomethane (THMs) concentrations prior to Cycles 1 and 2 were 52 and 42 µg/L, respectively, also well within the 80 µg/L drinking water standard for THMs. The 125 percent recovery sample for Cycle 1 is reported to contain 0.99 µg/L THMs. Similar to the HAAC5, only the stored water and the zero percent recovery samples contained detectable THMs concentrations of 40 and 31 µg/L. THM concentrations can persist for weeks to months at decreasing concentrations before they totally degrade. However, oxidation of pyrite and its products accelerate the degradation of THMs to non-detectable concentrations.

CONCLUSIONS

This report focused on two ASR pilot tests performed at the ASR Beltz 8 well location, but includes the associated Monitoring Well data and provides comparisons with the ASR Beltz 9 well data for potential future considerations. All three wells are completed in the Plio-Pleistocene –aged Purisima Formation aquifer and generally have similar aquifer characteristics and groundwater geochemistry, but there are differences in the amount of volcanic glass in the aquifer mineralogy and pH of the groundwater at the Beltz 8 and Beltz 9well locations. Native groundwater from both the Beltz 8 well and Beltz 9 well is potable.

The analytical data for the Cycle 1 and Cycle 2 ASR pilot testing on the Beltz 8 well indicate that the arsenic concentration of recovered water is unlikely to exceed the 10 micrograms per Liter (µg/L) primary drinking water standard. The recovered water through the 75 percent sample of the recovered recharge water volume is also less than the 0.05 milligram per Liter (mg/L) secondary aesthetic manganese drinking water standard in both Cycles 1 and 2. Manganese exceeded this standard in recovered water samples in the 100 to 150 percent recovered water samples. This volume of recovered water that meets the manganese drinking water standard may increase with repeated cycles. The dissolved iron concentration of the stored water is less than the laboratory detection level, but the total iron concentration of 0.31 mg/L is the only recovered water that barely exceeds the 0.3 mg/L secondary aesthetic drinking water standard in the two pilot test cycles. All other total iron concentrations are well below the drinking water standard. Continuation with Cycle 3 is recommended.

The 20 to 24 percent of volcanic glass in the Beltz 8 sediments and 31 to 32 percent in the SC-22 monitoring well sediments used for the previous Beltz 9 analysis are unique in ASR projects. The volcanic glass may be responsible for the pH value and arsenic concentration differences in the groundwater of the two potential ASR wells completed in the A Unit of the Purisima Formation aquifer system. More importantly, the higher amorphous silica precipitation from the conversion of volcanic glass to smectite clay in the Beltz 9 groundwater may be responsible for shielding exposure of the pyrite source of arsenic from the groundwater that oxidizes the pyrite and releases arsenic to the groundwater.

The comparison and modeling of the Beltz 9 well data performed and described in appropriate sections of this document indicate that, if the Beltz 9 well is to be considered for ASR purposes, the same 3 Cycle pilot testing could proceed at the Beltz 9 without having to install a Beltz 9 MW and associated groundwater analyses for the MW.

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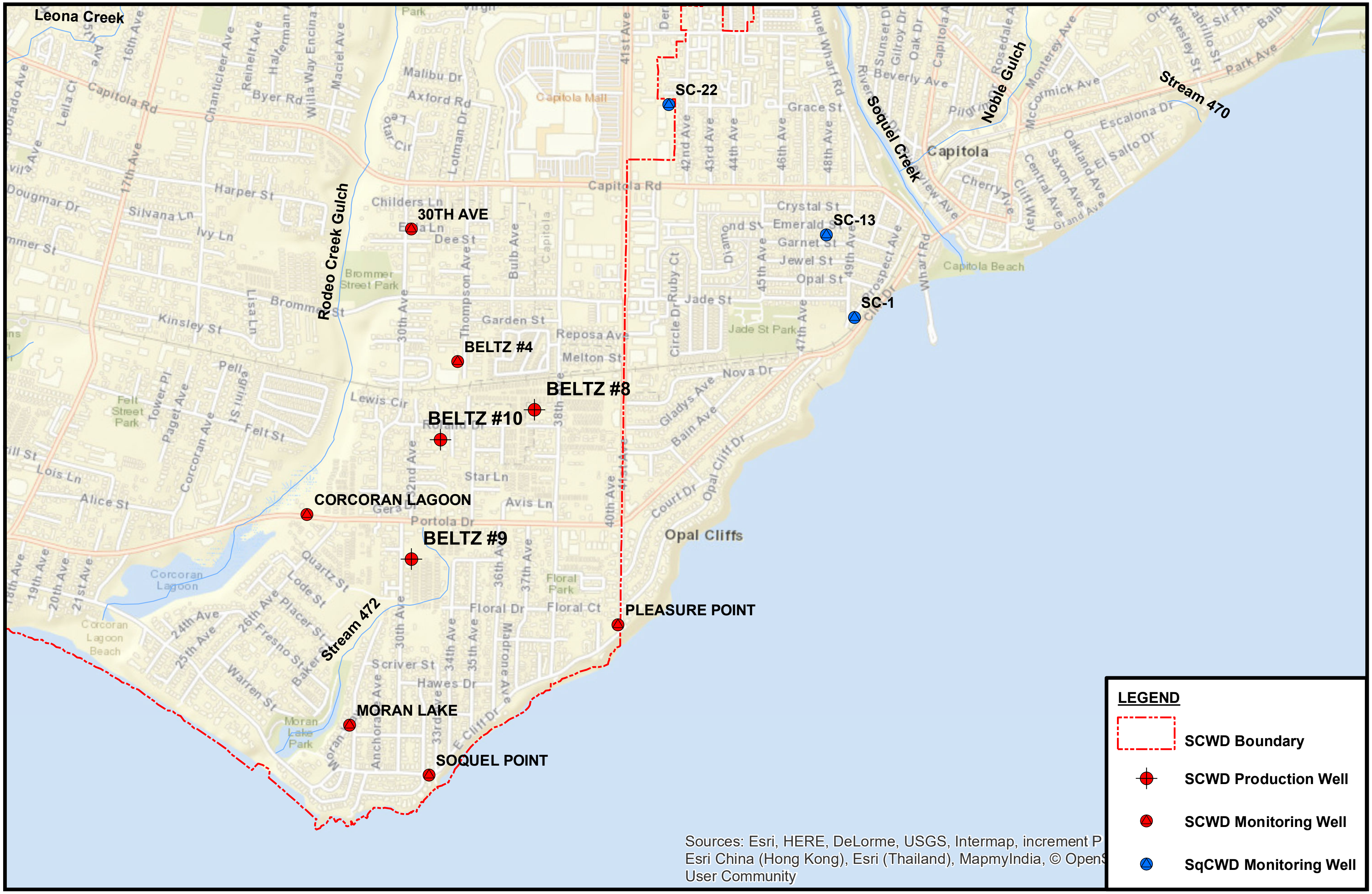

PUEBLO water resources

N
W E
S

1 inch = 1,500 feet

0 750 1,500 3,000 Feet

FIGURE 5. WELL LOCATION MAP
ASR Pilot Test Work Plan - Beltz 8
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department

15-0113
City of Santa Cruz
ASR Feasibility - Phase 2 - Beltz 8 ASR Pilot Test

Water Chemistry Results - ASR Cycles 1 - 2

TABLE 1 - BELTZ 8

Analyte Method Summary | **Results Summary - ASR Cycle 1** | **Results Summary - ASR Cycle 2**

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date								Sample Date								
Group ID						**3/18/20**	**3/19/20**	**3/23/20**	**3/23/20**	**3/23/20**	**3/23/20**	**3/24/20**	**3/24/10**	**3/30/20**	**4/8/20**	**4/15/20**	**4/16/20**	**4/17/20**	**4/18/20**	**4/19/20**	**4/20/20**	**4/21/20**
Field Parameters						**Pre-Injection**	**Injection**	**Recovery**						**Injection**	**Storage**	**Recovery**						
Temperature	on-site	SM 2550	°C	0.5		19.37	16.68	16.91	16.83	16.96	17.90	19.18	18.59	17.13	17.26	17.88	17.42	18.10	18.70	19.97	20.72	21.43
EC	on-site	EPA 120.1	umho/cm	10		625	428	461	443	446	476	548	577	489	628	561	449	445	452	551	621	614
pH	on-site	EPA 150.1	Std Units	0.01		6.98	7.20	7.11	7.30	7.32	7.27	7.12	7.10	7.31	7.07	6.89	7.26	7.27	7.24	7.12	7.09	7.03
ORP	on-site	USGS	mV	10		53.4	615.1	82.6	7.6	2.6	0.1	10.4	14.2	606	71.7	7.3	114.5	227.8	203.6	204.2	15.1	-7.8
Cl Residual	on-site	Hach	mg/L	0.05		0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.02	0.00	0.01	0.02	0.01	0.00	0.00	0.01
Diss O2	on-site	Hach	mg/L	0.2		0.00	9.06	0.02	0.00	0.00	0.00	0.00	0.00	9.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turbidity	on-site	Hach 2100Q	NTU	0.1		--	1.66	0.00	0.00	0.00	0.00	--	--	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SDI	on-site		Std Units	0.01		NA	1.78	NA	NA	NA	NA	NA	NA	2.76	NA	NA	NA	NA	NA	NA	NA	NA
General Mineral Analysis																						
Alkalinity (Total)	Lab	SM2320B	mg/L	5		140	110	120	120	120	120	140	140	120	120	140	120	120	120	130	140	140
Ca	Lab	EPA 200.7	mg/L	0.03		73	53	54	52	54	52	73	80	52	65	72	54	53	52	62	69	71
Cl	Lab	EPA 300.0	mg/L	0.5	250	55	21	25	25	25	28	54	56	25	25	24	24	25	25	40	54	53
EC	Lab	EPA 120.1	umho/cm	10	900	680	430	460	460	460	490	680	680	420	500	540	460	460	460	570	660	640
F	Lab	EPA 300.0	mg/L	0.1	2	0.052	0.16	0.12				0.073		0.14	0.11	0.092		0.1		0.085		
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	ND	ND	ND	ND	0.024	ND	ND	ND	ND	ND	ND	ND	0.022	ND	ND	ND
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	0.18	ND	0.13	0.062	0.057	0.051	0.066	0.068	ND	0.31	0.2	0.037	0.03	0.029	0.035	0.045	0.049
K	Lab	EPA 200.8	mg/L	1		6.1	1.9	2.1	2.3	3.4	4.7	6.9	7.3	1.9	2.2	2.4	2	2.3	4.1	6.2	6.4	6.3
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	ND				ND		ND	ND	ND		ND		ND		
Mg	Lab	EPA 200.8	mg/L	0.5		19	9.4	10	9.4	10	11	18	19	9.2	12	13	9.7	9.4	9.4	13	17	18
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.1		0.02	0.026	0.036	0.043	0.082	0.091	ND	0.021	0.025	0.019	0.033	0.044	0.067	0.078	0.093
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	0.095	ND	0.017	0.03	0.041	0.048	0.093	0.079	ND	0.019	0.022	0.022	0.031	0.046	0.063	0.085	0.1
Na	Lab	EPA 200.7	mg/L	0.05		39	24	24	24	26	28	40	41	24	26	26	25	25	25	32	38	40
NH3	Lab	EPA 350.1	mg/L	0.05		0.054	ND	ND				0.057		ND	ND	ND		ND		ND		
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	ND				ND		ND	ND	ND		ND		ND		
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	ND	0.2	ND	0.12	0.14	0.13	ND	ND	0.29	ND	ND	ND	ND	ND	ND	ND	ND
P (Total)	Lab		mg/L	0.001		0.11	0.19	0.14				ND		0.2	0.18	0.16		ND		0.1		
pH	Lab	EPA 150.1	Std Units	0.01		7.3	7.5	7.4	7.6	7.7	7.7	7.6	7.6	7.7	7.5	7.4	7.6	7.6	7.7	7.6	7.6	7.6
SiO2	Lab	EPA 370.1	mg/L	2		61	18	27	36	46	51	61	62	19	27	30	34	40	45	51	56	60
SO4	Lab	EPA 300.0	mg/L	0.5	250	130	72	77	74	75	82	120	120	72	110	120	76	76	77	100	120	120
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND	ND				ND		ND	ND	ND		ND		ND		
TDS	Lab	SM2540C	mg/L	5	500	470	260	290	290	310	340	460	440	280	340	380	290	300	290	380	450	460
TKN	Lab	EPA 351.2	mg/L	0.2		ND	ND	0.24				2.3		ND	ND	ND		ND		ND		
Inorganic Trace Metals																						
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND				ND		ND	ND	ND		ND		ND		
Al	Lab	EPA 200.8	ug/L	10	200	ND	21	ND				ND		22	ND	ND		ND		ND		
As	Lab	EPA 200.8	ug/L	1	10	1.4	ND	ND	1.1	1.4	1.6	3.1	3.8	ND	ND	1.2	4.2	6	5.5	5.8	4.9	4.5
B	Lab	EPA 200.8	ug/L	50		ND	59	64				ND		0.059	0.072	0.076		ND		ND		
Ba	Lab	EPA 200.7	ug/L	1	1000	53	33	36				55		32	44	48		33		51		
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND				ND		ND	ND	ND		ND		ND		
Br	Lab	EPA 200.9	ug/L	100		210	16	43	43	48	61	210	220	13	70	65	49	55	59	130	210	210
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND				ND		ND	ND	ND		ND		ND		
Co	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND		ND	ND	ND		ND		ND		
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND	ND				ND		ND	ND	ND		ND		ND		
Cu	Lab	EPA 200.8	ug/L	5	1000	9.4	ND	ND				ND		ND	ND	ND		ND		ND		
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
I	Lab	EPA 200.8	ug/L	100		3.6	ND	7.1				3.8		ND	16	13		5.6		4.8		
Li	Lab	EPA 200.7	ug/L	1		14	14	15				14		13	15	20		10		11		
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND	ND				ND		ND	ND	ND		ND		ND		
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND		ND	ND	ND		ND		ND		
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND	ND				ND		ND	ND	ND		ND		ND		
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND	ND				ND		ND	ND	ND		ND		ND		
Sr (Total)	Lab	EPA 200.7	ug/L	1		250	270	260				280		0.26	0.33	0.36		0.25		0.24		
Sr 86/Sr 87 (ratio)	Lab	EPA 200.8	ug/L	0.1																		
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND				ND		ND	ND	ND		ND		ND		
U	Lab	EPA 200.8	ug/L	0.5		ND	ND	ND				ND		ND	ND	ND		ND		ND		
V	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND		ND	ND	ND		3.1		4.4		
Zn	Lab	EPA 200.8	ug/L	10	5000	46	ND	ND				ND		ND	ND	ND		ND		ND		
Bio / Organics																						
Coliform	Lab		CFU	<1		ND	ND	ND				ND		ND	ND	ND		ND		ND		
HAA5's	Lab	EPA 552.2	ug/L	1	60	ND	33					ND		24	19	12				ND		
HPCs	Lab	SM9215B	CFU	<1		150	4	2300				590		<1	>5700	>5700		3100		3600		
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		0.77	1.9					0.89		1.3	1.4					0.8		
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		0.43	1.4					0.43		1.3	1.3	1.2				0.6		
TTHM's	Lab	EPA 502.2	ug/L	1	80	ND	52					0.99		45	40	31				ND		
Miscellaneous																						
CH4	Lab	RSK-175	ug/L	5		0.37	0.22	0.31				0.58		0.34	0.26	0.38		0.32		0.43		
Gross Alpha	Lab	EPA 900.0	pCi/L		15	6.4	3.6	5.4				4.6		ND	5.1	8.5		4.2		6.2		
Color	Lab	SM2120B	Color Units	3	15	ND	ND	ND				ND		ND	ND	5		3		ND		
Hardness	Lab	SM2340B	mg/L	10		260		180				280		170	210	230		170		210		
Tu	Lab	EPA 180.1	NTU	0.1	5	1.1	0.14	0.98				0.54		0.18	2	2.1		0.23		0.21		
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND				ND		ND	ND	ND		ND		ND		

Notes:
Values denoted in **bold** text exceed MCL.

15-0113
City of Santa Cruz
ASR Feasibility - Phase 2 - Beltz 8 ASR Pilot Test

Water Chemistry Results - ASR Cycles 1 - 2

TABLE 2 - BELTZ 8 MW

Analyte Method Summary						Results Summary			
Parameter	**Location of Analysis**	**Method**	**Unit**	**PQL**	**MCL**	**Sample Date**			
Group ID						**3/18/20**	**4/15/20**	**4/21/20 9:45**	**4/21/20 11:15**
Field Parameters						**Pre-Injection**	**ASR Cycle 2 Recovery**		
Temperature	on-site	SM 2550	°C	0.5		20.21	18.55	21.72	21.86
EC	on-site	EPA 120.1	umho/cm	10		547	585	460	516
pH	on-site	EPA 150.1	Std Units	0.01		7.55	7.82	6.97	7.25
ORP	on-site	USGS	mV	10		-87.5	-28.6	-36.7	-70.6
Cl Residual	on-site	Hach	mg/L	0.05		0.00	0.00	0.02	0.00
Diss O2	on-site	Hach	mg/L	0.2		0.02	0.00	0.00	0.00
Turbidity	on-site	Hach 2100Q	NTU	0.1		NA	NA	0.59	0.00
SDI	on-site		Std Units	0.01		NA	NA	NA	NA
General Mineral Analysis									
Alkalinity (Total)	Lab	SM2320B	mg/L	5		160	130	120	110
Ca	Lab	EPA 200.7	mg/L	0.03		55	74	48	36
Cl	Lab	EPA 300.0	mg/L	0.5	250	40	26	40	39
EC	Lab	EPA 120.1	umho/cm	10	900	670	630	540	480
F	Lab	EPA 300.0	mg/L	0.1	2	0.28	0.14	0.11	
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.3	0.092	ND	0.2
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	0.34	0.14	0.56	0.87
K	Lab	EPA 200.8	mg/L	1		6.3	6.2	5.2	4.7
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	ND	
Mg	Lab	EPA 200.8	mg/L	0.5		22	19	17	16
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.09	0.083	0.079	
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	0.087	0.082	0.13	0.078
Na	Lab	EPA 200.7	mg/L	0.05		54	28	35	36
NH3	Lab	EPA 350.1	mg/L	0.05		ND	0.11	ND	
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	ND	
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	ND	ND	ND	ND
P (Total)	Lab		mg/L	0.001		0.17	ND	0.4	
pH	Lab	EPA 150.1	Std Units	0.01		7.8	8	7.6	7.5
SiO2	Lab	EPA 370.1	mg/L	2		55	49	61	59
SO4	Lab	EPA 300.0	mg/L	0.5	250	130	140	86	80
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND	ND	
TDS	Lab	SM2540C	mg/L	5	500	470	440	380	330
TKN	Lab	EPA 351.2	mg/L	0.2		ND	ND	ND	
Inorganic Trace Metals									
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND	
Al	Lab	EPA 200.8	ug/L	10	200	ND	ND	ND	
As	Lab	EPA 200.8	ug/L	1	10	**29**	6.5	7.4	5.4
B	Lab	EPA 200.8	ug/L	50		ND	53	ND	
Ba	Lab	EPA 200.7	ug/L	1	1000	50	40	49	
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND	
Br	Lab	EPA 200.9	ug/L	100		140	67	150	150
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND	
Co	Lab	EPA 200.8	ug/L	1		ND	ND	ND	
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND	ND	
Cu	Lab	EPA 200.8	ug/L	5	1000	ND	ND	ND	
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND	ND
I	Lab	EPA 200.8	ug/L	100		2.1	5.2	2	
Li	Lab	EPA 200.7	ug/L	1		20	17	11	
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND	ND	
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND	
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND	ND	
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND	ND	
Sr (Total)	Lab	EPA 200.7	ug/L	1		400	300	310	
Sr 86/Sr 87 (ratio)	Lab	EPA 200.8	ug/L	0.1					
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND	
U	Lab	EPA 200.8	ug/L	0.5		ND	ND	ND	
V	Lab	EPA 200.8	ug/L	1		ND	ND	ND	
Zn	Lab	EPA 200.8	ug/L	10	5000	ND	ND	ND	
Bio / Organics									
Coliform	Lab		CFU	<1		180	110	1	
HAA5's	Lab	EPA 552.2	ug/L	1	60	ND	ND	ND	
HPCs	Lab	SM9215B	CFU	<1		1900	3200	59	
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		8.3	1.5	0.55	
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		7.6	1	0.45	
TTHM's	Lab	EPA 502.2	ug/L	1	80	ND	0.88	ND	
Miscellaneous									
CH4	Lab	RSK-175	ug/L	5		0.25	0.59	0.12	
Gross Alpha	Lab	EPA 900.0	pCi/L		15	14	13	ND	
Color	Lab	SM2120B	Color Units	3	15	5	ND	3	
Hardness	Lab	SM2340B	mg/L	10		230	260	160	
Tu	Lab	EPA 180.1	NTU	0.1	5	0.34	0.55	1.2	
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND	

Notes:

Values denoted in **bold** text exceed MCL.

MINERALOGY-INC
WHERE SCIENCE GETS DOWN TO EARTH

ASR ph 2 | Beltz 8 MW

Santa Cruz, CA

15-0113

Requested by:
Robert Marks
Pueblo Water Resources

Mineralogy, Inc. Number 20096

Date:
July 10, 2020

Submitted by:

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CONDITIONS AND QUALIFICATIONS

Mineralogy, Inc. will endeavor to provide accurate and reliable laboratory measurements of the samples provided by the client. The results of any x-ray diffraction, petrographic or core analysis test are necessarily influenced by the condition and selection of the samples to be analyzed. It should be recognized that geological samples are commonly heterogeneous and lack uniform properties. Mineralogical, geochemical and/or petrographic data obtained for a specific sample provides compositional data pertinent to that specific sampling location. Such "site-specific data" may fail to provide adequate characterization of the range of compositional variability possible within a given project area, thus the "projection" of these laboratory findings and values to adjoining, "untested" areas of the formation or project area is inherently risky, and exceeds the scope of the laboratory work request. Hence, Mineralogy, Inc. shall not assume any liability risk or responsibility for any loss or potential failure associated with the application of "site or sample-specific laboratory data" to "untested" areas of the formation or project area. Unless otherwise directed, the samples selected for analysis will be chosen to reflect a visually representative portion of the bulk sample submitted for analysis. Where provided, the interpretation of x-ray diffraction, petrographic or core analysis results constitutes the best geological judgment of Mineralogy, Inc., and is subject to the sampling limitations described above, and the detection limits inherent to semi-quantitative and/or qualitative mineralogical and microscopic analysis. Mineralogy, Inc. assumes no responsibility nor offers any guarantee of the productivity, suitability or performance of any oil or gas well, hydrocarbon recovery process, dimension stone, and/or ore material based upon the data or conclusions presented in this report.

This report is to only be replicated in its entirety.

Sample Retention: Samples will be stored for a period of 30 days and thereafter discarded. If additional sample storage time and/or return shipping is required, appropriate charges will be billed to the client.

Introduction

Four drill cutting samples have been evaluated from the Beltz 8 Monitoring Well located near Santa Cruz, CA. The cutting materials are being evaluated in support of geochemical modeling & management efforts for the Phase 2 ASR study for the coastal aquifer system. Test methods have included: x-ray diffraction (XRD) mineralogical analysis, x-ray fluorescence (XRF) chemical analysis, cation exchange capacity (CEC) analysis, particle size distribution analysis, acid insoluble residue analysis, and petrographic analysis of the drill cutting materials. The petrographic evaluation has included qualitative assessments of grain mount thin section samples and SEM specimens prepared for these aquifer intervals.

Sample ID	MI#	Testing Protocol
100 - 120 ft.	20096-01	XRD, XRF, CEC, SEM, Sieve, Acid, TSP
120 - 140 ft.	20096-02	XRD, XRF, CEC, SEM, Sieve, Acid, TSP
140 - 160 ft.	20096-03	XRD, XRF, CEC, SEM, Sieve, Acid, TSP
160 - 180 ft.	20096-04	XRD, XRF, CEC, SEM, Sieve, Acid, TSP

XRD = X-ray Diffraction • XRF = X-ray Fluorescence • CEC = Cation Exchange Capacity • SEM = Scanning Electron Microscopy • Acid = Acid Insoluble Residue • TSP = Thin Section Petrography

Summary

The most significant findings of the materials analysis for these well cutting samples are noted as follows:

- The results of the x-ray diffraction mineralogical analysis (XRD) are summarized in Table I. The aquifer sands are feldspar-rich, with oligoclase (42-49%) and orthoclase (7-8%) feldspar varieties dominating the detrital mineralogy. Quartz accounts for ~ 24 - 27% of the mineral mass. Ferro-magnesian minerals are common & include significant amounts of augite, hornblende, and magnetite. Calcite and pyrite are present as grain-replacement & pore-filling cement materials. Pyrite is present as a replacement cement within leached volcanic RFs. Clay minerals identified in the aquifer sand samples include: smectite (~ 5 - 6.5%), illite/ mica (0.5-1%), kaolinite (0.5-1%), and traces of chlorite (<1%). Significant amounts of clay are localized within leached and corroded detrital grains.
- The results of the x-ray fluorescence chemical analysis obtained for these sediment samples are presented in Table II. The elemental composition for these sand-rich intervals is dominated by silicon, aluminum, iron, calcium, sodium, magnesium, potassium, and sulfur. Accessory elemental phases include traces of titanium, phosphorus, manganese, chloride, and barium. The elemental distributions noted in Table II are roughly complimentary of the x-ray diffraction assessments reported in Table I for crystalline mineral phases present in these cutting materials. It is noteworthy that amorphous volcanic glass is not represented in the x-ray diffraction summary presented in Table I.
- The results of the cation exchange capacity analysis are summarized in Table III. Cumulative CEC values for these sediment samples range from ~ 10.02 - 20.49 meq/100 grams of sediment. The three cutting intervals from 120 - 180 ft. (20096-02 - 20096-04) exhibit a hierarchy of exchangeable cation species that include calcium (Ca) > sodium (Na) > magnesium (Mg) > potassium (K). The uppermost cutting interval from the Beltz 8 monitoring well (100 - 120 ft; 20096-01) exhibits a relatively small cumulative CEC value (10.02 meg/100 grams), with an ion exchange hierarchy of Na > Ca > Mg > K. Variations in the exchange capacity for these sediment intervals likely reflect contrasts in the relative abundance of authigenic smectite.
- The results of the acid insoluble residue analysis are reported in Table VI. Acid insoluble residue fractions range from ~ 95.7 - 98.0% within these sediment samples. Localized concentrations of calcite cement and limestone RF (rock fragment) materials are the principal sources of acid soluble mineral matter present within these drill cutting samples.
- A composite graph & tabular summary of the particle size data is presented in Table V. The sediment size distribution is reasonably uniform throughout the drill cutting depth range, with each interval characterized as medium-grained and moderately to moderately well-sorted. Silt and clay-sized particulates typically account for < 1.5% of the weight distribution within these sediment materials. The sediment samples from 140 - 160 ft. (20096-03), & 160 - 180 ft. (20096-04) locally contain granule to pebble-sized concretions of calcareous litharenitic sandstone. The drill cuttings from

160 - 180 ft. also contain pebble-sized concentrations of silty mudstone. The silty mudstone materials are exceedingly microporous and could represent drilling contaminants that are admixed with he aquifer sands. Interval specific particle size distributions accompany the thin section and SEM data for each of the sand intervals within Appendix II.

