Technical Report
Aquifer Storage and Recovery Pilot Test at Sonoma Test Well #6A

Sonoma County Water Agency

Prepared by

GEI Consultants, Inc., Rancho Cordova, CA

Pueblo Water Resources, Santa Barbara, CA

Sonoma County Water Agency, Santa Rosa, CA

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1 Introduction

This Technical Report was prepared by GEI Consultants (GEI), on behalf of the Sonoma County Water Agency (Water Agency) and the City of Sonoma (City), to describe the proposed design, methods and procedures for implementing an Aquifer Storage and Recovery (ASR) pilot test. Additionally, this Technical Report provides information required for submittal of a Notice of Intent (NOI) to perform an ASR pilot test under the State Water Resources Control Board's (SWRCB) Water Quality Order 2012-0010, *General Waste Discharge Requirements for Aquifer Storage and Recovery Projects that Inject Drinking Water into Groundwater* (ASR General Order). This proposed pilot test involves several cycles of recharge, storage, and recovery of drinking water through a confined aquifer system of the Sonoma Volcanics in the Sonoma Valley underlying the City of Sonoma. The source of the drinking water to be used for the pilot test will be the Water Agency's Russian River Riverbank Filtration Facility. Approximately 20 acre feet (af) of drinking water is planned to be recharged into the aquifer, stored, and recovered via Test Well #6A (TW-6A) located at 150 First Street West in the City of Sonoma. Existing City municipal supply well #6 (City Well #6) is located approximately 60 feet from the test well and will be used as a monitoring well during the pilot test. The general location of the project site is shown on **Figure 1 – Site Location Map**.

The overall objective of the pilot test is to verify and empirically determine specific hydrogeologic and water-quality factors to support a technical and economic viability assessment of ASR techniques in the region. Specifically, the proposed pilot test has been designed to:

- Evaluate the ability to recharge the Sonoma Volcanics, as well as verify geochemical compatibility of native and recharged waters with aquifer mineralogy.
- Assess basic aquifer recharge and hydraulic parameters.
- Assess well hydraulics (e.g., specific capacity, plugging rates, etc.) for ASR operations.
- Evaluate short-term water quality changes.

If feasible, the pilot test data will be used to complete CEQA documentation for a full scale or permanent ASR project, and provide design information for the project. Results from the pilot test will also provide information on the technical feasibility for ASR in Sonoma Valley to other local agencies, including the Valley of the Moon Water District and the Sonoma Valley Groundwater Sustainability Agency (GSA).

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ASR Pilot Project Sonoma County, California	GEI Consultants	Site Location Map	
Sonoma County Water Agency		DECEMBER 2017	FIGURE 1

1.1 Background

Due to uncertainties in the reliability of regional future water supplies (both surface water and groundwater), the Water Agency, City of Sonoma, and other local partners, including the cities of Rohnert Park and Cotati, Valley of the Moon Water District, and the Town of Windsor (study participants) conducted a feasibility study for a regional groundwater banking program (Groundwater Banking Feasibility Study) and an investigation of the viability of enhancing the conjunctive management of surface water and groundwater resources (GEI, 2013).

Conceptually, the groundwater banking program would involve the diversion and transmission of surplus Russian River water, after treatment at the existing drinking water production facilities, during wet weather conditions (i.e., the winter and spring seasons) for storage in aquifers beneath the Santa Rosa Plain and/or Sonoma Valley. The stored water would then be available for subsequent recovery and use during dry weather conditions (i.e., the summer and fall seasons) or emergency situations. The Groundwater Banking Feasibility Study provided an evaluation of the regional needs and benefits, source water availability and quality, regional hydrogeologic conditions, and alternatives for groundwater banking. Additionally, based on initial findings from the Groundwater Banking Feasibility Study, site-specific evaluations were completed for several existing wells deemed suitable for pilot-scale ASR testing, including evaluations of the adjacent City Well #6:

- Groundwater quality data were collected, analyzed, and incorporated into a geochemical model, along with the source water quality data, to assess the potential interaction between the source water and native groundwater. The findings are summarized in the **Geochemical Evaluation Technical Memorandum for Sonoma Well #6 (Appendix A**)
- An assessment of physical and hydraulic constraints associated with recharge was performed to determine the operational criteria for a pilot demonstration project. The findings are summarized in the **Preliminary Injection Capacity and Constraints Analysis for City of Sonoma Well #6 (Appendix B**).