- The results of the thin section petrography, scanning electron microscopy, and particle size distribution analysis for individual cutting intervals represented in the sample suite are presented in Appendix II. The petrographic results include descriptive summaries of the detrital mineralogy and sedimentary fabric along with representative images of the unconsolidated grain materials. SEM images obtained for these sand samples typically offer detailed views of grain replacement cements and matrix materials as well as allogenic, grain-coating matrix components associated the sand-rich sediments.
- Drill cutting samples evaluated from the Betlz 8 MW include unconsolidated and disaggregated, sand-rich sediment materials. The unconsolidated sands are medium-grained and moderately sorted. Mean grain diameters are estimated to range from ~ 0.31 - 0.36 mm with scattered granules and pebbles present as localized concretions of calcite-cemented sandstone. The detrital sand grains are sub-rounded to sub-angular and locally contain modest amounts of admixed silt and very fine sand.
- Grain materials are dominated by igneous RFs (rock fragments), feldspar and quartz-rich sand grains. The igneous rock fragment population includes: basalt, andesite, dacite, rhyolite, scoria, and obsidian RFs. Feldspar crystals and grains are predominantly comprised of oligoclase + subordinate amounts of orthoclase feldspar. Quartz grains include mono-crystalline and poly-crystalline quartz varieties. Minor lithic grain types include metaquartzite, limestone particles, and chert RFs. Minor amounts of augite, hornblende, magnetite, pyrite, rutile and pyrite are also distributed within the sand intervals from this aquifer.
- Intra-particle dissolution and corrosion of selected igneous RFs and feldspar grains has contributed to the localized fragmentation, replacement, and infiltration / migration of grain remnant materials within the pore system. Clusters of smectite-rich matrix materials +/- leached grain fragments attributed to grain corrosion are present in each of the sand intervals from this aquifer and are susceptible to migration and 'brush-piling' within the intergranular pore throats. Authigenic smectite clay is a common replacement for volcanic glass within the igneous RFs and also occurs as a replacement associated with leached feldspar crystals. Minor clay types include illite, as well as localized concentrations of kaolinite and chlorite. Calcite, magnetite, hematite, goethite, and pyrite cement locally occur as authigenic replacement cements.

Conclusions

Drill cutting materials from this coastal aquifer system are medium-grained, moderately sorted and sub-rounded to sub-angular. The detrital grain population is mineralogically immature & contains large amounts of volcanic and igneous RF material + detrital feldspar grains and crystals that are susceptible to corrosion and intraparticle dissolution / replacement. Macro porosity within the in situ aquifer intervals includes well preserved & interconnected, intergranular void space + secondary dissolution porosity (including grain-mildic & intraparticle dissolution voids). Authigenic smectite is common as a common grain-replacement phase. The infiltration, migration, and localized brush-piling of authigenic matrix clusters + corroded grain remnants is likely to constitute the most significant challenge to the maintenance & optimization of transmissivity for this aquifer.

Locally significant indications of barium + iron mineralization (including the precipitation of pyrite, iron oxide & iron oxide hydroxide cement phases) could pose challenges to water quality for this aquifer system. The pyrite & iron oxide cements are widely distributed as grain-replacements. A more detailed characterization of trace element chemistries (including Ba, As and Pb concentrations) and their distribution within the aquifer sediments is recommended to supplement the XRF chemical evaluation included in this ASR Phase 2 study.

Appendix I

X-ray Diffraction, X-ray Fluorescence, Cation Exchange Capacity, Acid Insoluble Residue, & Sieve Analysis

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X-ray Diffraction

Table I

Client:	Pueblo Water Resources	MI#:	20096
Project:	ASR ph 2 / Beltz 8 MW	P.O.#:	15-0113
Location:	Santa Cruz, CA	Method:	X-ray Diffraction

Mineral Constituent	**Sample ID**	**100 - 120 ft.**	**120 - 140 ft.**	**140 - 160 ft.**	**160 - 180 ft.**
	MI#	**20096-01**	**20096-02**	**20096-03**	**20096-04**
	Chemical Formula	**Relative Abundance (%)**			
Quartz	SiO_2	25	24	26	27
Oligoclase	$(Na,Ca)AlSi_3O_8$	49	48	44.5	42
Orthoclase	$KAlSi_3O_8$	7	7	8	7
Calcite	$CaCO_3$	2	3	5	5
Augite	$Ca(Fe,Mg)Si_2O_6$	4	5	4	5
Hornblende	$Ca_2(Mg,Fe)_5(Si,Al)_8O_{22}(OH)_6$	1	1	1	1
Pyrite	FeS_2	2	2	3	3
Magnetite	alpha-Fe_3O_4	2	2	2	3
Akaganeite	beta-FeOOH			0.5	
Heulandite	$Ca_{1.23}(Al_2Si_7)O_{18} \cdot 6H_2O$	<0.5		<0.5	
Kaolinite	$Al_2Si_2O_5(OH)_4$	1	0.5	0.5	0.5
Chlorite	$(Mg,Al)_6(Si,Al)_4O_{10}(OH)_8$				0.5
Illite / Mica	$KAl_2(Si_3AlO_{10})(OH)_2$	1	1	0.5	1
Smectite	$Na_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot xH_2O$	6	6.5	5	5
Total		**100**	**100**	**100**	**100**

X-ray Fluorescence

Table II

Client:	Pueblo Water Resources	MI#:	20096
Project:	ASR ph 2 / Beltz 8 MW	P.O.#:	15-0113
Location:	Santa Cruz, CA	Method:	X-ray Fluorescence

Sample ID	100 - 120 ft.	120 - 140 ft.	140 - 160 ft.	160 - 180 ft.
MI#	20096-01	20096-02	20096-03	20096-04
Elemental Phase	Results (Mass %)			
Na2O	3.4148	3.2024	3.0896	2.952
MgO	1.7806	1.8016	1.9594	1.9345
Al2O3	14.5086	14.2626	13.8171	13.8147
SiO2	65.4937	65.1214	64.3647	63.5738
P2O5	0.2966	0.2483	0.2425	0.266
S	0.706	0.6882	0.7213	0.9111
Cl	0.0373	0.0339	0.0347	0.0254
K2O	2.4651	2.3716	2.3632	2.4385
CaO	4.4014	5.1657	6.2954	6.7454
TiO2	0.5209	0.5531	0.5085	0.4849
Cr	ND	0.0274	ND	0.0153
MnO	0.0727	0.0813	0.0885	0.0845
Fe2O3	5.0104	5.1594	5.2087	5.1594
Zn	0.0079	0.0092	ND	ND
Rb	0.0077	0.0066	0.0089	0.0079
Sr	0.0601	0.061	0.0593	0.0592
Zr	0.0119	0.012	0.0132	0.009
BaO	0.1298	0.1331	0.129	0.1327

ND = Not Detected

Cation Exchange Capacity

Table III

	Calcium		Magnesium		Potassium		Sodium		
	Results	PQL**	Results	PQL**	Results	PQL**	Results	PQL**	Cumulative
Sample ID	(meg/100g)		(meg/100g)		(meg/100g)		(meg/100g)		CEC
100 - 120 ft.	2.84	0.1	0.628	0.1	0.466	0.1	6.09	0.1	10.024
20096-01									
120 - 140 ft.	13.4	0.1	0.833	0.1	0.513	0.1	5.74	0.1	20.486
20096-02									
140 - 160 ft.	10.2	0.1	0.7	0.1	0.466	0.1	5.13	0.1	16.496
20096-03									
160 - 180 ft.	11.5	0.1	0.750	0.1	0.513	0.1	4.83	0.1	17.593
20096-04									

Method Reference: 40 CFR 136, 261, Method for Chemical Analysis of Water and Waste EPA-600/4-79-020 March 1983

CEC Method Reference: Method of Soil Analysis, Chemical and Microbiological Properties, 2nd Ed.; American Society of Agronomy, Iinc.

Soil Science Society of America, Inc. page 160.

**CEC analysis provided by Accurate Laboratories & Training Center; Stillwater, OK*

***PQL= Practical Quantitation Limit*

Acid Insoluble Residue

Table IV

Client:	Pueblo Water Resources	MI#:	20096
Project:	ASR ph 2 / Beltz 8 MW	P.O.#:	15-0113
Location:	Santa Cruz, CA	Method:	Acid Insoluble Res.

Depth	Lab ID	Acid Insoluble Residue (%)
100 - 120 ft.	20096-01	98.02
120 - 140 ft.	20096-02	97.03
140 - 160 ft.	20096-03	95.67
160 - 180 ft.	20096-04	95.85

Sieve Analysis

Table V

Client:	Pueblo Water Resources	MI#:	20096
Project:	ASR ph 2 / Beltz 8 MW	P.O.#:	15-0113
Location:	Santa Cruz, CA	Method:	Sieve

Sample ID	2.00 mm	1.00 mm	710 µm	500 µm	425 µm	300 µm	250 µm	212 µm	180 µm	125 µm	90 µm	75 µm	63 µm	PAN <63 µm
100-120’	0.00	0.42	1.27	6.12	8.65	43.89	18.15	12.66	5.70	1.69	0.21	0.21	0.21	0.82
120-140’	0.00	0.00	1.18	5.52	7.30	35.50	15.38	13.81	7.50	8.48	3.55	0.79	0.39	0.59
140-160’	4.46	1.55	2.91	5.23	8.72	36.82	13.57	10.27	5.43	6.40	2.33	0.97	0.39	0.97
160-180’	4.29	3.93	3.39	6.79	6.61	40.36	12.68	10.00	4.64	4.29	1.61	0.54	0.18	0.71

Appendix II

Scanning Electron Microscopy, Thin Section Petrography, & Particle Size Data

100 - 120 ft.

ASR ph 2 / Beltz 8 MW

MI#20096-01 - SEM

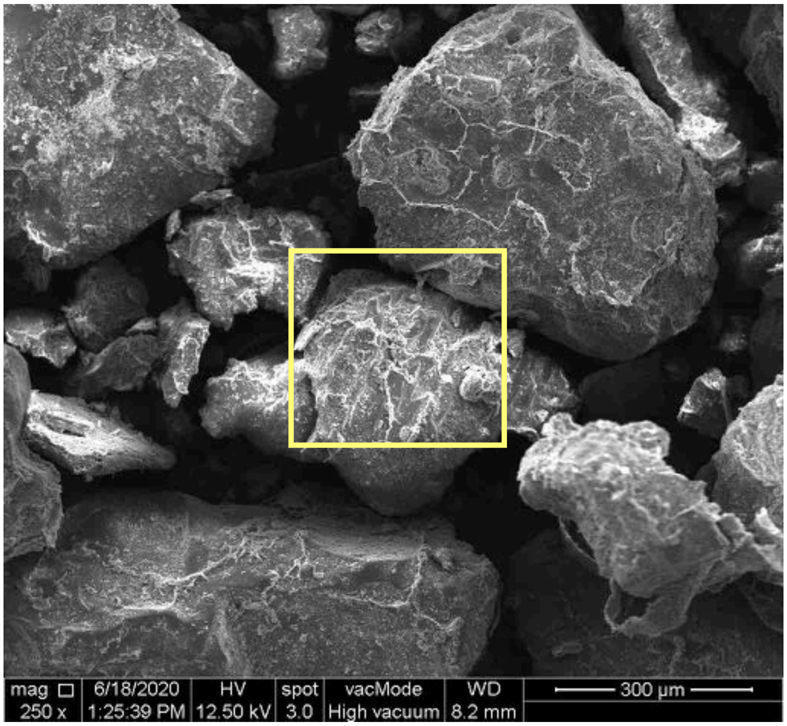
Summary: Drill cuttings from this interval are comprised of medium-grained, moderately-sorted, sub-angular, unconsolidated and disaggregated, feldspathic litharenitic sand material. The approximate mean diameter for the grain mount thin section prepared for this interval is 0.30 mm, with a maximum grain diameter of 1.2 mm. The detrital sand fraction is sub-rounded to sub-angular. Detrital grains include: igneous RFs (rock fragments), feldspar (including plagioclase and K-feldspar), quartz, augite, hornblende, limestone RFs, metaquartzite RFs, chert RFs, magnetite, and mica. Igneous RFs are commonly glass-rich volcanic fragments with crystals and phenocrysts of plagioclase feldspar +/- pyroxine +/- hornblende. Igneous lithotypes include basalt, andesite, dacite, rhyolite, and scoria rock fragments. Intra-particle corrosion and localized replacement with authigenic clay matrix and iron oxide cement materials +/- pyrite cement are relatively common. Traces of calcite spar occur as inter-particle cements concentrated within scattered sandstone concretions. The SEM images obtained for this aquifer interval reveal localized presence of grain-coating clays. The clay matrix clusters are generally poorly-crystallized and locally incorporate calcareous skeletal fragments, feldspar and quartz-rich silt grains, and relatively dense clusters of micro-crystalline smectite. Most of the clay matrix within this interval is attributed to intra-crystalline and intra-particle replacement of feldspar and glass-rich RFs. The clusters of allogenic matrix are locally poorly-attached to the grain surfaces and are susceptible to migration and brush-piling within the inter-granular pore throats of the producing aquifer.

20096-01 Photo Index: (bookmarks)

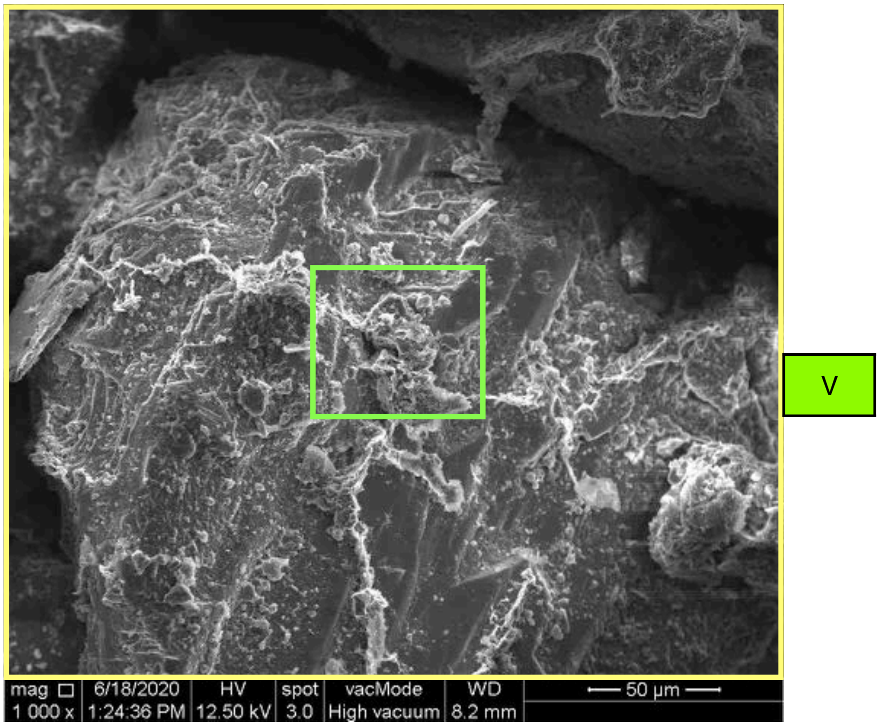
Sample ID	Magnification
20096-01A	250X
20096-01B	1000X
20096-01C	5000X
20096-01D	600X
20096-01E	5000X

Volcanic rock fragment	V
Calcite	C
Authigenic smectite	A
Detrital feldspar	F

20096-01A 250X

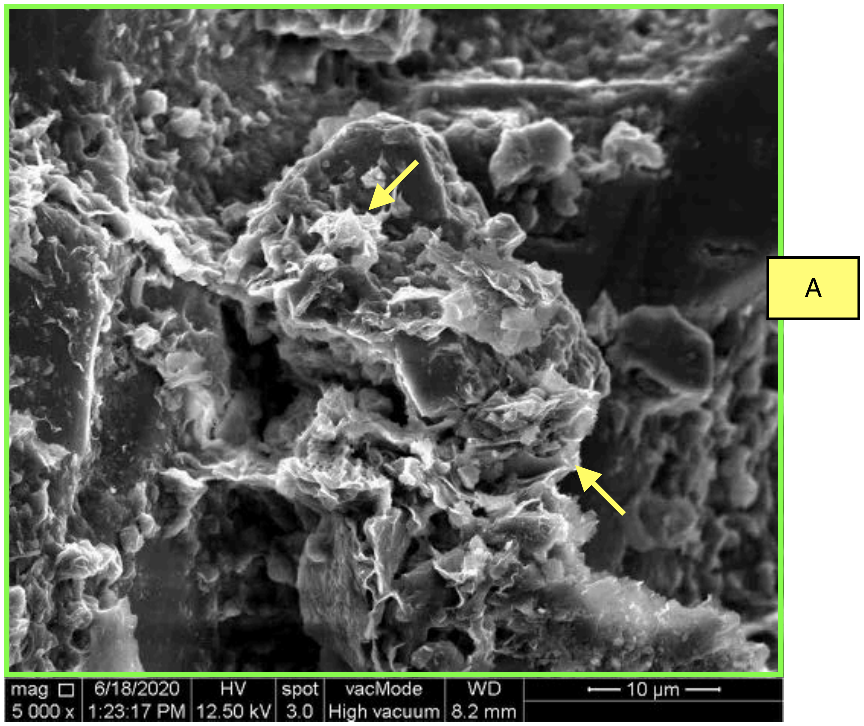


20096-01B 1000X

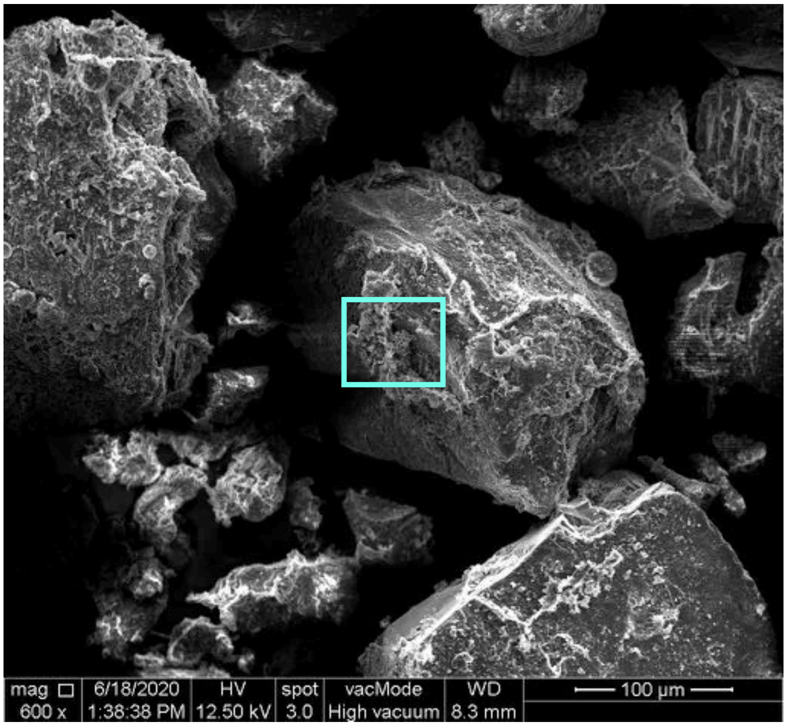


20096-01 Photo Index

20096-01C 5000X

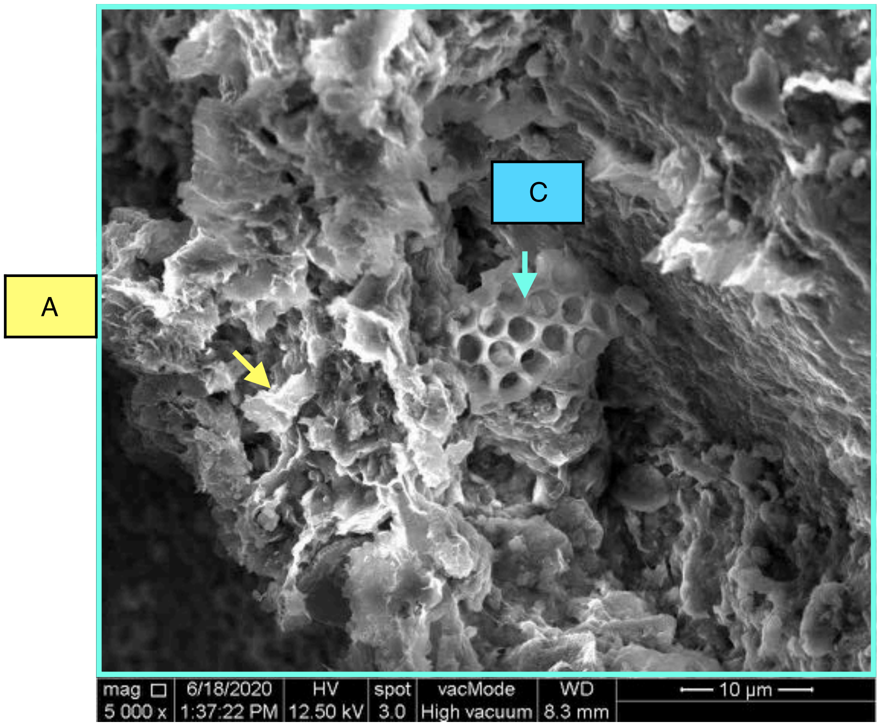


20096-01D 600X

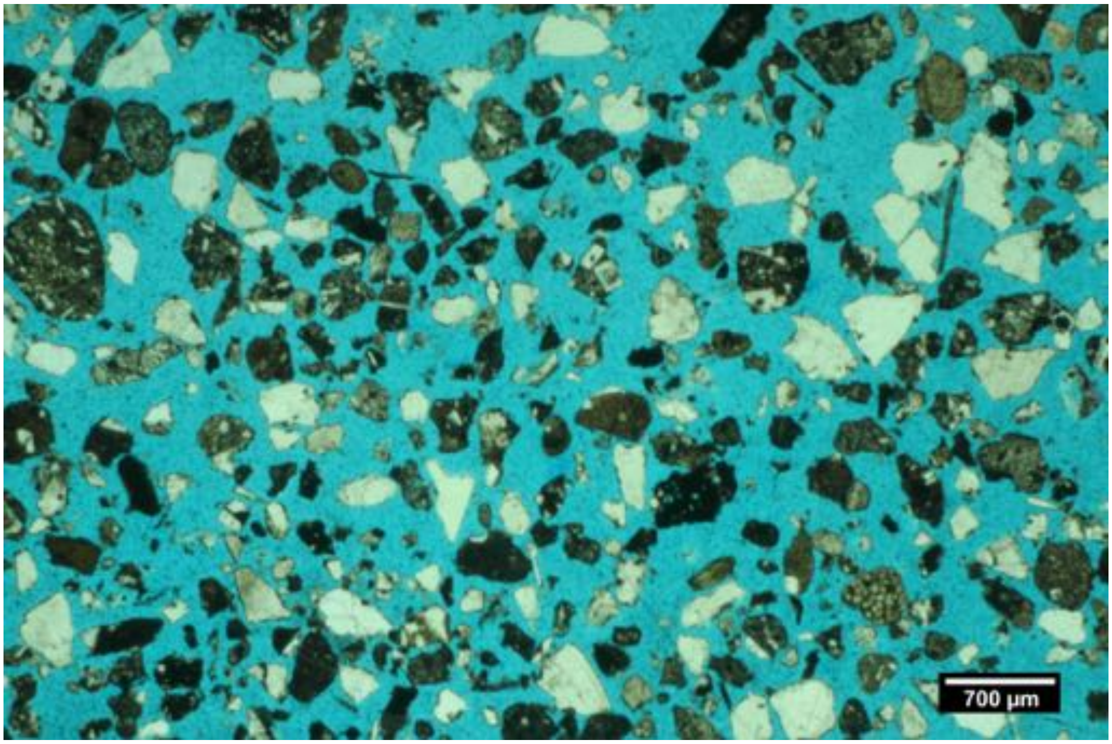


[20096-01 Photo Index](#)

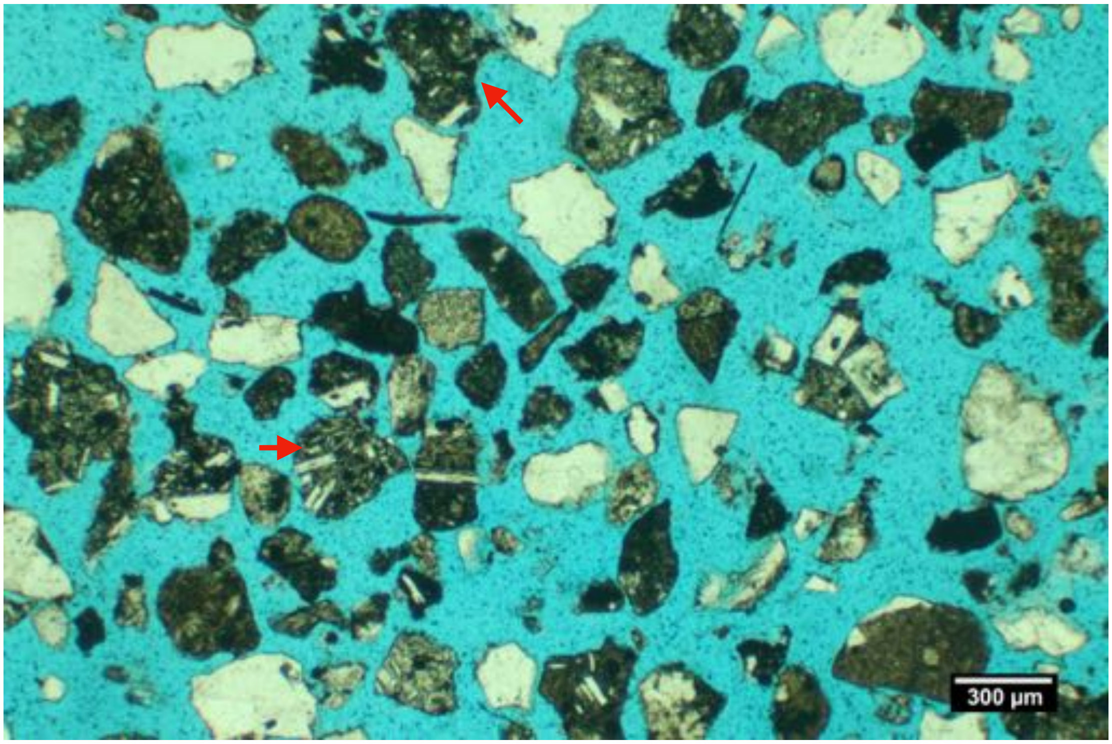
20096-01E 5000X



100 - 120 ft.; MI#20096-01

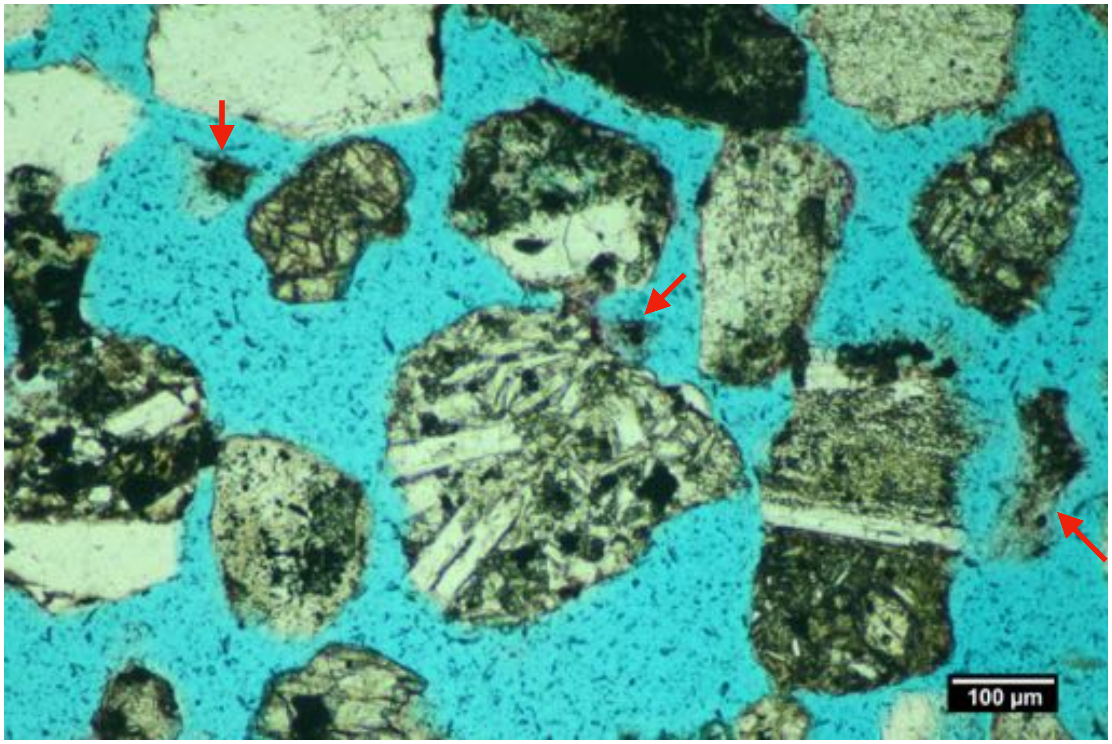


1A. Drill cuttings from this interval are unconsolidated, medium-grained, moderately sorted, and comprised of feldspathic litharenitic sand materials.

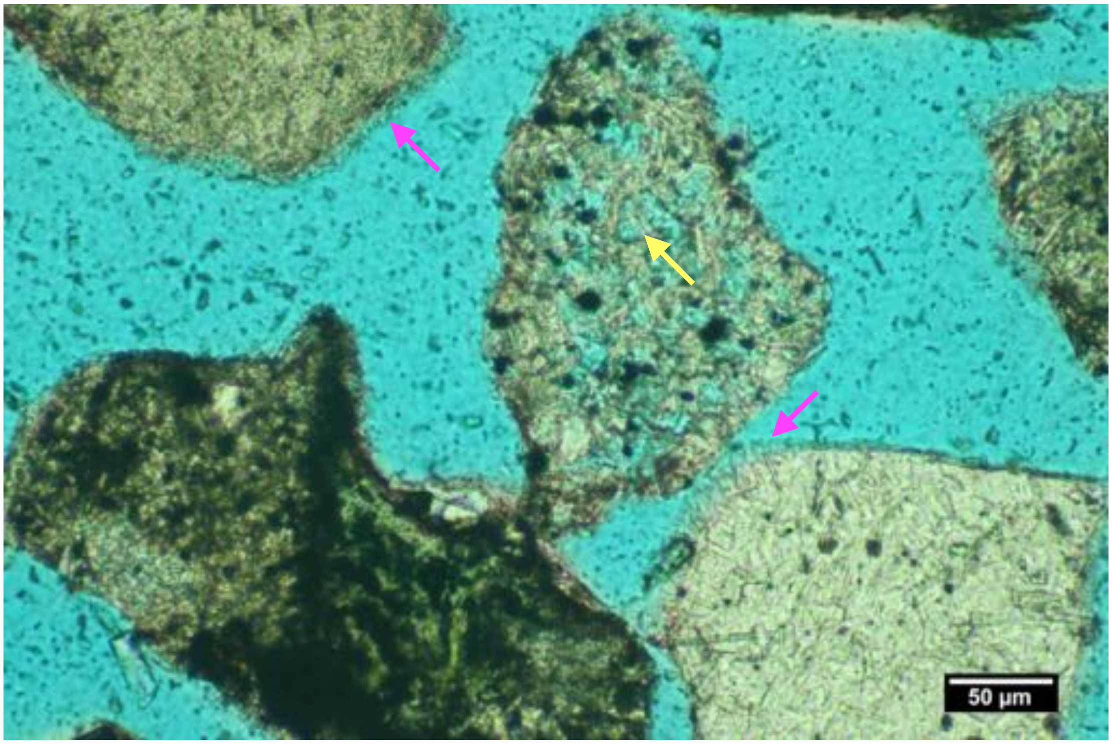


1B. The volcanic RFs (red <) commonly include feldspar crystallites & phenocrysts + glass-rich groundmass materials. Authigenic smectite + pyrite are common replacement minerals.

100 - 120 ft.; MI#20096-01



1C. The dissolution & replacement of the volcanic RFs has contributed to the movement & localized ‘brush-piling’ of matrix & cement constituents in the pore system (red <).

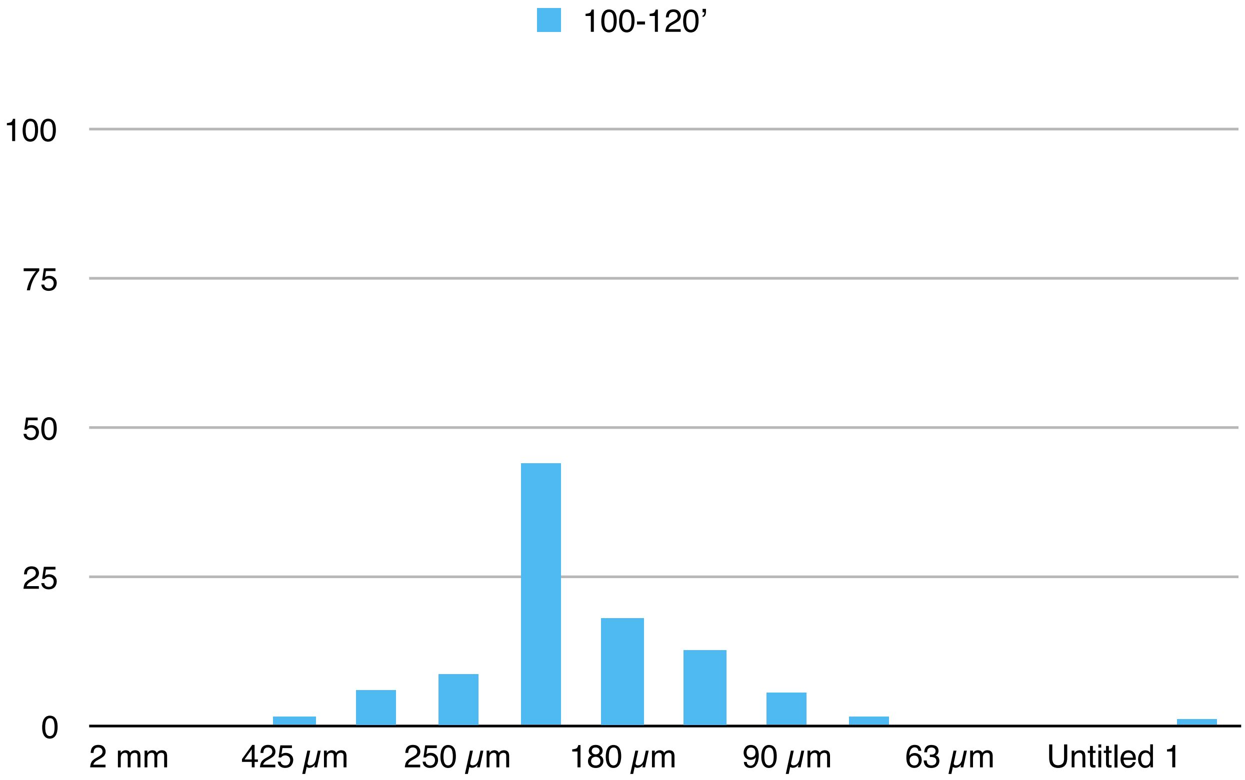


1D. A leached volcanic RF with significant intraparticle dissolution porosity (blue; yellow <). Note the ‘whisker-like’ indications of authigenic grain-coating clay matrix (magenta <).

Sieve Analysis

100 -120 ft.

Client:	Pueblo Water Resources	MI#:	20096-01
Project:	ASR ph 2 / Beltz 8 MW	P.O.#:	15-0113
Location:	Santa Cruz, CA	Method:	Sieve



Sample ID	2.00 mm	1.00 mm	710 µm	500 µm	425 µm	300 µm	250 µm	212 µm	180 µm	125 µm	90 µm	75 µm	63 µm	PAN <63 µm
100-120’	0.00	0.42	1.27	6.12	8.65	43.89	18.15	12.66	5.70	1.69	0.21	0.21	0.21	0.82

120 - 140 ft.

ASR ph 2 / Beltz 8 MW

MI#20096-02 - SEM

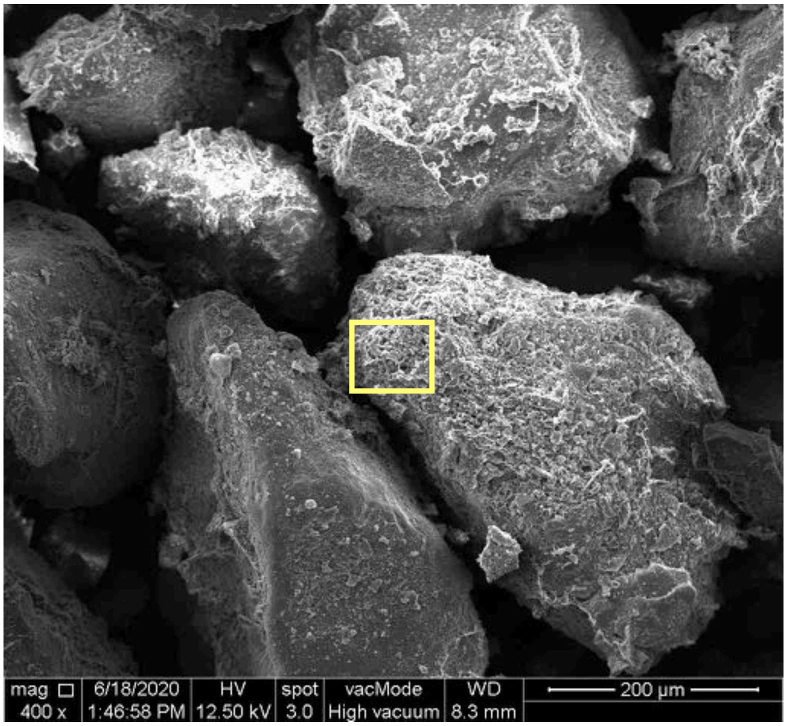
Summary: This interval of the aquifer is characterized as a medium-grained, moderately well-sorted, sub-angular, unconsolidated and disaggregated, slightly calcareous, feldspathic litharenitic sand. The mean grain diameter for the thin section specimen is estimated at ~ 0.32 mm with a maximum grain diameter of 0.85 mm. Detrital grain types are dominated by igneous RFs (rock fragments) coupled with significant amounts of feldspar and quartz-rich sand. Minor detrital grain varieties include augite, hornblende, limestone, chert, metaquartzite RFs, magnetite, and mica. The igneous RF materials are locally corroded and exhibit common intra-particle replacement with authigenic clay matrix +/- cement. Grain replacement cements include calcite, iron oxide, and pyrite. The igneous RF population is dominated by basalt + andesite and dacite fragments with minor amounts of rhyolite and scoria also detected. SEM images for this grain mount exhibit localized concentrations of grain coating authigenic smectite. The distribution and lithology of the authigenic smectite is attributed to the localized brush-piling of grain replacement matrix materials within the inter granular pore throats of the aquifer. Clay matrix materials are dominated by authigenic smectite coupled with minor amounts of illite, kaolinite, and chlorite.

20096-02 Photo Index: (bookmarks)

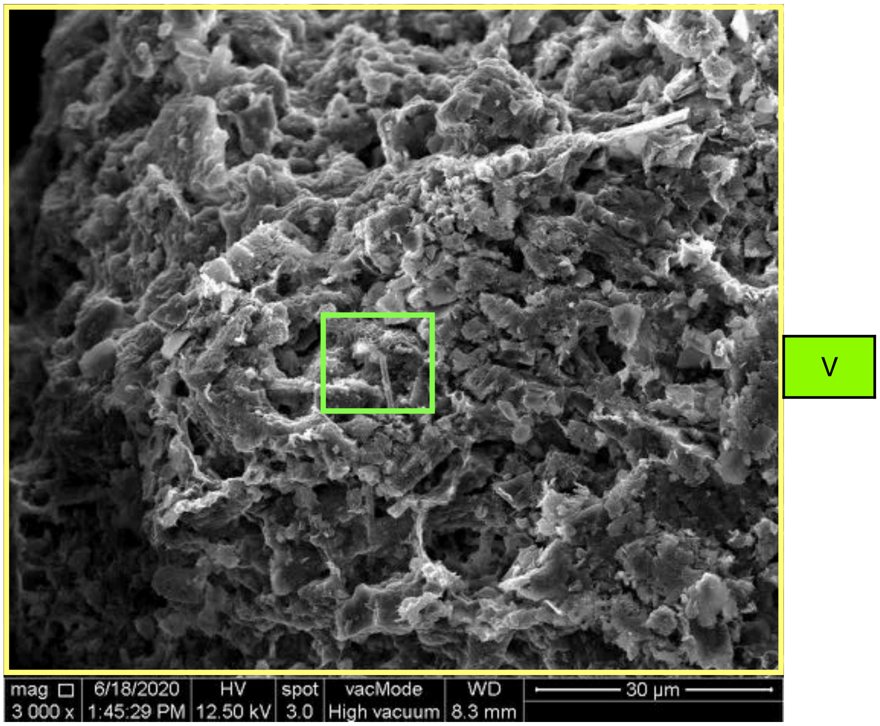
Sample ID	Magnification
20096-02A	400X
20096-02B	3000X
20096-02C	12000X
20096-02D	400X
20096-02E	1500X
20096-02F	6000X

Volcanic rock fragment	V
Calcite	C
Authigenic smectite	A
Detrital feldspar	F

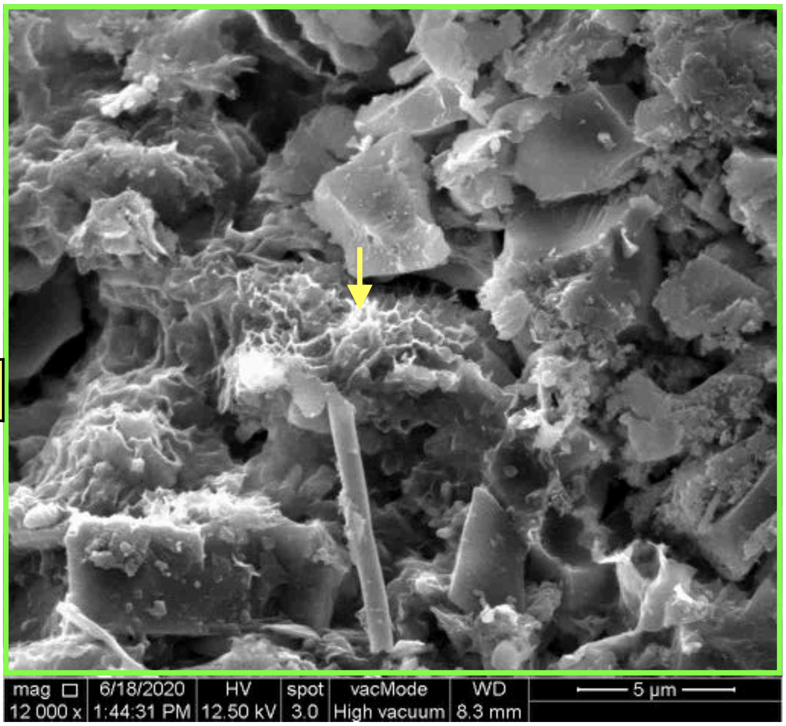
20096-02A 400X



20096-02B 3000X

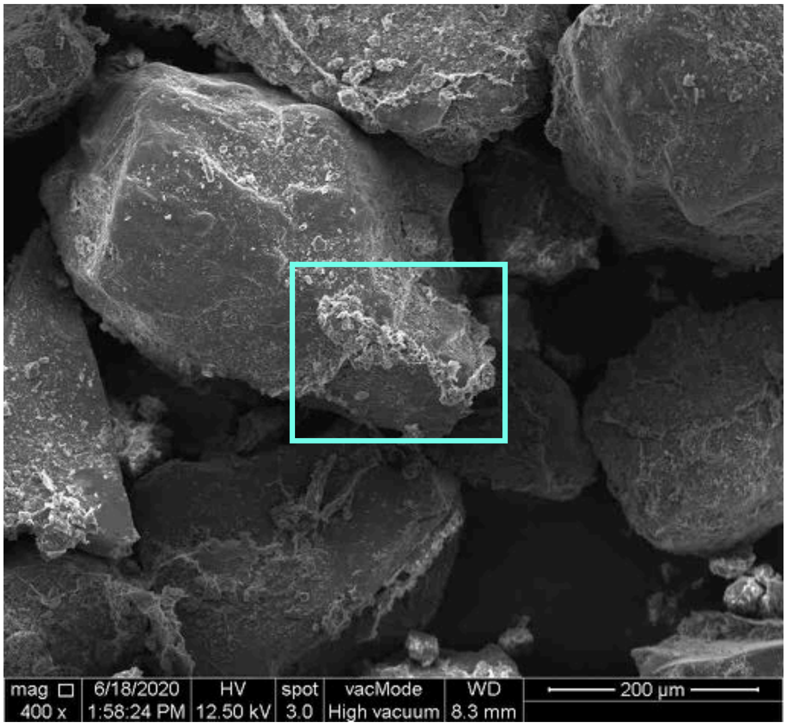


20096-02C 12000X



A

20096-02D 400X



20096-02 Photo Index

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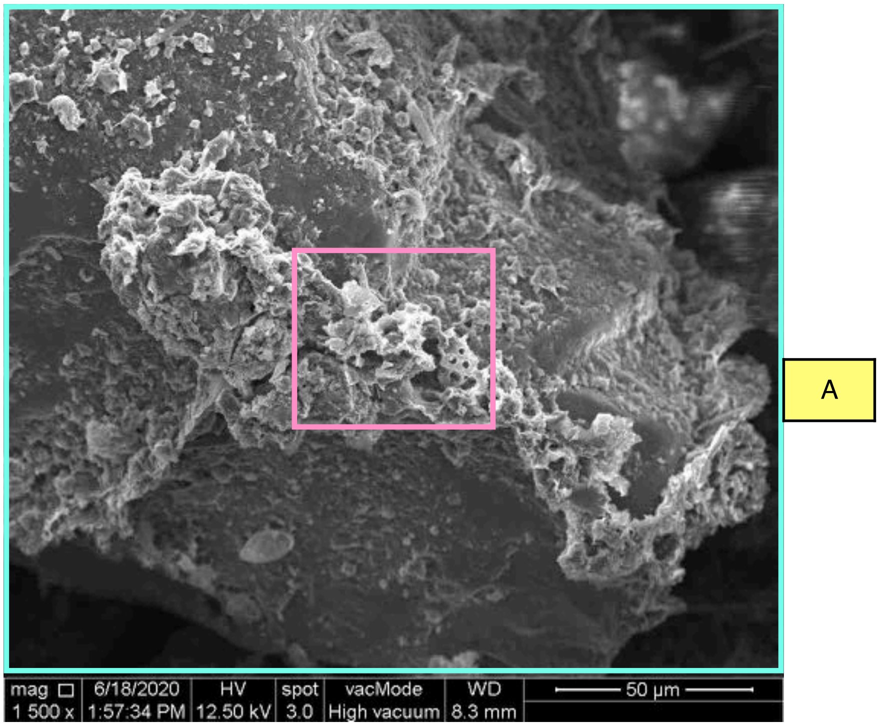
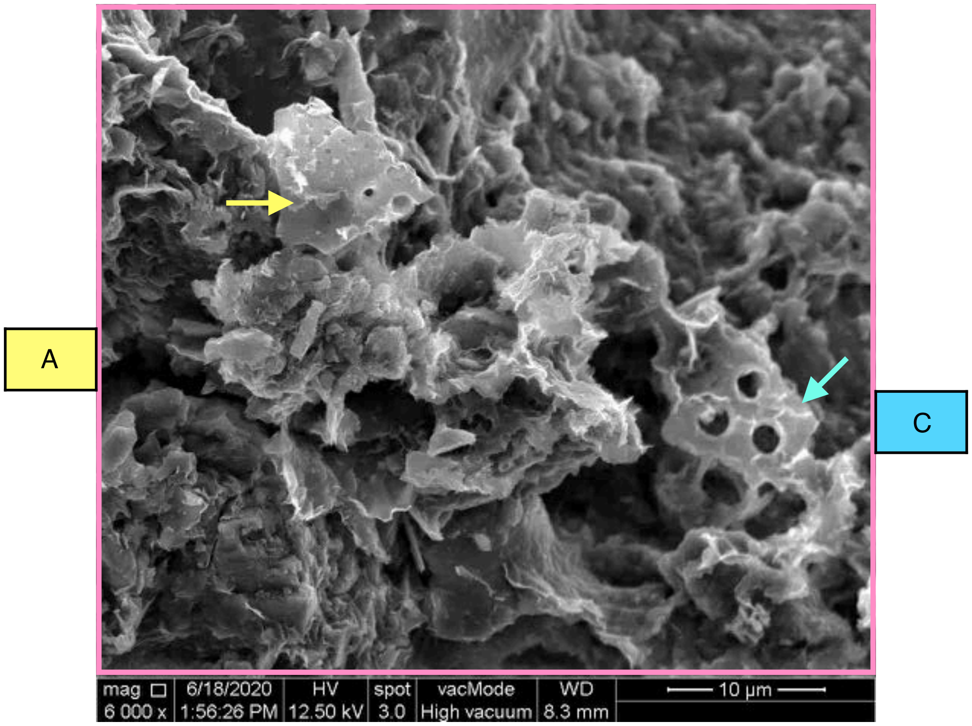
20096-02E 1500X



20096-02F 6000X



20096-02 Photo Index

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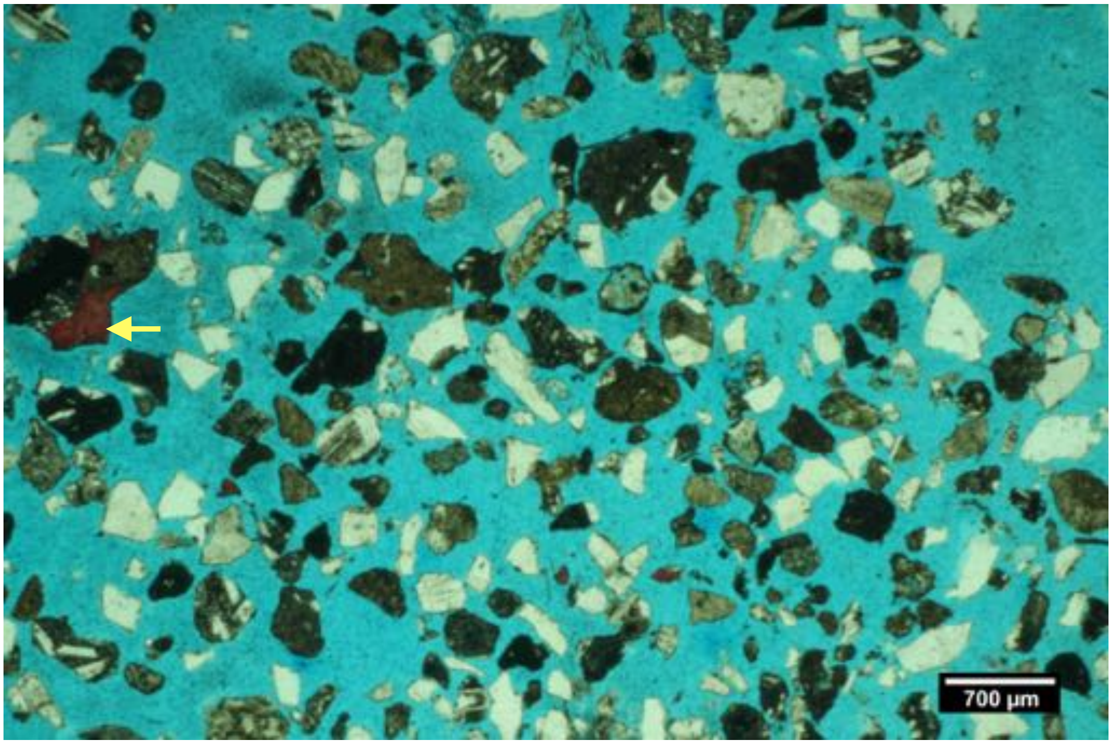
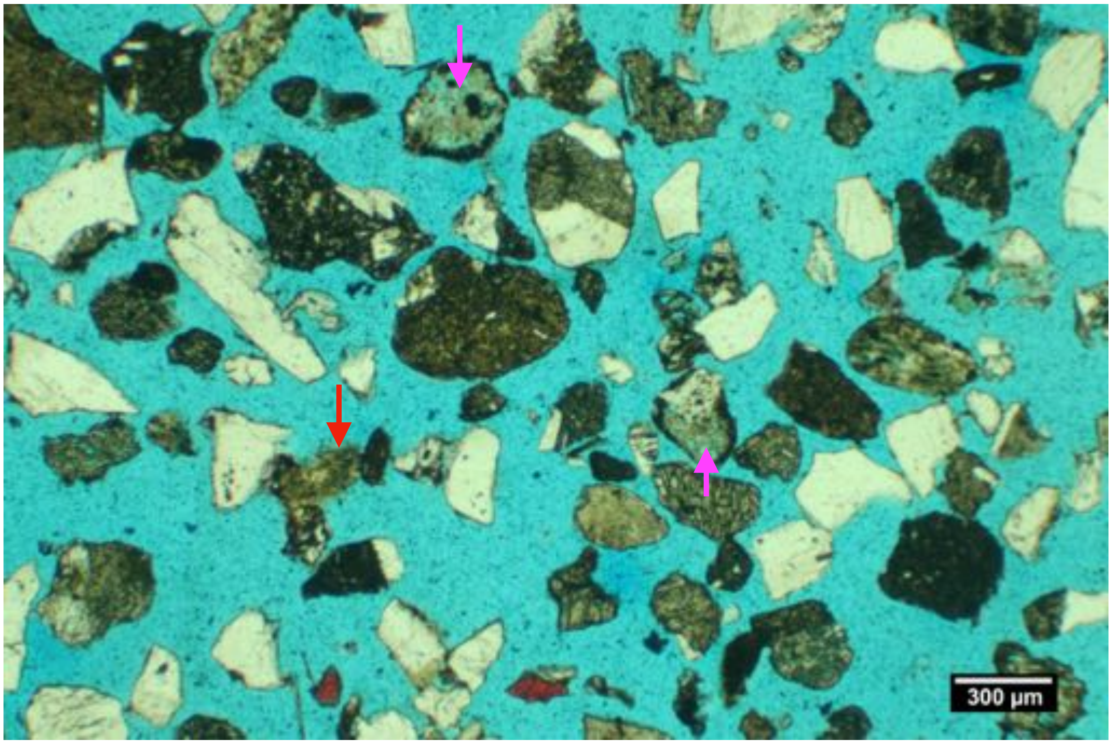
120 - 140 ft.; MI#20096-02

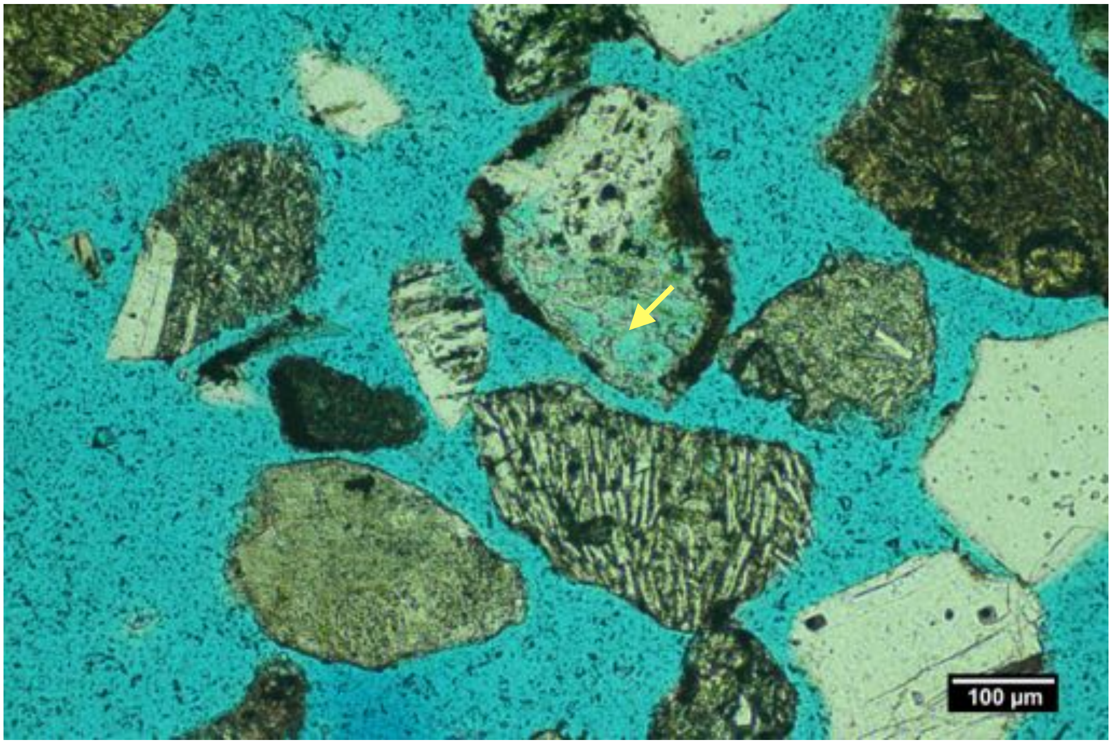


2A. Unconsolidated, medium-grained, moderately sorted, feldspathic lihtarenitic sand. Note the calcite spar cement (red; yellow <).

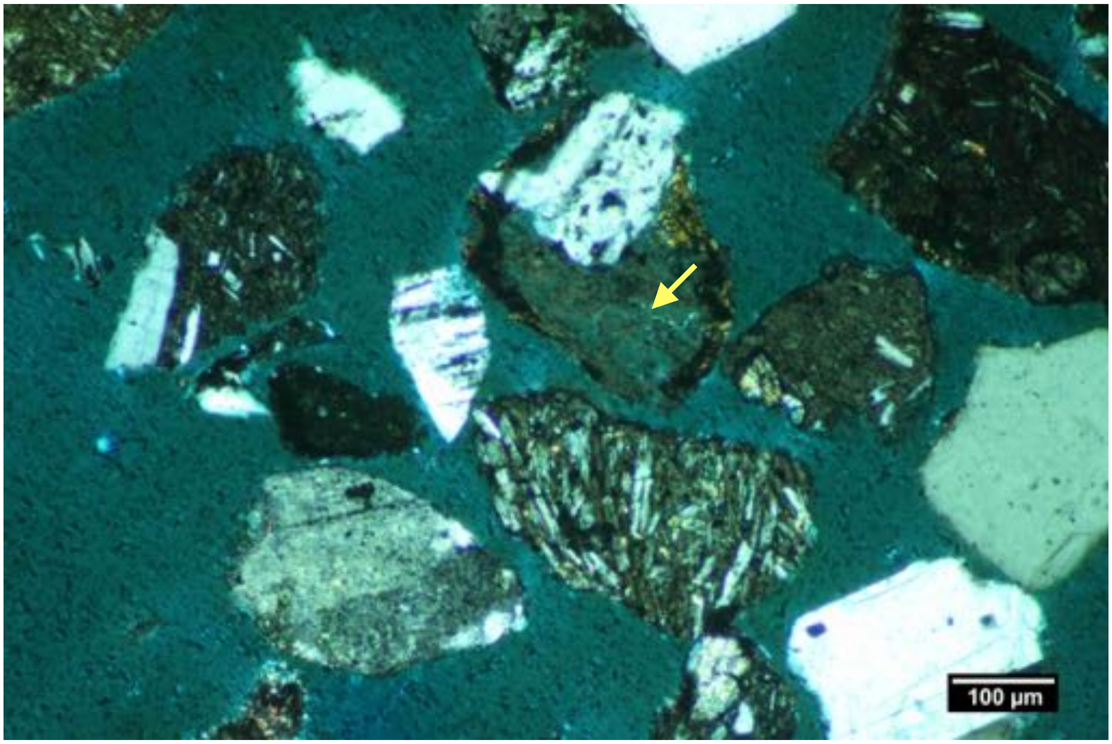


2B. Glass-rich volcanic RFs are locally susceptible to dissolution (e.g., magenta <) +/- replacement with authigenic clay (e.g., red <).

120 - 140 ft.; MI#20096-02

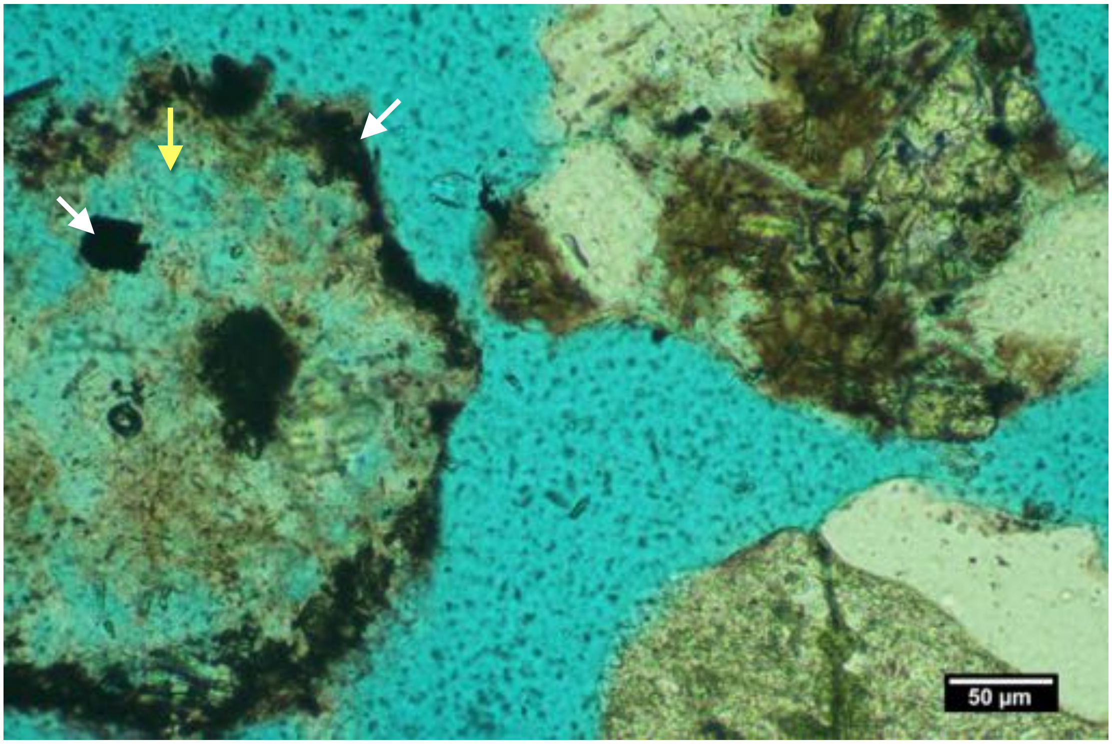


2C. A leached volcanic RF with intraparticle dissolution porosity (yellow <) surrounded by a rind of Fe-rich volcanic glass.

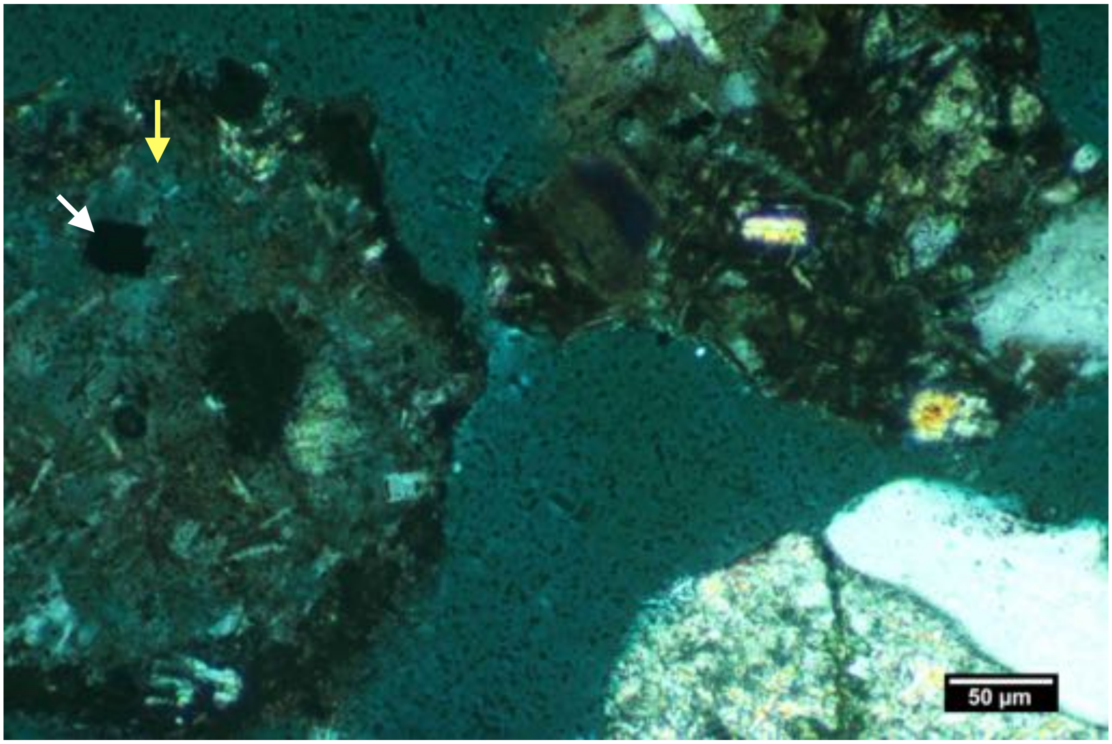


2D. As in Figure 2C, with cross polarized light. The volcanic glass constituents are non-crystalline & opaque (dark gray; yellow <).

120 - 140 ft.; MI#20096-02



2E. Intraparticle dissolution porosity (blue; yellow <). The perimeter of the grain is partially replaced with authigenic clay + microcrystalline pyrite cement (black; white <).

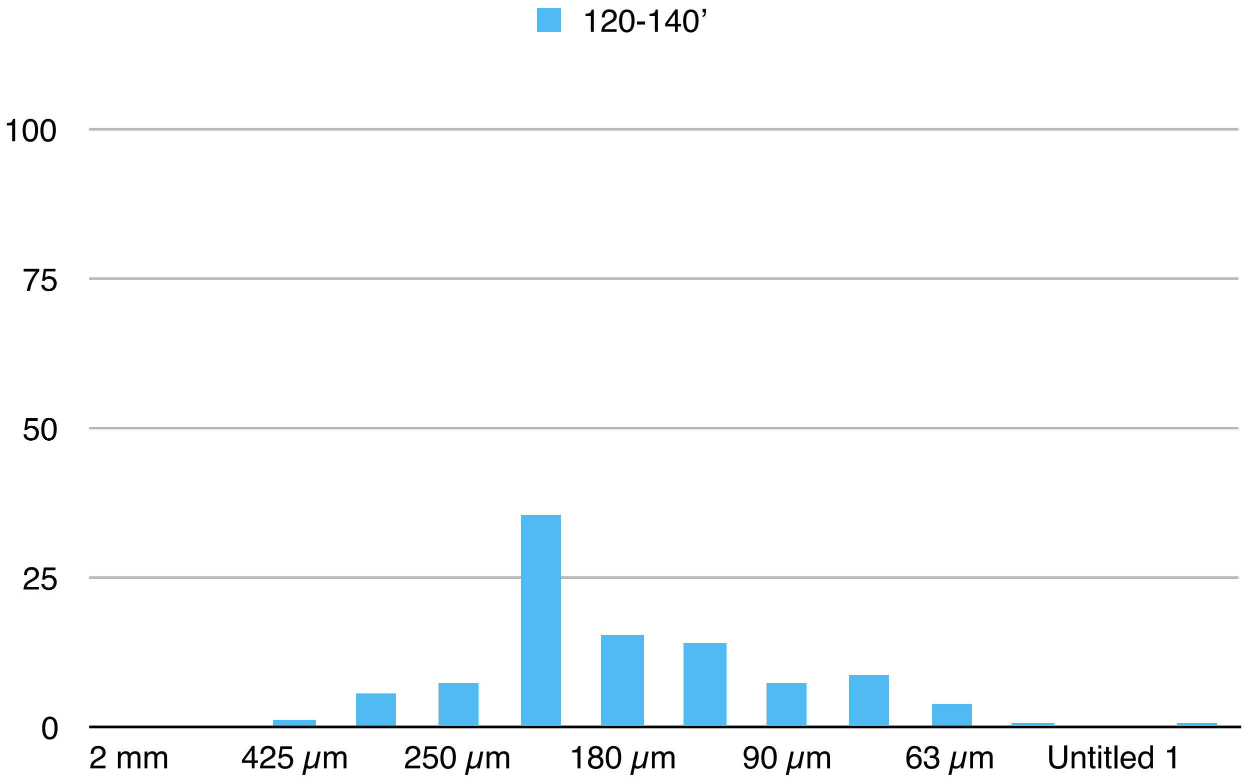


2F. As in Figure 2E, with cross polarized light. Microcrystalline smectite is the dominant replacement phase for the altered volcanic glass materials.

Sieve Analysis

120 -140 ft.

Client:	Pueblo Water Resources	MI#:	20096-02
Project:	ASR ph 2 / Beltz 8 MW	P.O.#:	15-0113
Location:	Santa Cruz, CA	Method:	Sieve



Sample ID	2.00 mm	1.00 mm	710 µm	500 µm	425 µm	300 µm	250 µm	212 µm	180 µm	125 µm	90 µm	75 µm	63 µm	PAN <63 µm
120-140’	0.00	0.00	1.18	5.52	7.30	35.50	15.38	13.81	7.50	8.48	3.55	0.79	0.39	0.59

140 - 160 ft.

ASR ph 2 / Beltz 8 MW

MI#20096-03 - SEM

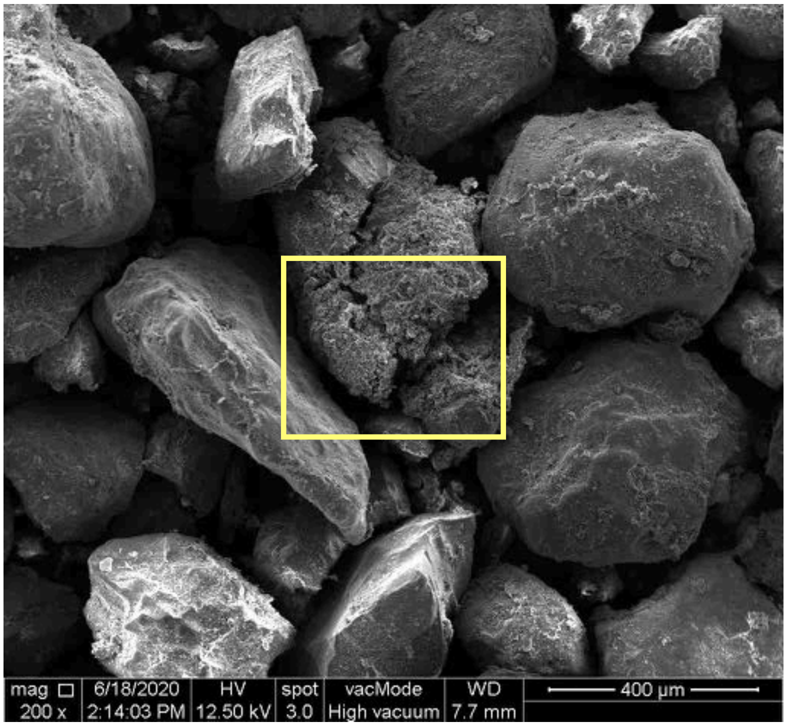
Summary: The drill cuttings from this interval are medium-grained, moderately to poorly sorted, sub-angular, slightly calcareous, feldspathic litharentic sands. The sediments are unconsolidated and disaggregated and incorporate significant amounts of silt-sized grain remnant materials. Scattered granule to pebble-sized concentrations of calcareous litharentic sand are locally present. The mean grain diameter estimated for the thin section sample is ~ 0.35 mm, with a maximum grain diameter of 1.24 mm. Grain materials are sub-angular to sub-rounded and exhibit common evidence of intra-particle corrosion and grain replacement with authigenic clay matrix minerals and/or cements. Detrital sand components include igneous RFs (rock fragments; mostly basalt, andesite, dacite, rhyolite, and scoria fragments). In addition to the volcanic RFs, significant amounts of plagioclase and K-feldspar, quartz, metaquartzite RFs are also present. Minor to accessory grain types include: augite, hornblende, calcite, chert RFs, magnetite, and mica. Smectite is a common authigenic replacement associated with the leached and corroded volcanic RFs. The dissolution and localized replacement of volcanic RF materials has generated significant amounts of silt-sized grain remnant materials (e.g., see Figure 3B). The void volume for this aquifer interval is dominated by inter-particle macro porosity. Minor amounts of intra-particle dissolution void space are present, however, most of this void space is relatively ineffective due to minute pore sizes and constrictions related to grain replacement clay matrix materials. The mobilization and brush-piling of silt to clay-sized grain remnants and matrix materials is likely to pose the most significant challenge to the efficient management for this aquifer interval.

20096-03 Photo Index: (bookmarks)

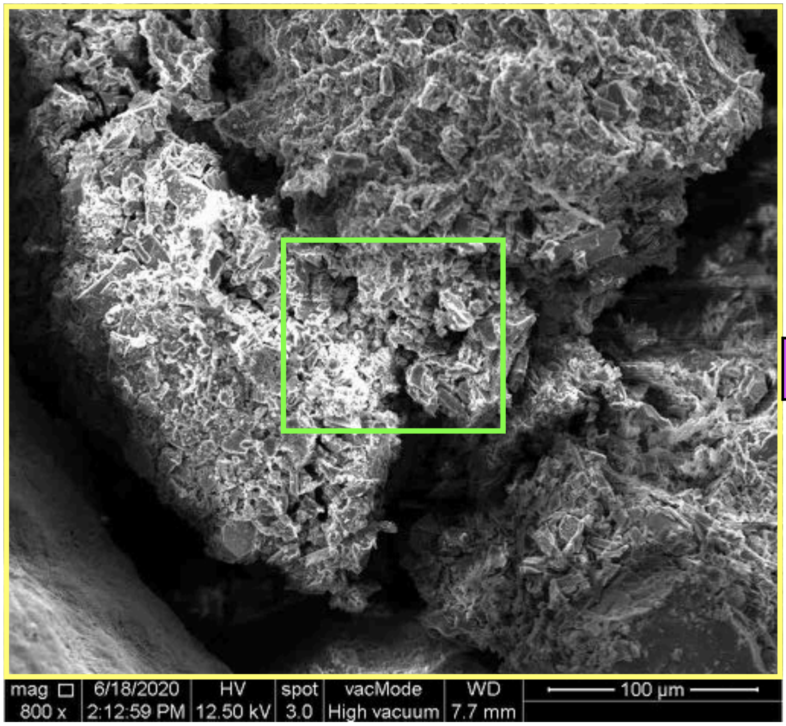
Sample ID	Magnification
20096-03A	200X
20096-03B	800X
20096-03C	3000X
20096-03D	400X
20096-03E	1500X
20096-03F	6000X

Volcanic rock fragment	V
Calcite	C
Authigenic smectite	A
Detrital feldspar	F

20096-03A 200X



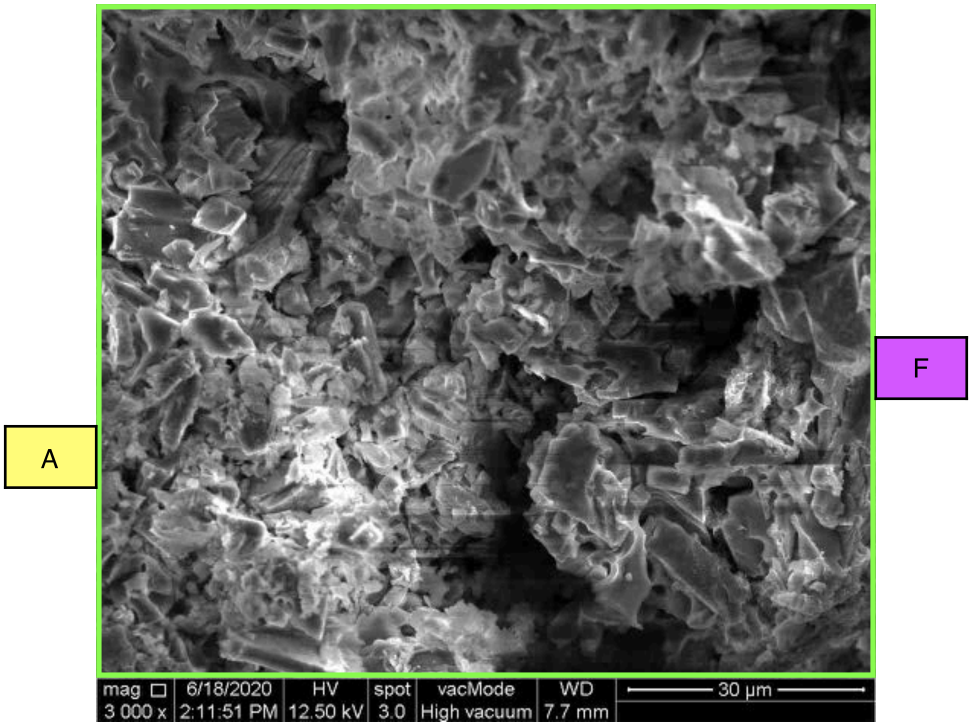
20096-03B 800X



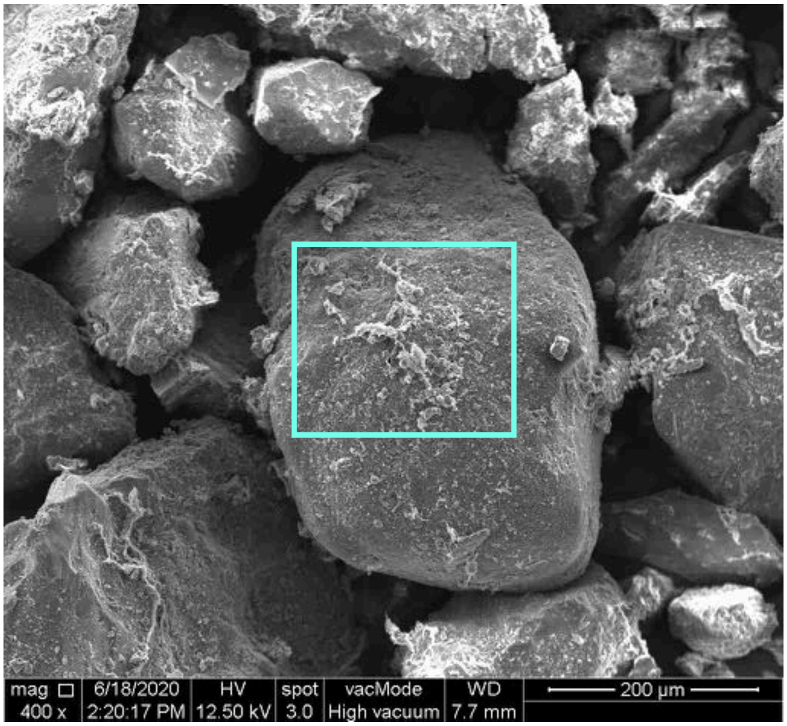
F

20096-03 Photo Index

20096-03C 3000X



20096-03D 400X



20096-03 Photo Index

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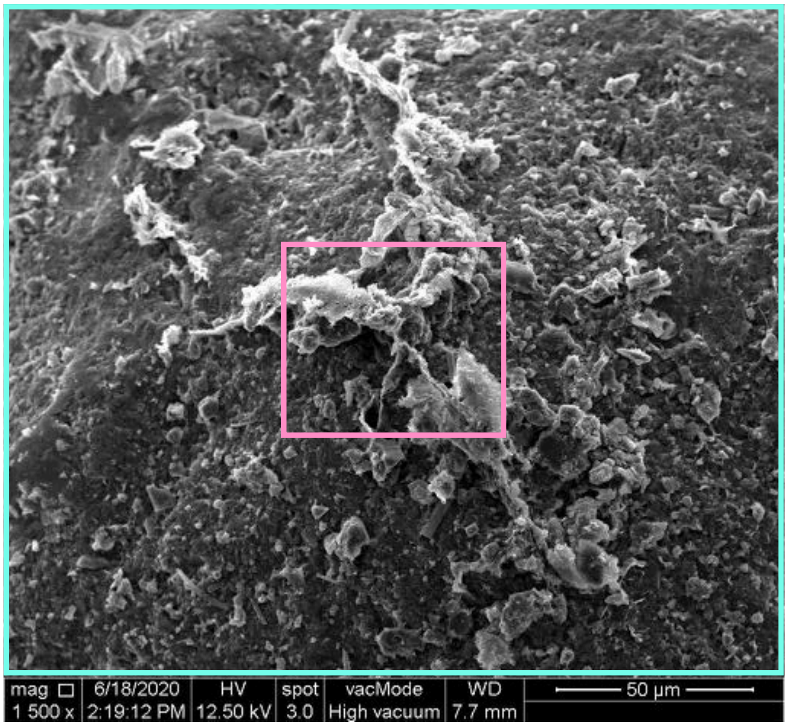
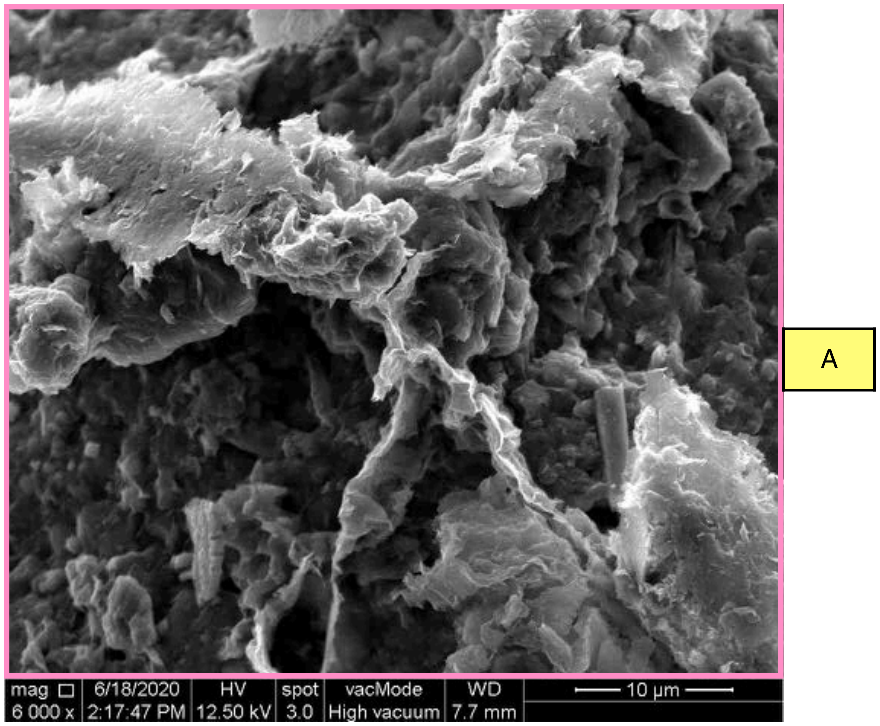
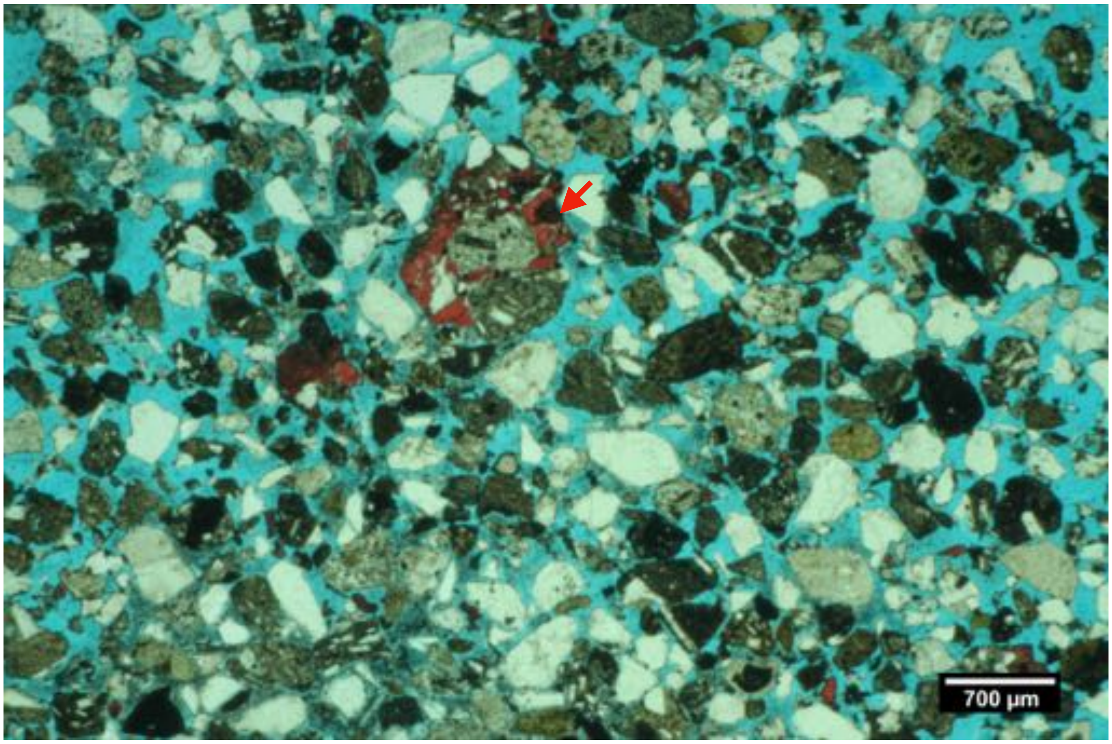
20096-03E 1500X



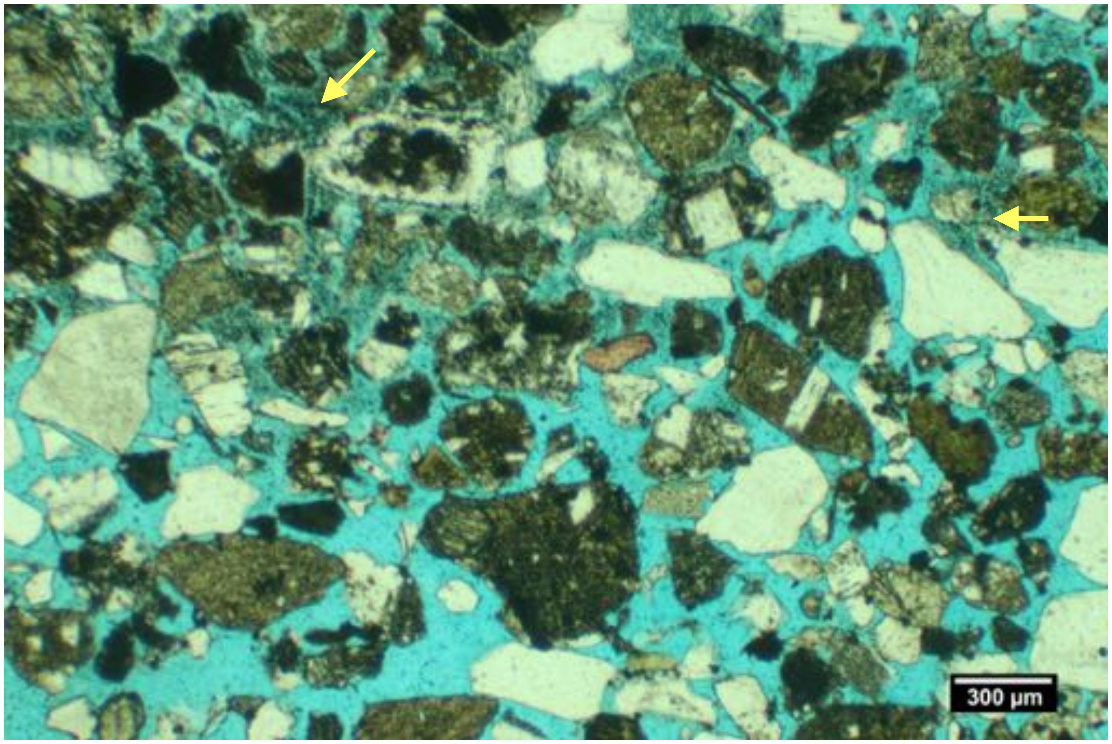
20096-03F 6000X



140 - 160 ft.; MI#20096-03

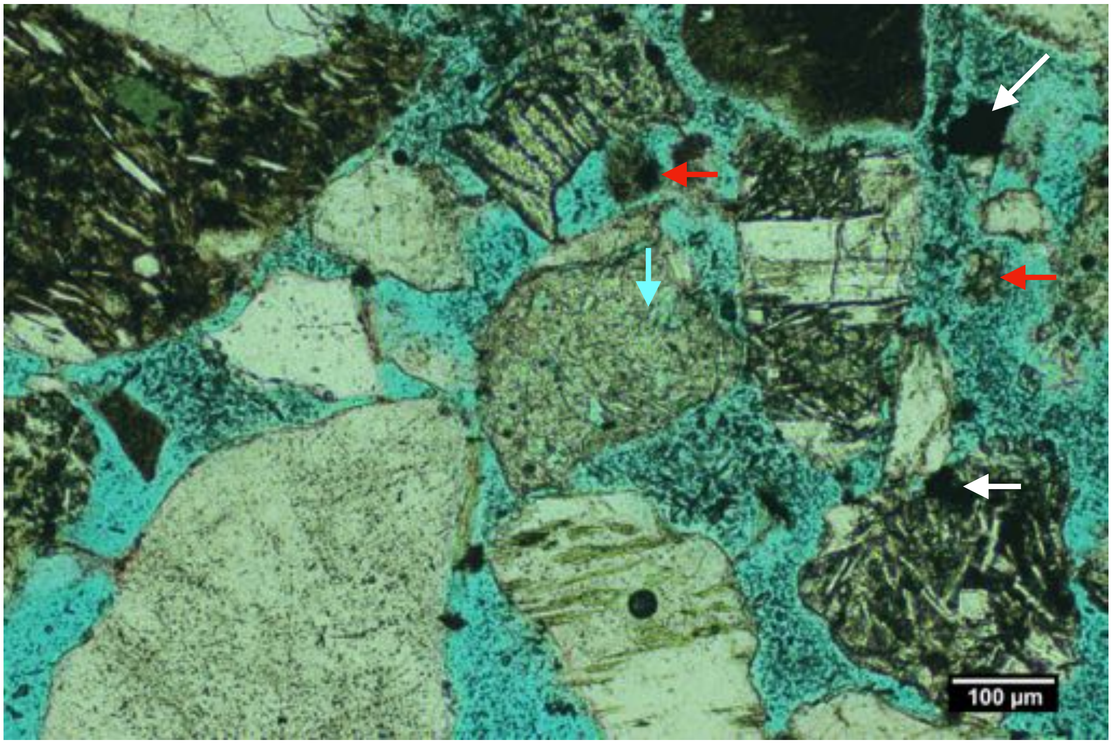


3A. A granule-sized concretion of calcareous feldspathic litharenitic sandstone (red <) suspended in this unconsolidated sand sample. Calcite is stained red in this view.

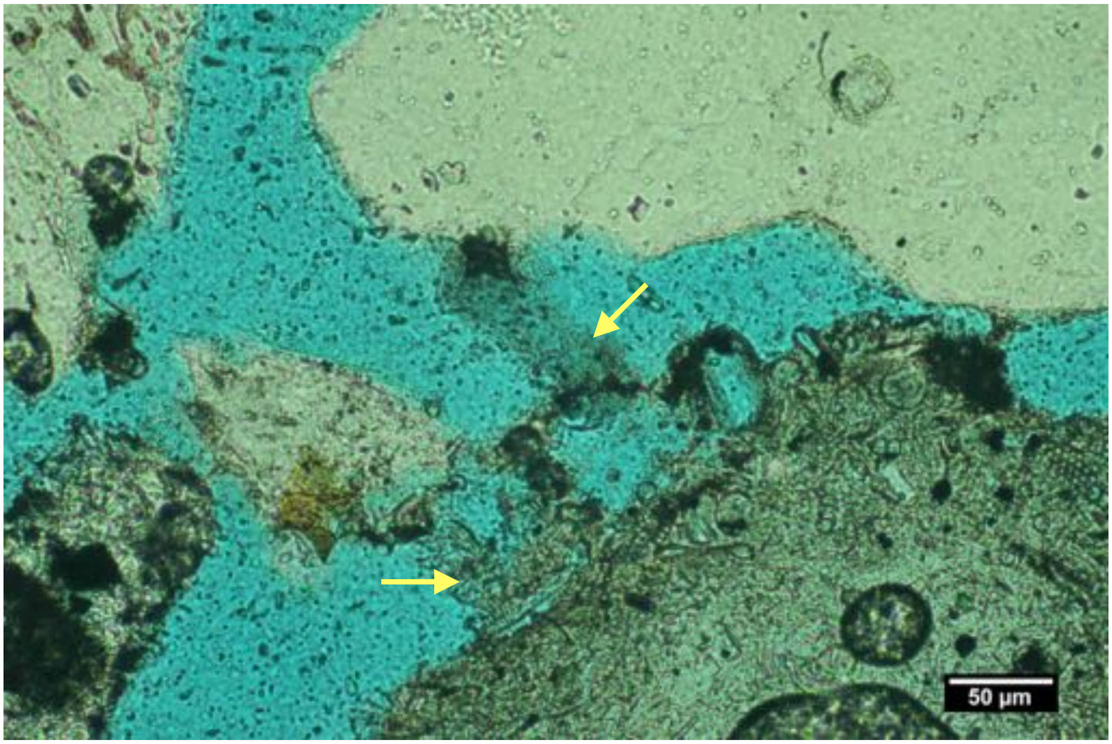


3B. Diffuse clusters of microporous clay (yellow <) are present in portions of the grain mount fabric for this interval.

140 - 160 ft.; MI#20096-03

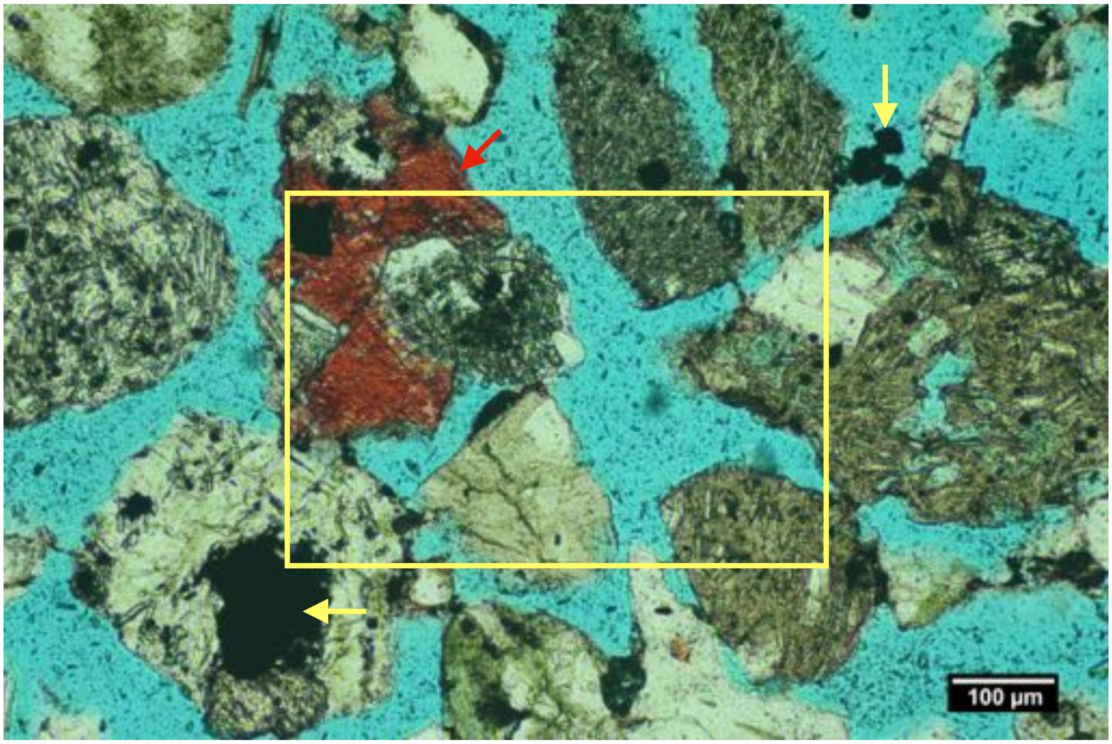


3C. A glass-rich rhyolite RF (blue <) containing significant inter crystalline microporosity. Note the pyrite cement (white <) & clusters of weakly attached matrix material (red <)

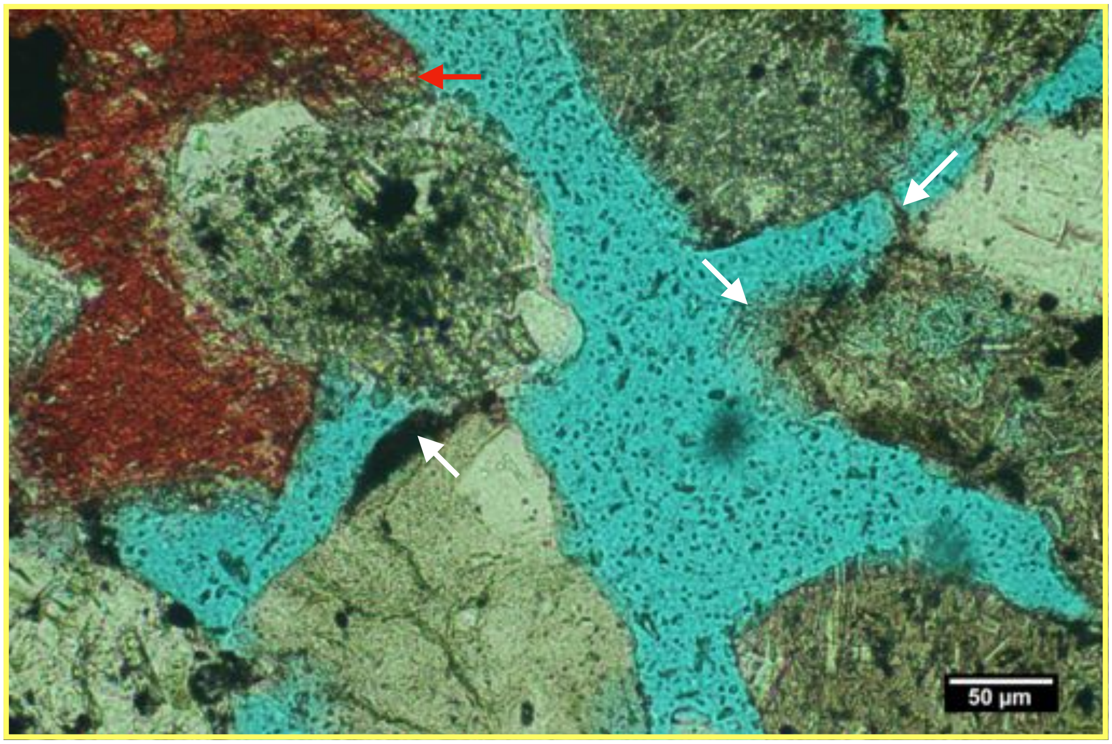


3D. Weakly attached clusters of microporous clay (yellow <) are locally concentrated in the pore throats due to grain-replacement & 'brush-piling' of leached grain remnants.

140 - 160 ft.; MI#20096-03



3E. Calcite cemented sandstone fragment (red <). Note the grain-replacement & grain-coating pyrite cement crystals (yellow <).

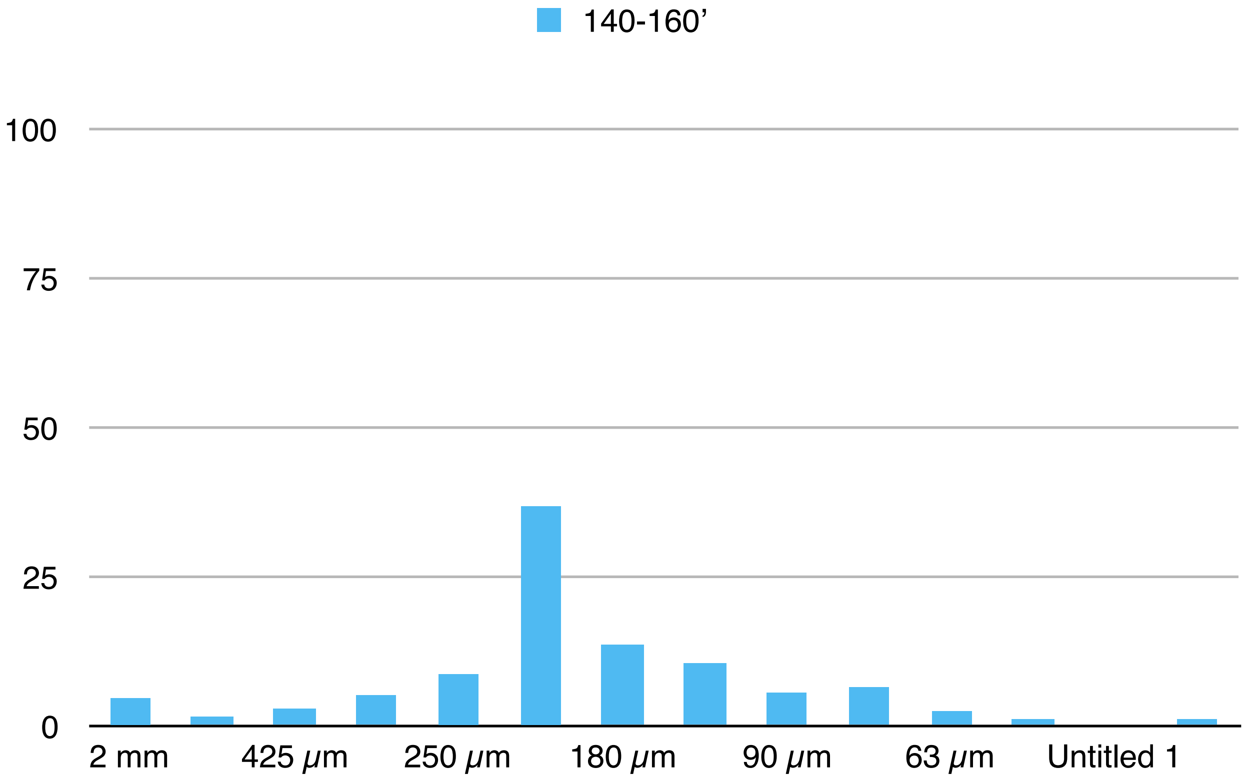


3F. Detail of the yellow highlighted field of view from Figure 3E. Note the clusters of allogenic clay distributed on selected grain surfaces (white <).

Sieve Analysis

140 -160 ft.

Client:	Pueblo Water Resources	MI#:	20096-03
Project:	ASR ph 2 / Beltz 8 MW	P.O.#:	15-0113
Location:	Santa Cruz, CA	Method:	Sieve



Sample ID	2.00 mm	1.00 mm	710 µm	500 µm	425 µm	300 µm	250 µm	212 µm	180 µm	125 µm	90 µm	75 µm	63 µm	PAN <63 µm
140-160’	4.46	1.55	2.91	5.23	8.72	36.82	13.57	10.27	5.43	6.40	2.33	0.97	0.39	0.97

160 - 180 ft.
ASR ph 2 / Beltz 8 MW
MI#20096-04 - SEM

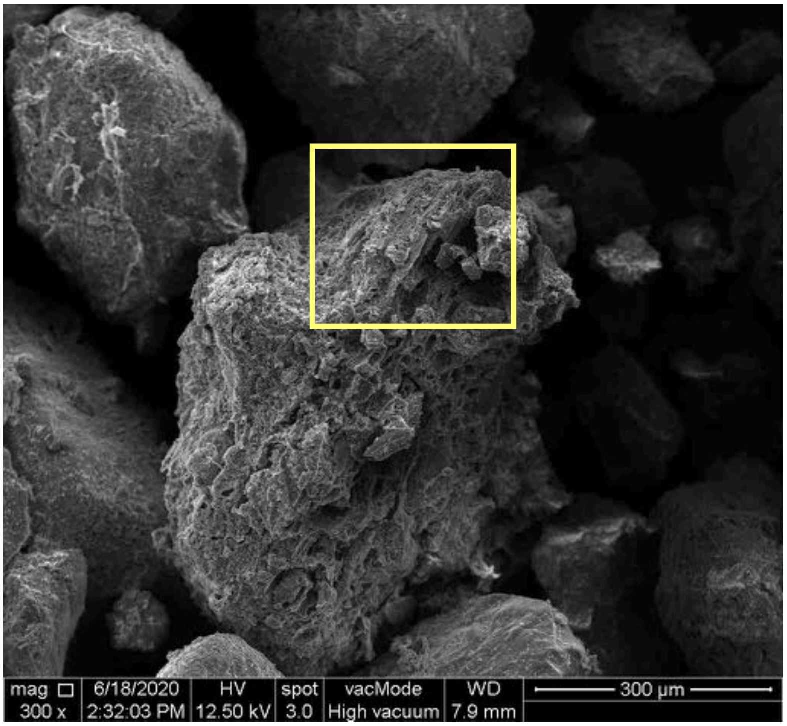
Summary: Drill cuttings from this interval are medium-grained, moderately-sorted, slightly-calcareous and matrix-rich, feldspathic litharentic sands. Scattered concretions of calcareous litharenitc sand + silt and clay-rich mudstone materials are locally incorporated within the cutting fmaterials for this interval. The calcareous sandstone aggregates are granule to pebble-sized concretions suspended in the grain mount slides. The mudstone particles are granule to pebble-sized 'fragments' that are microporous and cohesively unstable. As within the previously described intervals from the Beltz 8 well, detrital components are dominated by igneous RFs (including: basalt, andesite, dacite, rhyolite, and minor amounts of scoria). Detrital sand grains also include significant amounts of feldspar, quartz, metaquartzite RFs, ferromagnesian minerals (including augite, hornblende, and magnetite), chert RFs, calcite, and mica. Grain replacement smectite is locally abundant in association with the corroded and leached volcanic RFs contained in the sediment. Feldspar crystals and grains are also susceptible to replacement and localized dissolution. Iron-rich minerals within the igneous RFs are commonly susceptible to corrosion and replacement with pyrite cement as well as a host of iron oxide phases including magnetite, hematite, and iron oxide hydroxide.

20096-04 Photo Index: (bookmarks)

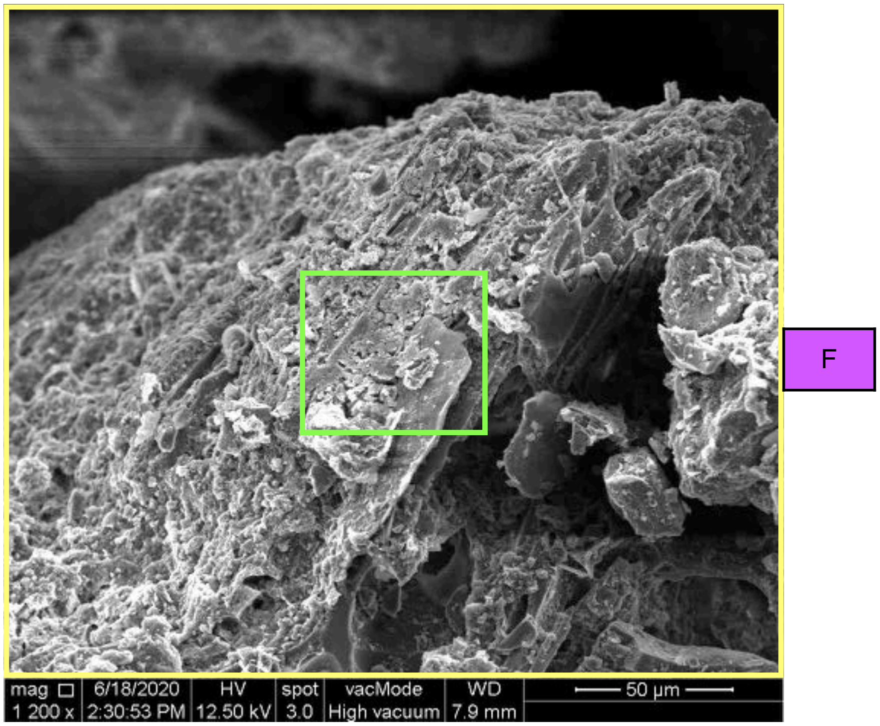
Sample ID	Magnification
20096-04A	300X
20096-04B	1200X
20096-04C	5000X
20096-04D	400X
20096-04E	800X
20096-04F	3000X

Volcanic rock fragment	V
Calcite	C
Authigenic smectite	A
Detrital feldspar	F

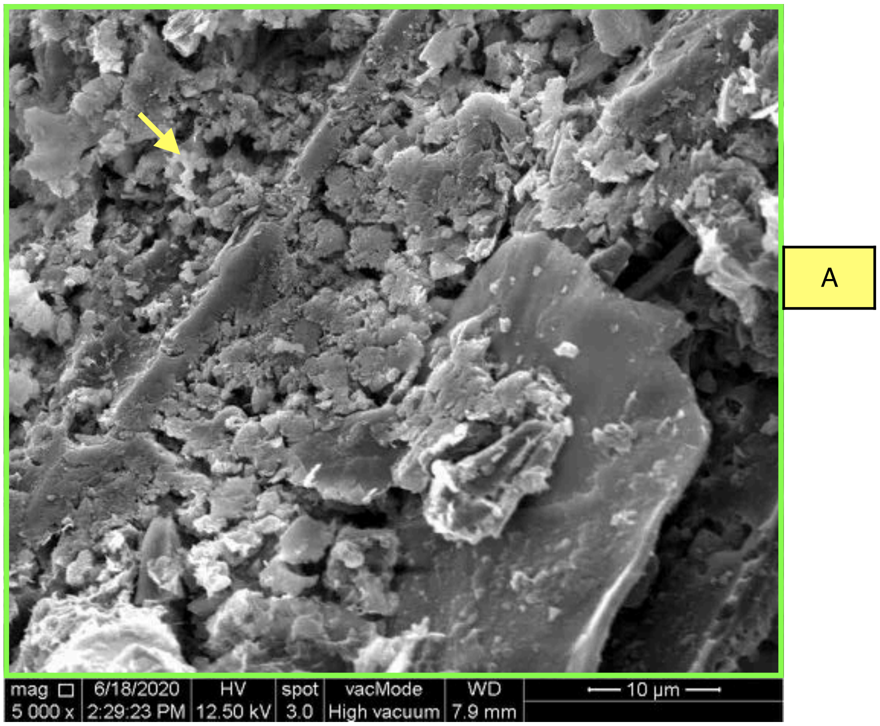
20096-04A 300X



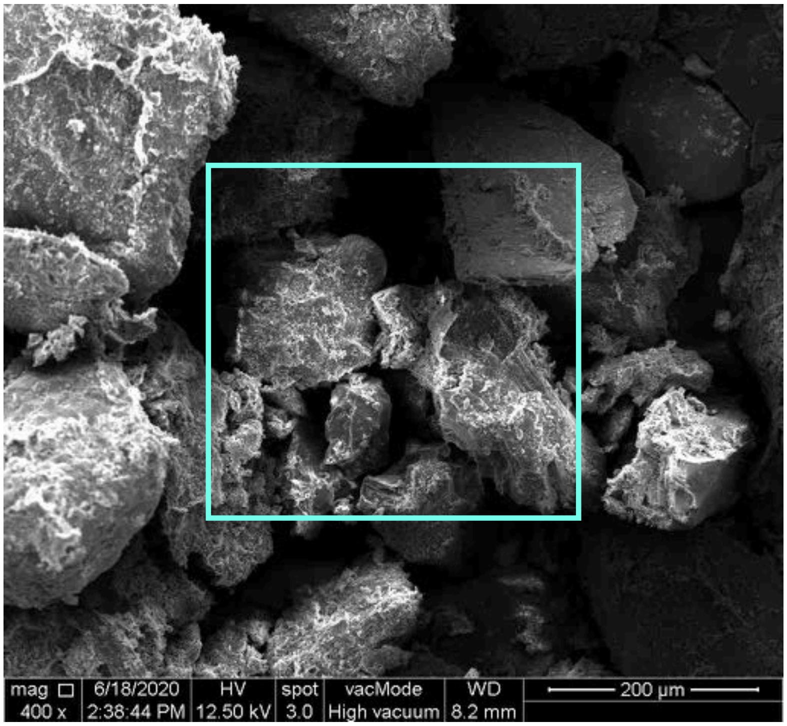
20096-04B 1200X



20096-04C 5000X



20096-04D 400X



20096-04 Photo Index

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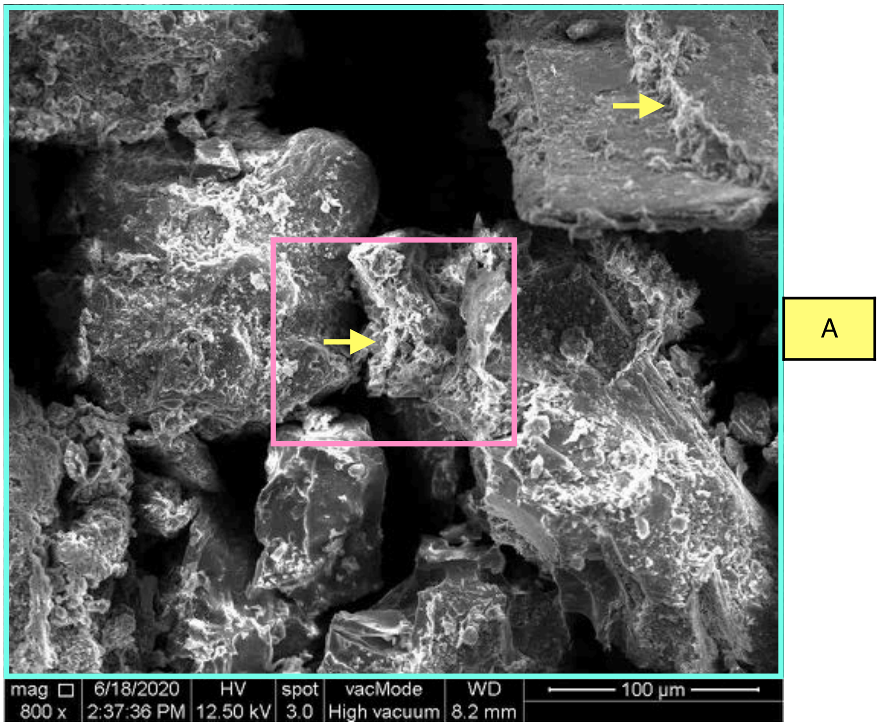
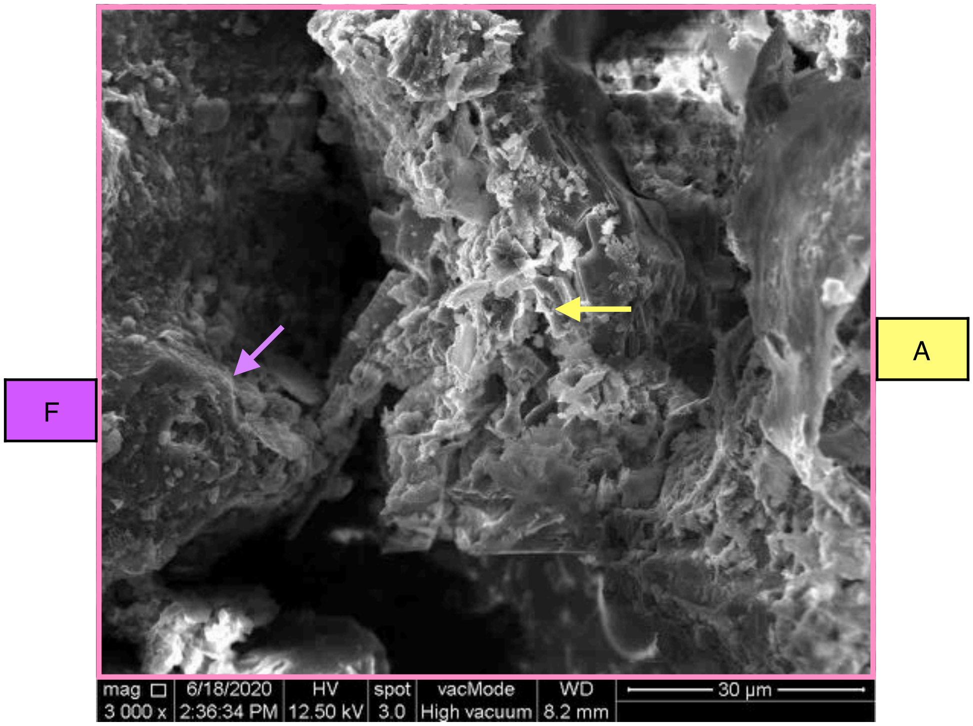
20096-04E 800X

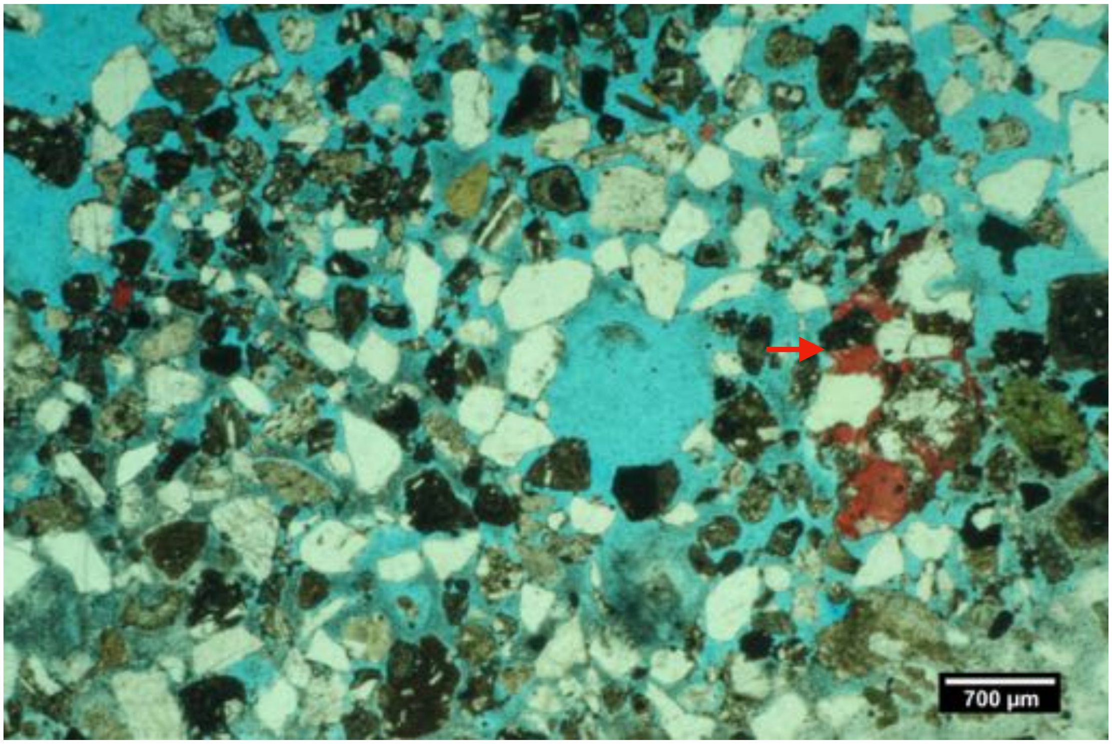


20096-04F 3000X

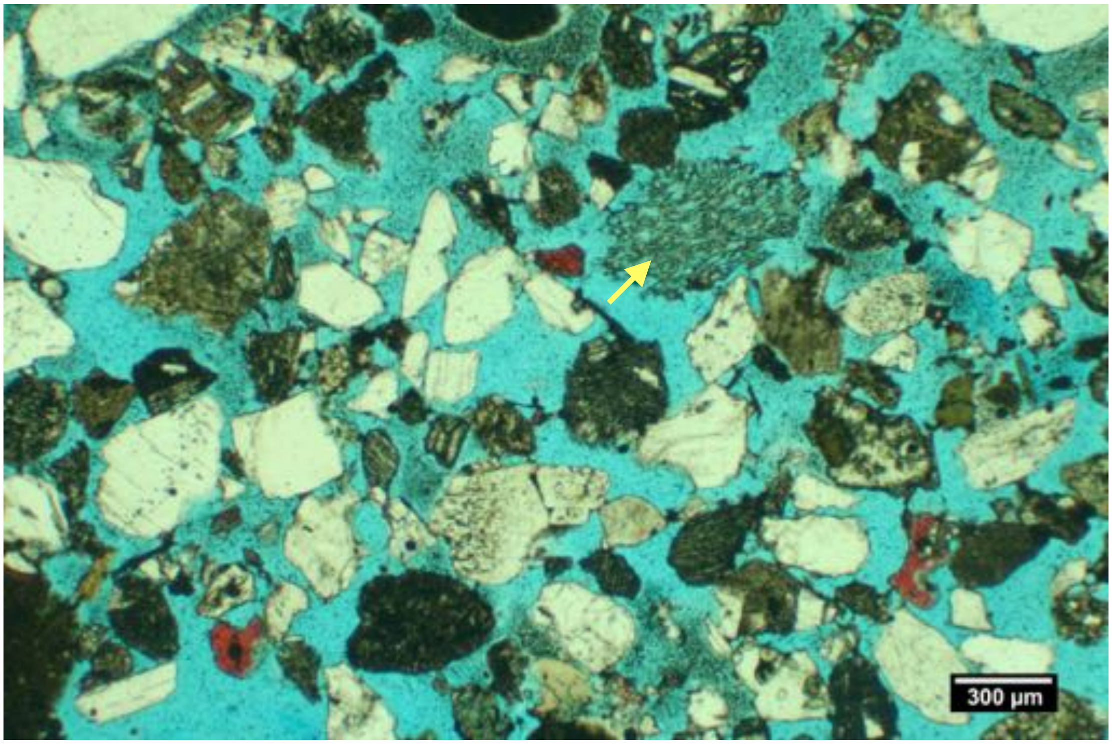


20096-04 Photo Index

160 - 180 ft.; MI#20096-04

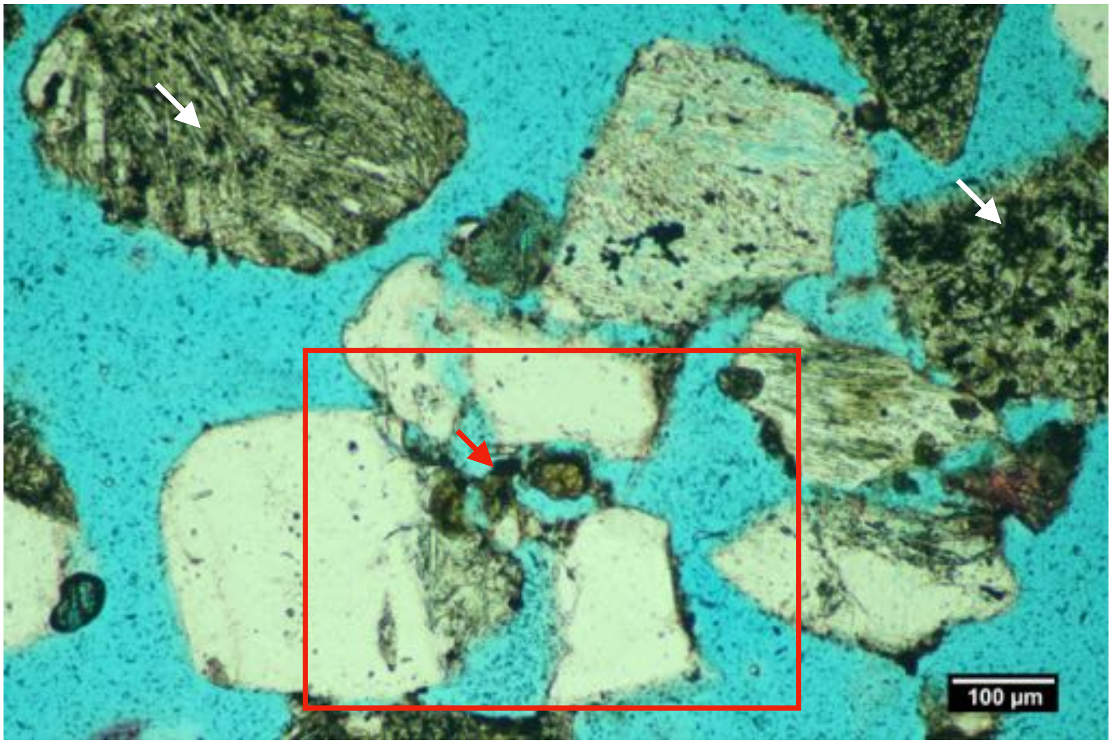


4A. Calcareous feldspathic litharenitic sandstone (red <) suspended in a grain mount of unconsolidated sand.

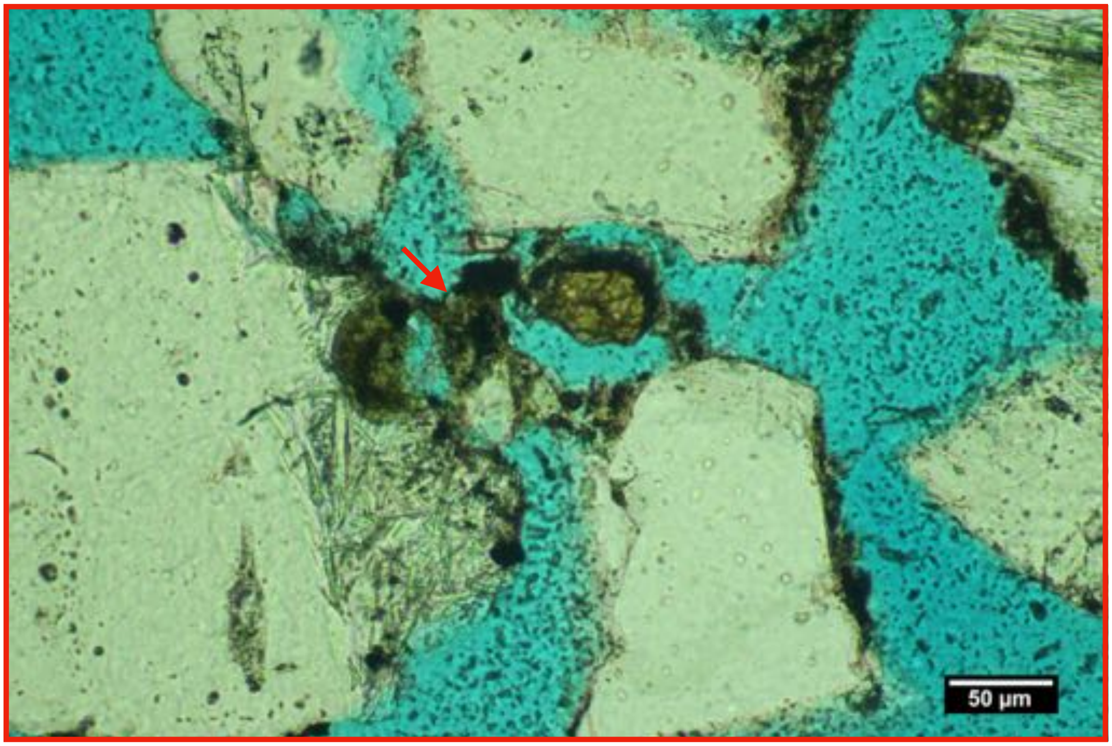


4B. Glassy remnants of an extensively leached volcanic RF (yellow <).

160 - 180 ft.; MI#20096-04



4E. Grain-coating authigenic clay (red <) admixed-with silt-sized grain remnants + pyrite cement. Note the basalt RF materials (white <)

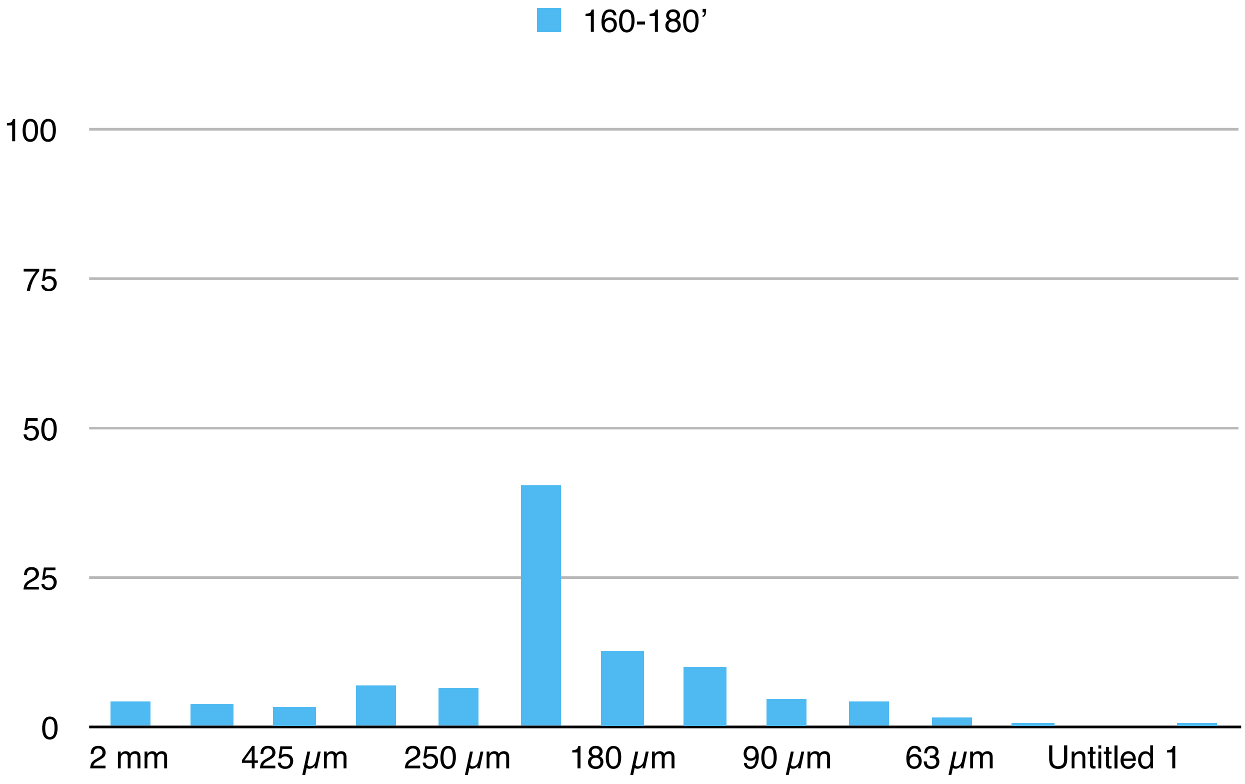


4F. Detail of the highlighted field of view from Figure 4E. XRD indicates the clay fraction is nearly completely dominated by smectite (white <).

Sieve Analysis

160 -180 ft.

Client:	Pueblo Water Resources	MI#:	20096-04
Project:	ASR ph 2 / Beltz 8 MW	P.O.#:	15-0113
Location:	Santa Cruz, CA	Method:	Sieve



Sample ID	2.00 mm	1.00 mm	710 µm	500 µm	425 µm	300 µm	250 µm	212 µm	180 µm	125 µm	90 µm	75 µm	63 µm	PAN <63 µm
160-180’	4.29	3.93	3.39	6.79	6.61	40.36	12.68	10.00	4.64	4.29	1.61	0.54	0.18	0.71

TECHNICAL MEMORANDUM
Pueblo Water Resources, Inc.
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To:	Santa Cruz Water Department	Date:	September 16, 2021
Attention:	Leah Van Der Maaten, P.E.	Project No:	15-0113
Copy to:			
From:	Robert C. Marks, P.G., C.Hg. Principal Hydrogeologist		
Subject:	Santa Cruz ASR Project – Phase 2 Feasibility Investigation; Beltz 8 ASR Pilot Test – ASR Cycle 3a Geochemical Interaction Evaluation		

INTRODUCTION

The purpose of this Technical Memorandum (TM) is to transmit the subject geochemical interaction evaluation performed by Dr. Richard Glanzman and to provide Pueblo Water Resources, Inc's. (PWR's) high-level interpretation of the key findings and recommendations for next steps in the investigation. The geochemical interaction evaluation was performed on the results of Aquifer Storage and Recovery (ASR) Pilot Test Cycle 3a implemented at the Santa Cruz Water Department (SCWD) Beltz 8 well during the period during the period April 6 through June 1, 2021.

Background

During ASR Pilot Test Cycles 1 and 2 at Beltz 8, performed during the period March 14 through April 21, 2020, arsenic concentrations in the recovered waters were shown to have been elevated relative to pre-injection concentrations in the native groundwater, indicating that potentially adverse geochemical reactions between the injected water, native groundwater and/or aquifer minerals were occurring at the site. Although the arsenic concentrations in the recovered waters did not exceed the drinking water standard Maximum Contaminant Level (MCL) for arsenic of 10 micrograms per liter (ug/L), peaking at a concentration of 6.0 ug/L, the increase relative to the baseline concentration of 1.4 ug/L (an approximate four-fold increase) was of sufficient concern for the ASR pilot test program to be temporarily suspended, and a geochemical interaction evaluation of the ASR Cycle 1 and 2 results was performed before continuing ASR pilot test operations at the site.

A geochemical interaction analysis of ASR Cycles 1 and 2 was performed by Dr. Richard Glanzman (a subconsultant to PWR) and was documented in a TM dated October 1, 2020. The principal findings developed from that analysis were that the mechanism of arsenic release was believed to be the result of oxidation of pyrite minerals present in the aquifer matrix by the injection source water, and that it was considered unlikely that continued ASR operations at the site would result in the arsenic concentration increasing above the MCL of 10 ug/L. Based on these findings, PWR developed a revised ASR Cycle 3 test program[1], as described below.

The original plan for ASR Cycle 3 generally consisted of one month of continuous injection (interrupted only for periodic backflushing), followed by two months of storage and then one month of recovery pumping. Given the relatively large volumes of injection and recovery for Cycle 3 compared to the previous two cycles, the original plan was to recover the Cycle 3 water into the distribution system, rather than "wasting" it to the storm drain system. However, given the concern that arsenic concentrations during Cycle 3 recovery pumping might exceed the MCL, the revised program essentially bifurcated the original plan into two separate complete cycles, as summarized in **Table 1** below:

Table 1. Revised ASR Cycle 3 Test Program

ASR Cycle No.	Injection				Storage	Recovery				
	Period (days)	Rate (gpm)	Total Volume		Period (days)	Period (days)	Rate (gpm)	Volume		Discharge Location
			(mg)	(af)				(mg)	(af)	
3a	14	300	6.05	18.6	30	14	450	9.07	27.8	Storm Drain
3b	14	300	6.05	18.6	60	14	450	9.07	27.8	Distribution

Total Active Duration (days):	146
Total Injection Volume (af):	37.1
Total Recovery Volume (af):	55.7

As shown, the original ASR Cycle 3 plan for a continuous injection period of one month was bifurcated for the revised plan into two two-week periods, termed as Cycles 3a and 3b. The overall volumes of injection and recovery for Cycles 3a and 3b were equivalent; the only significant difference between Cycles 3a and 3b was to be the extended duration of the storage period and discharge location for Cycle 3b. The extended storage period of Cycle 3b of 60 days was the same as originally planned for Cycle 3 and was intended primarily to be of sufficient duration to observe a completed disinfection by-products (DBPs) ingrowth and degradation cycle during aquifer storage, as well as arsenic behavior during extended storage. Cycle 3a recovery was directed to the storm drain system. Assuming the results of Cycle 3a were favorable (i.e., arsenic concentrations remain below the MCL), then the risk associated with directing Cycle 3b discharge into the distribution system would be minimized.

FINDINGS

The geochemical interaction analysis of ASR Cycle 3a performed by Dr. Richard Glanzman is documented in the attached TM, dated August 28, 2021. As with the previous TM prepared by Dr. Glanzman, the attached TM is very thorough and highly technical, and addresses a variety of geochemically relevant issues related to ASR at the Beltz 8 well, which

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[1] Pueblo Water Resources, Inc., *Santa Cruz ASR Project – Phase 2 Feasibility Investigation; Revised ASR Pilot Test Work Plan for Beltz 8 – ASR Cycle 3*, prepared for SCWD dated March 31, 2021.

will not be repeated here. The primary critical issue for advancement of the project at this time is the issue of mobilization of arsenic, and we believe the key findings developed from Cycle 3a are as follows:

1. Based on evaluating the water chemistry data developed from ASR Cycle 3a, the arsenic concentrations at Beltz 8 are believed to primarily result from the dissolution of obsidian, and secondarily from pyrite, minerals that are present in the geologic matrix of the target aquifer at the site (the A Unit of the Purisima Aquifer system).

2. The availability of arsenic in the aquifer matrix initially exposed during ASR Cycles 1 and 2 was decreased during ASR Cycle 3a, which indicates an arsenic reduction with incremental ASR cycles such that repeated ASR cycles are likely to result in progressively lower arsenic concentrations in the recovered water. In addition, the analysis suggests that increasing the storage time of the injected water could result in further lowering of arsenic concentrations in recovered waters at the site.

3. There is no apparent need for additional short-term ASR Cycle tests; rather, it is recommended that the next step for the project be to perform an initial injection period at the planned volume of recharge for long-term ASR operations at Beltz 8 (as practicable), followed by at least one month of storage, followed by recovery.

In addition, although not addressed in the subject TM by Dr. Glanzman, the DBP data collected during ASR Cycle 3s showed no ingrowth of either Total Trihalomethanes (TTHMs) nor Haloacitic Acids (HAAs) during the storage period, and near total degradation by the end of the 30-day storage period, with non-detectable levels by the end of the recovery period. These results are very similar to those observed during the recent ASR pilot test at the Beltz 12 well, and indicate that performing the planned Cycle 3b with the extended storage period would provide little additional information.

Given the findings developed from ASR Cycle 3a, regarding both the arsenic and DBP issues, we recommend not proceeding with the previous planned ASR Cycle 3b at the site. Instead, the SCWD should implement a full season of injection at the well and recharge as large a volume as possible (given the availability of excess surface water for injection) during this upcoming 2022 wet season, followed by a minimum one-month storage period, and then recovery of the previously injected volume into the distribution system to meet customer demands when needed. This long-term ASR cycle should include the implementation of a robust Sampling and Analysis plan, similar to that implemented during ASR Cycles 1 through 3, to confirm that the water quality behavior is consistent with the current expectations.

CLOSURE

This memorandum has been prepared exclusively for the City of Santa Cruz Water Department for the specific application to the City of Santa Cruz ASR Feasibility – Phase 2 Investigation at the Beltz 8 Well. The findings and conclusions presented herein were prepared in accordance with generally accepted hydrogeologic practices. No other warranty, express or implied, is made.

DRAFT TECHNICAL MEMORANDUM

TO: Robert C. Marks, Pueblo Water Resources/Ventura, CA

FROM: Dick Glanzman/Glanzman Geochemical LLC/ Lakewood, CO

DATE: August 28, 2021

SUBJECT: Geochemical Review and Evaluation of City of Santa Cruz Cycle 3 Pilot Test of the Beltz 8 ASR Well

SUMMARY AND RECOMMENDATIONS

Cycle 3 chemical analyses of water from the ASR well indicate that the arsenic and manganese concentrations primarily result from the dissolution of obsidian – the black glass in the aquifer sediments and secondarily by a limited amount of pyrite both within and distributed in the aquifer sediments becomes exposed to injected water with time in the aquifer. The availability of arsenic initially exposed in the aquifer sediments are probably responsible for the initially higher arsenic concentrations in both the ASR and MW. The slow dissolution of obsidian is probably the reason for the continuing presence of, and declining arsenic concentrations in the ASR well. The maximum arsenic concentration measured in Cycle 3 water analyses at the Beltz 8 ASR well location is 3.5 µg/L but earlier pilot test cycles 1 and 2 indicate that recovered water from earlier cycles may contain up to about 7 µg/L. Recovery of native groundwater moving through the injected water affected aquifer volume of cycles 1 and 2 indicates an arsenic reduction with incremental ASRcycles. In other words, repeated ASR cycles in aquifers with the same aquifer mineralogy as that of the ASR pilot test well are likely to result in progressively lower arsenic concentrations in the recovered water at that well location. The manganese concentration will likely also decrease but remain at concentrations above the drinking water standard for many ASR cycles..

The chemical characteristics of most ions in samples collected during the Cycle 3 pilot test show a similar trend from both the MW and the ASR well. The major difference between the MW and the ASR well data is apparently the presence of siderite in the aquifer sediments at the MW location but apparently not at the ASR well. The arsenic concentration in water from the MW location has a maximum arsenic concentration of 4.4 µg/L and although it is well within the current drinking water standard of 10µg/L it is higher than the maximum of 3.5 µg/L in water from the ASR well.

The dissolved iron in recovered water from both wells is essentially non-detectable at a 0.02 detection limit and total iron is also non-detectable in recovered ASR water samples. However the presence of siderite in the MW aquifer sediments results in total iron concentrations of 0.7 to 1.6 mg/L in the recovered water from the MW, well above the drinking water standard of 0.3 mg/L. Total iron is probably primarily present as iron oxyhydoxide colloids and flocculates that can at least partially be reduced by increasing storage time thereby allowing the iron oxyhydroxide to be sorbed to the aquifer sediments. The iron oxyhydroxide in the MW water is probably responsible for the higher arsenic concentrations in the recovered water from the MW since iron oxyhydroxide is one of the best adsorption media to remove arsenic from groundwater. This suggests that increasing storage time of the injected water could result in a lower arsenic concentration in the recovered water at the MW location and other parts of the aquifer sediments containing siderite.

There is no apparent need for additional pilot testing. The major question still to be determined is the amount of the aquifer that has siderite in its aquifer mineralogy. This would be best determined by performing an initial recharge at the planned volume of recharge for long-term ASR operations at the ASR well. The injected water could be recovered at the end of this initial recharge but it would be more informative if about a month of storage was allowed prior to recovery. Injected and recovered water chemistry should be at least the same as that for the third cycle but this frequency may need to be increased as the analytical results are reported.

INTRODUCTION

This report is an extension of the review and evaluation of Cycles 1 and 2 of pilot testing the Beltz 8 ASR Well (October 1, 2020). The results from that report are not repeated in this report except where the information is appropriate for this pilot test data and/or comparisons are needed. This report specifically addresses the questions of why the arsenic concentrations in the recovered water did not get as high as was expected from the first two pilot test results, can future arsenic concentrations from this well be expected to remain less than the current drinking water standard and will additional pilot testing be performed before putting the Beltz 8 ASR well into planned ASR production?

The available chemical analyses of groundwater, injected recharge water and recovered water from the Cycle 3 pilot of the Beltz 8 well are listed in Table 1 and the Beltz 8 Monitoring Well (MW) in Table 2. The summaries of injected and recovered water for all three cycles are listed in tables 3 and 4.

There are only very minor changes in the five available injected water analyses and no change in water chemistry type between March 30, 2020 and April 20, 2021. Therefore, changes in stored and recovered water are assumed to be a result of simple mixing the injection water with the native groundwater or chemical reactions between the injected recharge water mixing with native groundwater and/or aquifer mineralogy.

All of the Cycle 3 water analyses are of suitable quality for this geochemical review and evaluation. With the exception of the April 13, 2021 injection water used for the Beltz 8 pilot test with a mass balance error of 10.5 percent, the errors for the remaining majority of analyses are less than 3.8 percent. The errors for the MW analyses are all less than 7.5 percent. These errors are exceptionally low when the mineralogy of the aquifer is considered.

AQUIFER MINERALOGY

The Beltz 8 Purisima Formation aquifer mineralogy is unusual since it is dominated by relatively soluble sodium-rich plagioclase feldspar (oligoclase) and iron-rich black volcanic glass (obsidian) that together comprise over 50 percent of the total mineralogy. The poorly soluble silica mineral, quartz, is usually the dominant mineral in alluvial aquifers but is only about 20 to 30 percent in this aquifer. Swelling smectite clays formed by the dissolution of the plagioclase and obsidian comprises about 6 percent of the total aquifer mineralogy. The iron sulfide mineral pyrite and the calcium carbonate mineral calcite each comprise about 2 to 4 percent of the mineralogy. Pyrite exposed to the groundwater and recovered water is typically responsible for iron, sulfate, manganese and arsenic concentrations in the waters. However, obsidian may also be a source of these parameters with or without the presence of pyrite in the obsidian.

CYCLE 3 ASR BELTZ 8 PILOT TEST

Table 3 is a data summary of all three pilot tests dates, percent recovery of the injected water volume, and the arsenic concentrations (micrograms per Liter) of recovered water for both the ASR Beltz 8 well and the nearby Monitoring Well (MW). The initial elevated arsenic concentration in groundwater from the MW and the increase in the arsenic concentration in the recovered water from Cycle 2 compared to Cycle 1 raised concern about continuing the pilot testing without reviewing all the data from these first two cycles before proceeding to a Cycle 3 pilot test. The review was reported in "The Preliminary Report on the Geochemistry of Beltz 8 Groundwater at the City of Santa Cruz ASR Project Site" (10/1/2020). Further review and discussion of these data resulted in the decision to perform this Cycle 3 pilot test. The following sections describe the results of the Cycle 3 pilot test.

BELTZ 8 ASR WELL LOCATION RESULTS

This section begins with a discussion of the major ion chemistry followed by the individual ion chemistry. A trilinear diagram is used to show changes in the six individual major ions, calcium, magnesium, sodium-potassium, bicarbonate, sulfate and chloride. Changes in the percentage of these major ions indicates if there are significant changes in the chemistry of the native groundwater, injected, stored, and recovered water resulting from the ASR pilot testing as these waters mix and potentially chemically react with the aquifer mineralogy.

FIELD PARAMETERS

The temperatures of the Cycle 3 ASR recharge water range between 16.7 and 17.2 degrees Celsius (°C) that is significantly cooler than the pre-cycle groundwater of 18.4°C. The stored injected water ranges between 17.6 and 17.9 °C indicating the slight heating imposed on the recharge water by the aquifer sediments. The recovered water of the four zero to 75 percent of the injected recharge volume shows a slight decrease from 17.9 to 17.5°C . There is then a significant step function increase to 18.1 to 18.5 °C as the native groundwater moves through the volume of aquifer sediments conditioned by the recharge water. The last recovered sample (150 percent recovery) with a temperature of 18.5 °C is essentially the same as the 18.4 °C temperature of the pre-cycle ASR well groundwater temperature. This trend is about the same trend of most but not all dissolved constituents in the recovered water samples indicating essentially no mixing of the native groundwater and the injection water (plug-flow) through at least 75 percent of the recovered water. Changes in the chemistry of the following recovered samples are either a result of mixing with the native groundwater or chemical reactions with the aquifer mineralogy.

Both the field and laboratory measured electrical conductivity (specific conductance) that reflects the total dissolved solids (TDS) of the samples show the same trend as the temperature. The field measured values are somewhat more variable than the laboratory values but there is an excellent correlation between the laboratory conductivity and the TDS.

The near neutral pH shows the same trend but there is a 0.7 to 0.8 pH unit increase between the field measured pH and the laboratory pH. An increase in pH between the two is a common occurrence as dissolved carbon dioxide is released from the water sample between sample collection and sample analysis. However, this is a considerably higher increase than that typically occurring in similar depth alluvial aquifer groundwater of less than about 0.5 pH units. This means that there is an elevated amount of carbon dioxide in the water in these aquifer sediments. Using the field pH, thermodynamic equilibrium modeling estimates equilibrium carbon dioxide concentration of 12 to 22 mg/L. Since the typical alluvial groundwater generally contains less than about 5 mg/L the carbon dioxide content of groundwater in these alluvial sediments is elevated and affects not only the pH of the water but also the aquifer mineralogy.

The oxidation reduction potential (ORP) of the injected water ranges between an elevated 622 and 660 millivolts (mv) reflecting not only the dissolved oxygen but also the chlorine residual contained in the recharge water. The most recently injected stored water sample suggests that both the dissolved oxygen (DO) and residual chlorine are totally consumed by oxidation of a small amount of the iron-sulfide mineral pyrite, organic carbon and microbial processes within the aquifer sediments in the first week of storage. This is confirmed by the DO concentrations in both the stored and the recovered water DO concentrations. However, the second and third longer stored waters indicate significant but not total consumption by the aquifer sediments. When converted to Eh by adding 240 mv to the slightly negative field measured ORP values of most waters associated with the aquifer sediments, the Eh ranges between positive 210 to 234 mv that is similar to other alluvial groundwater occurring at the similar depths.

MAJOR IONS

Figure 1 is a trilinear diagram showing the major ion percentage relationships of Beltz 8 Cycle 3 pilot test data. All of the data cluster in a very small group indicating that there are very limited changes in the major ion chemistry throughout the third cycle. This includes pre-cycle groundwater (April 1, 2021), injected water (April 6 through April, 2021), stored water (April 27 through May 1, 2021) and recovered water (May 18 through June 1, 2021). Even though the injected water is a calcium-bicarbonate water chemistry type and the native groundwater is a calcium-bicarbonate-sulfate water chemistry type (10 of the 14 samples), the chemical reactions between the injected water and both the native groundwater and aquifer mineralogy minimally changes the major ion chemistry. In other words, there is only a sufficiently slight increase in the sulfate percentage of the stored and recovered water for sulfate to be included in the water chemistry type. This suggests a limited exposure of pyrite in the aquifer sediments and likely inclusion of very fine-grained pyrite in the volcanic glass, obsidian.

The slight offset of samples to the upper right from the major cluster in all three parts of the diagram includes the pre-cycle groundwater and the last two recovered water samples indicating that the major ion chemistry of the 125 and 150 percent of native groundwater is unchanged from the initial groundwater sample after storage and moving back through the volume of aquifer treated by the three ASR pilot test cycles. This further supports a limited exposure of pyrite in the aquifer sediments.

Stored Water

Two individual samples are offset toward the upper part of the diamond distribution are the first two of three stored injection water. The uppermost sample is the first recovered stored sample (April 27) that is the last injected water after being stored one week in the aquifer sediments. It is a calcium-sulfate-bicarbonate water chemistry type, the only sample other than the injected water with a slightly different water chemistry type. The decrease in pH and increase in total iron and particularly sulfate in this first sampled from the stored water indicates oxidation and dissolution of pyrite is occurring in the last injected water into the aquifer after a week of storage.

However, the major ion chemistry of the second recovered stored water indicates that after about a second week in the aquifer, the major ion chemistry moves back into the calcium-bicarbonate-sulfate water chemistry type. This not only further indicates a limited exposure of pyrite in the aquifer sediments but that dissolution of calcite and probably obsidian rapidly returns the major ion chemistry to its original state. This interpretation is also supported by the slight decrease of the stored water of only about 0.3 of the injected water pH. Of considerable interest is the decrease in sulfate concentration in the stored water with storage time. Sulfate decreases from 150 milligrams per Liter (mg/L) in the initial stored sample (April 27) to 110 mg/L in the last stored sample (May 12) further indicating not only limited pyrite exposure to the injected water but also that iron oxyhydroxide is probably forming on the exposed pyrite limiting further oxidation and dissolution of the exposed pyrite.

There is no change in water chemistry type in the recovered water. Recovered water retains the calcium-bicarbonate-sulfate water chemistry type not only in the pre-cycle sample, the latter two stored samples but also in the initial sample (May 18) to 150 percent recovery of the injected volume of recharge water. This means that, even though there are significant changes in the major ion concentrations in the trilinear diagram, these major ion concentration changes result from mixing of the injected water with the native groundwater rather than chemical reactions with the aquifer mineralogy. Mixing is clearly indicated by chloride and particularly the bromide concentrations of the waters.

Mixing Indicated by Chloride and Bromide Concentrations Includes Other Constituents

Chloride concentrations of the waters are a constant 30 mg/L in the injected water, stored water and recovered water until 100 percent recovery of the injected water volume (May 27) when it increases to 44 mg/L. Chloride concentrations further increase to 53 mg/L in the last two recovered water that is essentially the same as the pre-Cycle 3 groundwater concentration of 54 mg/L. This indicates that, similar to the temperature, the bulk of the injected water volume mixes little with native groundwater throughout the pilot test until after more than 75 percent of the injected volume is recovered. The chloride concentration of the 100 percent recovery of the recharge volume estimates that it contains 81 percent of the chloride concentration in the pre-cycle groundwater. This means that changes in recovered recharge water chemistry through 75 percent recovery of the injected recharge volume (May 25) is a result of chemical reactions between the injected water and the aquifer mineralogy.

The chemical characteristics of trace ion, bromide, are very similar to those of chloride. However, bromide concentrations of the pre-cycle groundwater at 210 micrograms per Liter (µg/L) has a better contrast with the injection water bromide of 20 µg/L than chloride and therefore better shows the mixing between injected and the native groundwater. Bromide concentrations indicates the same mixing as chloride but the 100 percent recovery volume is probably a more accurate 76 percent of the pre-cycle groundwater and both the 125 and 150 percent volume recovery are 100 percent pre-cycle groundwater.

In addition to other major ions, temperature, total dissolved solids and pH show a similar to the same mixing characteristics. However, most of the trace constituents occur at similar low concentrations and are insufficiently determined to indicate any trends.

Unlike these constituents, silica, arsenic and manganese do not show much if any of these mixing characteristics but rather tend to increase in concentration throughout the storage and recovery samples.

Silica

Silica, another major ion, is the major dissolution product of obsidian and therefore its concentrations indicate the relative dissolution of obsidian. The first week of storage increased the injected water about 9 mg/L and it increased about 13 mg/L during storage. Mixing showed a slow increase in concentration through recovery ending at 95 percent of the pre-cycle silica concentration at 150 percent injection volume. This indicates that a small portion of silica is probably forming clay and zeolite minerals on the aquifer sediments. This interpretation is supported by the lack of dissolved aluminum. The slowest increase in the silica concentration occurred in the 25 percent injection volume sample (May 20) the part of the alluvial sediments that had been conditioned by pilot test cycles 1 and 2.

Unlike the other major ions, silica does not show the mixing but stays at the same concentration or increases in concentration throughout the storage and recovery volumes. In this respect silica appears to be more similar to the trace constituents arsenic and manganese and thereby suggest that obsidian may be a major source for both of these constitutents in the aquifer sediments rather than the more typical pyrite as the source. This does not mean that pyrite is not a contributing source but iron and sulfate concentrations do not have the similarities that silica has with the arsenic and manganese.

Iron

There are no dissolved iron concentrations above the very low detection limit of 0.05 mg/L in any of the analyzed water samples. There are also no detectable iron concentrations in the recharge water. However there was 1.4 mg/L total iron in the pre-cycle groundwater indicating the occurrence of colloidal iron oxyhydroxide in the groundwater that is probably responsible for the field and laboratory turbidity of the sample. There is also detectable total iron in the injected water during storage that ranged between 0.26 to 0.34 mg/L indicating that the aquifer contains a low concentration of iron oxyhydroxide precipitates from dissolved pyrite during early stages of storage (April 27 through May 1). This conclusion is supported by the elevated sulfate concentration in the storage sample (110 to 150 mg/L) compared to the low sulfate concentrations in the injected water (69 to 71 mg/L). However, the total iron in the initial recovered sample (May 18) is a marginally detectable 0.06 mg/ and sulfate declined to 100 mg/L. Furthermore there is no detectable dissolved or total iron present in any of the remaining recovered water. Sulfate concentrations in the recovered water after also being in the aquifer for a much longer time than the stored water indicates only mixing between the injection water and the native groundwater rather than chemical reactions with the aquifer mineralogy.

Manganese

Except for the pre-cycle sample with 0.2 mg/L manganese, dissolved and total manganese have no similarity to total iron or sulfate suggesting that the primary source of the manganese is not pyrite. The somewhat similarity with silica suggests that dissolution of obsidian is likely the primary manganese source.

There are only slight differences between the dissolved and total manganese concentrations in all of the samples, a typical groundwater condition in manganese concentrations locally originating from the aquifer mineralogy. Manganese was not detectable in any of the injected water samples (less than 0.05 mg/L). Manganese concentrations in the zero through 50 percent recovered injection water volume samples did not exceed the standard water standard of 0.05 mg/L although the pre-cycle and subsequent recovered injection water samples did exceed the standard. This low manganese concentration in the early recovered samples is probably due to the aquifer conditioning of the first and second pilot test cycles in the ASR well. Unlike most other ions, manganese concentrations essentially incrementally increase during storage and throughout each of the recovered samples. Even with this increasing trend, the manganese concentration of the last recovered water (0.13 and 0.15 mg/L at 150 percent of the injected water volume) was significantly less than that of the pre-cycle manganese concentration (0.2 mg/L). These relationships indicate that manganese originated by chemical dissolution of obsidian rather than mixing between the injection water and native groundwater reflected by most other constituents but aquifer conditioning through repeated ASR cycles may decrease the manganese to less than the drinking water standard.

Arsenic

Arsenic concentrations have a similarity with both silica and manganese concentrations rather than most other constituents indicating that its major source is likely obsidian with a minor source from pyrite exposed to the injected water rather than mixing between the injected water and pre-cycle groundwater that is responsible for changes in most other constituents.

The arsenic concentration in the pre-cycle groundwater from the ASR well was 3.5 µg/L. This arsenic concentration is significantly lower than the last ASR Cycle 2 sample (150 percent injected water recovery volume) of 4.5 µg/L. This reduction suggests that the arsenic concentration continues to decrease in the ASR well groundwater with time as the trend line in Figure 1 of that report suggested .

The injected water and the first storage sample (April 27) contained less than 1 µg/L arsenic. The non-detect arsenic concentration in the first storage sample collected after about one week in contact with aquifer is in sharp contrast to the elevated total iron and sulfate contained in that sample believed to be generated by the oxidation and dissolution of pyrite. This strongly supports the conclusion that pyrite is a minor contributor to the arsenic concentration in the water.

The arsenic concentration increases from 1.3 to 1.9 µg/L in the second and third storage samples, respectively (May 5 and May 12). The initial, zero, recovered water sample (May 18) also had 1.9 µg/L. This relationship suggests relatively slow dissolution expected for obsidian dissolution. This dissolution is represented by the silica concentration that has the same relative trend as that of the arsenic.

The second, 25-percent –recovered-water sample (May 20), contained 2.1 µg/L arsenic. This sample represents the most injection-water-conditioned portion of the aquifer and contains almost the same arsenic concentration as that of the pre-cycle groundwater sample of 2.3.µg/L. This relationship suggests that aquifer conditioning by the injection water slows the release of arsenic from the aquifer sediments to near that of the native groundwater.

The arsenic concentration in the recovered samples slowly increased from 2.1µg/L in the second recovered sample to 3.4 µg/L in the third, 50 percent recovery volume (May 23), through 3.3 µg/L in the fourth recovered sample (75 percent recovery) to its highest concentration of 3.5 µg/L in the fifth, 100 percent recovery of the injected water. These samples represent increased exposure of the injected water to the unconditioned aquifer sediments.

Finally the sixth and seventh, 125 and 150 percent of the recovered recharge volume) samples show a sharp arsenic concentration reduction to 3.1 and 3.0, respectively, as the native groundwater containing 2.3µg/L arsenic is brought back through the portion of the aquifer exposed to the injection water. These relationships suggest that aquifer conditioning effectively limits the arsenic concentration to about 3.5 µg/L in this recovered Cycle 3 injection water at this aquifer location. Furthermore, these relationships suggest that the arsenic concentration decreases with increased recovery of native groundwater as it moves back through the aquifer previously exposed to the injected water in pilot test cycles 1 and 2 (aquifer conditioning).

Figure 2 shows the arsenic concentrations for each of the three cycles. Cycle 3 indicates that the arsenic concentration decreased by almost 50 percent from Cycle 2 and the arsenic concentration appears to attain an almost stable concentration of about 3.1 to 3.5 3.4 µg/L but slowly declining trend following the highest concentration. The three pilot test cycles indicate that arsenic concentrations consistently decline with each cycle to at least the 3 µg/L and perhaps lower concentrations.

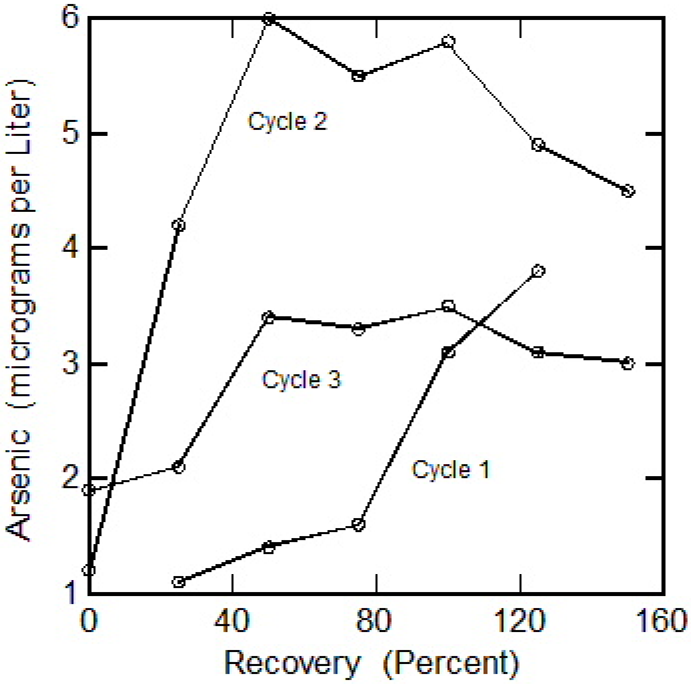

Figure 2. Arsenic concentrations in recovered water from the three ASR pilot test cycles of the Beltz 8 ASR well.

Thermoequilibrium Modeling

Thermodynamic modeling estimates the minerals, pH and Eh that control the chemistry and concentrations of the dissolved ions in the water. Minerals that are in equilibrium are generally those that control the ion chemistry contained in those minerals. Common minerals that are out of equilibrium are usually those controlled by pH and Eh (ORP).

Amorphous silica, plagioclase feldspar, dolomite and smectite-clay minerals are in equilibrium for most of the water analyses. This equilibrium condition reflects dissolution equilibrium particularly with respect to obsidian and plagioclase confirming what the above sections discuss. The typical western alluvial groundwater is in equilibrium with respect to the silica mineral cristobalite or quartz as well as plagioclase feldspars and smectite clay from the dissolution of plagioclase feldspar. They are also almost universally in equilibrium with respect to the calcium-carbonate mineral, calcite. Calcite is controlled by temperature, pH, calcium and the carbon series equilibria – carbon dioxide, carbonic acid, bicarbonate and carbonate, each becoming incrementally dominant as the pH increases from acidic to alkaline values.

Where pyrite is present, iron is usually in equilibrium with respect to dissolved and total total iron. The total iron concentration is commonly iron oxyhydroxide. The relative amount of both dissolved and total iron is controlled by temperature, pH and Eh (ORP). Accurate field measurements of temperature, pH and ORP are therefore very important.

Calcite is under-saturated using the field measured temperature and pH with the laboratory-measured calcium and alkalinity. The field measured pH is about 0.5 pH units lower than the laboratory pH in the pre-cycle groundwater and between 0.6 to 0.9 pH units lower in the stored and recovered water. This difference is usually caused by the evolution (loss) of carbon dioxide gas from the sample between the field and the laboratory. A typical western alluvial aquifer groundwater has an model-estimated equilibrium carbon dioxide content of about 1 mg/L but can range between near zero to about 5 mg/L. These waters have an estimated equilibrium carbon dioxide between 8 and 16 mg/L after adjusting the pH to calcite equilibrium instead of 16 to 31 mg/L using the field measured pH. This means that there is an elevated level of carbon dioxide in these waters. This may be reflecting microbial conversion of methane gas to carbon dioxide in this aquifer. Measured methane concentrations in the Cycle 3 waters range between 0.27 and 0.46 µg/L but like carbon dioxide methane is expelled from the water between the field and laboratory where a portion of both are lost when the samples are opened for chemical analysis. The heterotrophic plate count (HPC) measurement estimate the number of microbial organisms in the water. The HPC values on the native, and particularly stored and recovered waters are quite elevated but coliform measurements are non-detect meaning that the TOC/DOC and methane contents are probably sufficient to support these elevated HPC measurements. Based on these HPC values, there are more than sufficient native microbial organisms to produce the probable and estimated carbon dioxide content affecting the calcite equilibrium status.

Using the total iron concentration, the field measured ORP values have to be decreased 50 to 100 millivolts for the iron concentration to be in equilibrium at the temperature and corrected pH for the waters. Iron, like calcite is typically in equilibrium because both typically and rapidly react to changes in conditions between the field and laboratory. Exposure to oxygen in the atmosphere rapidly increases the measured ORP values both in the field and particularly the repeated reopening of the samples in the laboratory to extract water for analysis.

Summary

Cycle 3 chemical analyses of water from the ASR well indicate that the arsenic and manganese concentrations primarily result from the dissolution of obsidian – the black glass in the aquifer sediments and secondarily by a limited amount of pyrite exposed with time in the aquifer. The maximum arsenic concentration measured in Cycle 3 water analyses at the Beltz 8 ASR well location is 3.5 µg/L but aquifer conditioning by earlier pilot test cycles 1 and 2 indicate that recovered water from earlier cycles may contain up to about 7 µg/L. Recovery of native groundwater moving through the injected water affected aquifer volume of cycles 1 and 2 indicates an arsenic reduction with incremental ASRcycles. In other words, repeated ASR cycles in aquifers with the same aquifer mineralogy as that of the ASR pilot test well are likely to result in progressively lower arsenic concentrations in the recovered water at that well location. The manganese concentration will likely also decrease but remain at concentrations above the drinking water standard for many ASR cycles..

MONITORING WELL LOCATION RESULTS

The outline of this section follows the same sections as those in the above discussion and interpretations of the Baltz 8 ASR well. This nearby monitoring well responds to recharge from the Baltz8 ASR well and provides additional understanding of chemical reactions between injected recharge water, groundwater and the aquifer mineralogy at the monitoring well location. The monitoring well data documents the changes in recharge water and groundwater chemistry as the injected water moves into and through its down-gradient location relative to the ASR well. The following description uses the recovered water volume of recharge water that defined the recovery at the Beltz 8 water samples. The volume of injected water is the same but there is a relatively small but additional aquifer mineralogy through which the injected water passes compared to the ASR well. Furthermore, the aquifer characteristics particularly the mineralogy can differ considerably even at relatively small lateral distances between the two.

FIELD PARAMETERS

The temperatures of the Cycle 3 MW waters are two to three degrees Celsius (°C) cooler than the Cycle 2 water probably as a result of the cooler ASR pilot test recharge moving into the aquifer. The MW sample temperatures show the same trend as that of the ASR sample temperature but range between 17.5 °C in early recharge to 18.85°C in the last water sample about 0.2 to 0.3 warmer than that of the ASR samples

The MW conductivity and TDS values have similar relationships as those of the ASR well data. However, both the conductivity and the TDS of the MW recovered-water samples are less than their respective values in the ASR values. This decrease in MW recovered-water sample values also occurs with the MW recovered-water major ion concentrations, suggesting more dilution and mixing with the injected water into the groundwater of the MW sediments than in the ASR well sediments.

The MW pH values are slightly higher than the ASR pH values. This is probably the dissolution of more calcite by some sulfuric acid released by the oxidation of pyrite, dissolution of the iron-carbonate mineral siderite and consumption of some of the dissolved carbon dioxide. The equilibriurm carbon dioxide estimated by thermodynamic equilibrium ranged between 12 and 26 mg. This higher carbon dioxide at the MW location compared to ASR well location may be responsible for the slow precipitation of siderite in the aquifer sediments at the MW location and none measurable at the ASR location.

The MW samples ORP values are 40 to 110 mv lower than those of the ASR samples but still oxidized waters. This reduction in ORP, particularly during storage interval, are probably related to both the oxidation of the relatively small amount of pyrite exposed to the injected water as indicated by the sulfate concentration, the oxidation of the ferrous iron generated by this pyrite oxidation and dissolution of the ferrous iron-carbonate mineral siderite. This interpretation is supported by the significantly higher total iron in the MW water compared to that of the ASR water.

MAJOR IONS

Figure 3 is a trilinear diagram showing the major ion percentage relationships of Beltz 8 MW Cycle 3 and part of the Cycle 2 pilot test data for comparison purposes. All of the data cluster in 2 very small groups indicating that there are very limited changes in the major ion chemistry throughout the two cycles. This includes MW sampling pre-cycle groundwater for both cycles (March 18, 2020 and April 5, 2021, respectively), injected water during Cycle 3 (April 13,2021 and April 20, 2021), stored water (April 27. May 5 and May 12, 2021) and during recovery of Cycle 2 water (April 15, 2020 and April 21,2020) and Cycle 3 water (May 18, 2021 through June 1, 2021).

MW water is similar to that of the ASR well but it is slightly higher in the magnesium percentage suggesting more dissolution of dolomite and augite, perhaps somewhat more dolomite and augite are present in the aquifer sediments at the MW location than the ASR well location.

The majority of the major ion percentages comprise a small compact cluster so similar it is difficult to separate the individual samples. The magnesium percentage is essentially constant but the sodium/calcium percentages change as shown in the lower left part of the diagram. Unlike the ASR water, most of the samples from the MW include a rather variable calcium-magnesium-bicarbonate-sulfate and calcium-sodium-bicarbonate-sulfate water chemistry types. This latter type is dominant in both the ASR and MW. This variability is caused by the slight percentage differences between the sodium and magnesium percentages in the MW water rather than significant changes in aquifer mineralogy. The differences are so slight that they may be analytical rather than a change in water chemistry type.

The three samples that are separated from the major cluster in all three parts of the diagram involve an increase in sulfate and a decrease in bicarbonate percentages. The April 15, 2020 MW sample was the first sample during water injection in Cycle 2 of ASR well and is a calcium-sulfate-bicarbonate water chemistry type. The April 27, 2021 sample was collected when the pre-Cycle 3 ASR well was being collected and is a calcium-magnesium-sulfate-bicarbonate water chemistry type. This sample represents essentially a year of storage after the Cycle 2 pilot test. The third sample, May 12, 2021, collected the same time as the collection of the third ASR well stored injection water and is a calcium- sulfate-bicarbonate water chemistry type. Relatively short storage of injected water appears to generate an increase in sulfate percentage that dissipates as the bicarbonate percentage increases with storage time.

Mixing Trend Shown By Chloride, Bromide And Other Constitutents

Chloride, bromide and many of the other constituents have the same mixing characteristics as shown by the ASR well but there is more variability and differences in concentrations. Chloride shows the same trend in MW samples as in the ASR well but the chloride concentrations are more variable (28 to 31 mg/L compared to a constant 30 mg/L in the mixing zone). Bromide variably ranges between 61 and 73 µ/g in the MW water compared to 60 to 83 µ/g in the recovered ASR well water. The chloride concentration of the 100 percent recovery of the recharge volume samples from the ASR well was 81and 76 percent of the pre-cycle water, respectively, while at the same date, the bromide concentration was 90 and 93 percent respectively. Clearly, the MW aquifer sediments have a much higher plug-flow characteristic than the ASR aquifer sediments.

Silica

Silica concentration in the MW water shows the same characteristics as that of the ASR recovered water but has a consistently about 10 mg/L higher concentration and lower variability than the ASR water. However, the pre-cycle and 150 percent recovery dated sample (April 5 and June 1, 2021) are essentially the same. These relationships suggest that the obsidian content of the aquifer is essentially the same at both well locations but the silica concentration is more stable in the MW aquifer sediments than in the ASR well. This makes sense because the MW has additional aquifer volume than the ASR well. But it could also include or be differences in aquifer sediment heterogeneity in the two wells..

Iron

Iron concentrations and trend in the MW water is entirely different than ASR well iron concentrations. Dissolved iron concentrations in water from both wells are essentially non-detect within the laboratory precision and accuracy. However, the total iron does not have the same concentrations or mixing trend as sulfate and any other constituents in the MW or ASR water samples. Total iron concentrations in the MW samples are more than order of magnitude higher than those in the ASR samples. They also show a decrease during storage rather than the increase indicated by the ASR water. However, the total iron concentrations steadily but slowly increased with each MW water sample after the storage time. Clearly there is a different source of iron in the MW aquifer sediments other than obsidian and pyrite.

Thermodynamic equilibrium modeling indicates that the iron-carbonate mineral, siderite, is present and at equilibrium in the aquifer sediments. Siderite is probably responsible for the total iron concentrations in the MW. This is a significant for the arsenic concentrations because relatively soluble siderite does not typically sorb or contain arsenic but the iron dissolved when oxidized water dissolves siderite results in an iron oxyhydroxide colloid that does. This explains the at least partial correspondence between arsenic and total iron in the MW water and not in the ASR water. Arsenic becomes adsorbed to both the colloidal iron hydroxide precipitated and flocculated in the water as well by iron oxyhydroxide plated out on the aquifer particles. The decrease in the total iron concentration during the Cycle 3 MW storage following injection into the ASR well is probably a result of iron oxyhydroxide colloids and flocculates removed from the water by becoming attached to aquifer particulates. These relationships suggest that adding storage time may reduce not only total iron but also arsenic.

Manganese

The dissolved and total manganese concentrations in the MW water have nearly the same analytical values with a very narrow range between 0.082 and 0.16 mg/L While this range is slightly higher than that of the ASR water samples, the initial pre-cycle MW concentrations are slightly lower than that of the ASR pre-cycle concentrations but the final June 1, 2021 MW concentrations is equal to or just slightly higher than the ASR concentrations. Overall, the manganese concentrations and trend in the aquifer at both well locations are essentially the same but all manganese concentrations in MW waters exceed the drinking water standard of 0.05 mg/L. However, as described above, manganese concentrations in the zero through 50 percent recovered injection water volume samples at the ASR well did not exceed the standard even though the pre-cycle and subsequent recovered injection water did exceed the standard. This supports the conclusion that aquifer conditioning by the first and second pilot test cycles in the ASR well reduced the manganese concentration to less than the drinking water standard in the water sampled from the MW..

Arsenic

The arsenic concentration in water from the MW is more complex than that from the ASR well. The arsenic concentration decreased from 5.3 µg/L in the last sample collected during Cycle 2 pilot test to 3.8 µg/L in the first sample (pre-cycle sample) collected for Cycle 3. Conversely, the silica, total iron, manganese and sulfate concentrations slightly increased in these two samples. Arsenic concentrations slowly increased during the storage time at the Cycle 3 pilot test at the Mw but at a lower concentration (1.8 to 2.3 µg/L) than the initial 3.8µg/L. Silica and sulfate shows a strong increase but total iron and manganese show a decrease from that of the injected water concentrations and appear to be nearly stable at these lower concentrations.

Arsenic concentrations sharply increased from 2.3 µg/L in the last sample collected during the Cycle 3 storage time (May 12) at the MW to 3.6 the first sample collected for the initial recovery of the injected water from the MW well (May 18). It then decreased slightly to 3.5 µg/L in the sample collected for the 25 percent recovery (May 20) but then increased to a high of 4.4 mg/L in the sample collected for the 125 percent recovery from the ASR well. The non-detect arsenic concentration reported by the laboratory for the May 25 sample is in error and clearly not correct. Arsenic then decreased to 3.9 µg/L in the last MW sample collected at the same time as the 150 percent Cycle 3 recovery sampling of the ASR well. This last arsenic concentration (3.9µg/L) is only slightly higher than the pre-cycle concentration of 3.8 µg/L and similar to the first three Cycle 3 MW samples of 3.6, 3.5 and 4.0 µg/L, respectively, representing the portion of the aquifer sediments conditioned by the cycles 1 and 2 pilot testing. This suggests that the iron oxyhydroxide colloids and flocculates in the MW water stabilizes the arsenic concentration in this range.

The arsenic concentration trend differs from the silica consistently increasing trend that suggests that a fraction of the arsenic associated with the dissolution of the obsidian is probably being sorbed by the iron oxyhydoxide colloids and flocculates while at least partially becoming attached to the surfaces of the aquifer particles.

Comparison of the Cycle 3 with Cycle 2 arsenic concentrations data indicates that the higher arsenic concentrations in the Cycle 3 concentrations are about the difference between the MW samples collected during the injection of the recovered water and the injected water arsenic concentrations at the ASR well. In other words, the higher arsenic concentrations in the Cycle 3 MW samples during the Cycle 3 injection of the ASR well of 1.2 and 1.4 µg/L, respectively, and the non-detect arsenic concentration of the water injected at the ASR well is essentially the difference between the arsenic concentrations in the MW and ASR well samples reported by the laboratory. This is unlikely a coincidence but there is no credible reason for this.

Thermodynamic Equilibrium

All waters associated with the aquifer sediments at the MW location are in equilibrium with amorphous silica (obsidian), plagioclase feldspar, siderite, dolomite and swelling smectite clay. Calcite is undersaturated and iron oxyhyroxide is oversaturated in all samples except the last (June 1, 2021) MW sample representing the 150 recovery volume from the ASR well. The relationships between the water chemistry and equilibrium as discussed for the ASR well water are also applicable in explaining these equilibrium results.

Summary

The chemical characteristics of most ions in samples collected during the Cycle 3 pilot test show a similar trend from both the MW and the ASR well. The major difference between the MW and the ASR well data is apparently the presence of siderite in the aquifer sediments at the MW location but apparently not at the ASR well. The arsenic concentration in water from the MW location has a maximum arsenic concentration of 4.4 µg/L and although it is well within the current drinking water standard of 10µg/L it is higher than the maximum of 3.5 µg/L in the ASR well.

The dissolved iron in recovered water from both wells is essentially non-detectable at a 0.02 detection limit and total iron is also non-detectable in recovered ASR water samples. However the presence of siderite in the MW aquifer sediments results in total iron concentrations of 0.7 to 1.6 mg/L in the recovered water, well above the drinking water standard of 0.3 mg/L. Total iron is probably primarily present as iron oxyhydoxide colloids and flocculates that can at least partially be reduced by increasing storage time thereby allowing the iron oxyhydroxide to be sorbed to the aquifer sediments. The iron oxyhydroxide is probably responsible for the higher arsenic concentrations in the recovered water from the MW since iron oxyhydroxide is one of the best adsorption media to remove arsenic from groundwater. This suggests that increasing storage time of the injected water could result in a lower arsenic concentration in the recovered water at the MW location and other parts of the aquifer sediments containing siderite.

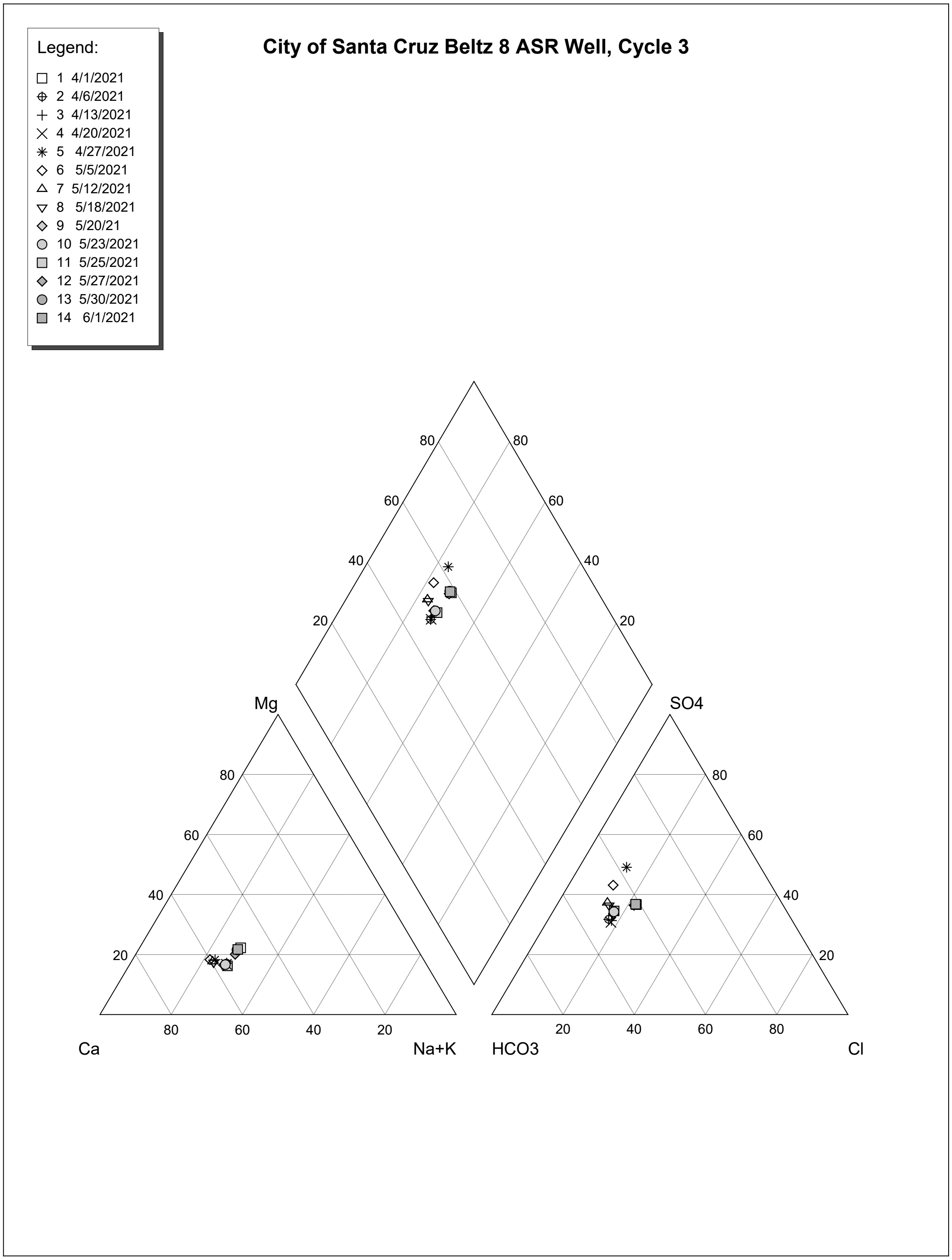

Figure 1. Trilinear Diagram showing the major ion relationships of the City of Santa Cruz Beltz 8 ASR Well Cycle 3 sampling.

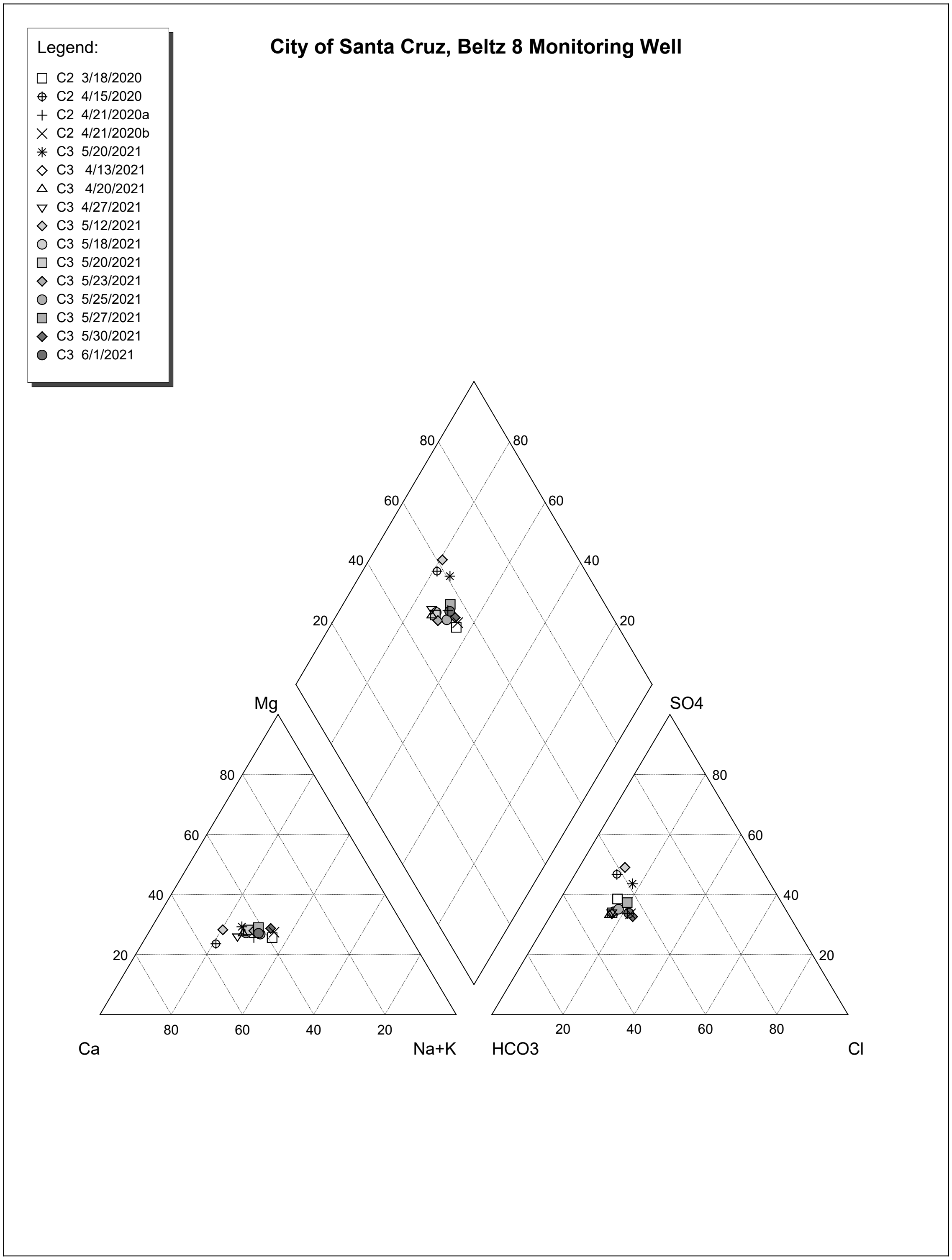

Figure 2. Trilinear Diagram showing the major ion relationships of the City of Santa Cruz Beltz 8 Monitoring Well, Cycle 2 (C2) and City 3 (C3) sampling.