Findings from the Groundwater Banking Feasibility Study indicate the following:

- A groundwater banking program would provide enhanced reliability of the regional water supply during droughts, natural hazard events (e.g., earthquakes), and periods of peak seasonal water demands. Russian River source water would be recharged in the winter period (November to April). Such operation reduces the hydraulic loading and improves the reliability of the Water Agency's transmission system during the high-demand summer period. Performing the pilot test during this period is representative of the time of year a permanent ASR project would be in operation.
- Additional potential benefits include improved habitat conditions by enhancing tributary base flows from reduced groundwater pumping, or in the case of Dry Creek within the Russian River watershed, reducing summer releases from Warm Springs Dam (due to reduced peak demands) thus improving flow conditions for Endangered Species Act-listed salmonids.

- Facilities owned and operated by the study participants, including drinking water production facilities along the Russian River and groundwater supply wells within the groundwater basins, are well suited for further testing and developing a groundwater banking program in an incremental and phased manner.
- In evaluating methods for implementing a groundwater banking program, ASR was deemed to be more practical than surface spreading for near-term implementation, based on: (1) the ability to incrementally establish an ASR program; (2) the ability to pilot test ASR in a phased manner; (3) the relatively lower costs associated with ASR; and (4) uncertainties related to the ability of surface spreading alternatives to convey water to aquifers suitable for storage and subsequent recovery.
- The Russian River provides a source of high quality drinking water, with a typical total dissolved solids (TDS) content of 160 milligrams per liter (mg/L) and very low particulate and nutrient content.
- If determined to be feasible, a long-term groundwater banking program could help address requirements under the Sustainable Groundwater Management Act (SGMA) by providing a water supply tool to assist in reducing the demands of native groundwater pumping, which could in turn help stabilize or recover declining groundwater levels and reduce the potential for saline intrusion.

The remaining sections of this Technical Report build on and provide additional details regarding these findings.

2 Project Conditions and Considerations

The following sections describe the site and project conditions, which include the project setting, hydrogeologic conditions, groundwater level conditions, and well construction details. This section also presents other information required by the ASR General Order, including assessments of source water and groundwater quality, geochemical conditions, the potential recharge capacity, the estimated hydrologic area of influence associated with the proposed pilot study, and a groundwater degradation assessment.

2.1 Project Setting

Test Well # 6A is located within the northern area of the City of Sonoma north of the Veterans Memorial Hall at 150 First Street West. Figure 1 shows the well location. The test well was constructed in 2016 on property owned by the County of Sonoma under a Permit to Enter Agreement by the Water Agency and was funded through a Local Groundwater Assistance Grant from the California Department of Water Resources. The Water Agency subsequently acquired property rights and an easement from the County for a 15- by 15-foot area surrounding the test well for the purposes of performing the proposed pilot study. City Well # 6 is located approximately 60 feet west of the test well and is also known as the Veterans Memorial Well and historically as the Mountain Cemetery well. The project area is located on flat to gently sloping terrain at a surface elevation of approximately 130 feet above mean sea level (msl) within the Sonoma Creek watershed. Land uses within the immediate vicinity of the project area include a cemetery, parks, police station, low-density residential, and undeveloped open-space areas.

2.2 Hydrogeologic Setting

The aquifer system underlying most of the City of Sonoma is part of the larger Sonoma Valley Groundwater Subbasin. The project area is located slightly outside the boundary of the Sonoma Valley Groundwater Subbasin (2-002.02), as mapped in DWR's Bulletin 118. However, the aquifer system beneath the project area is directly connected with the aquifer systems of the Sonoma Valley Groundwater Subbasin, as further described below. The hydrogeology of the Sonoma Valley is described in the Geohydrological Characterization, Water-Chemistry, and Ground-Water Flow Simulation Model of the Sonoma Valley Area, Sonoma County, California (Farrar, 2006), Sonoma Valley Groundwater Management Program Five Year Review Report (Water Agency, 2014), and the Santa Rosa Plain/Sonoma Valley Groundwater Banking Program Feasibility Study (GEI, 2013). These studies describe the stratigraphy, structure, and hydraulic characteristics of the aquifer systems. In general, useable groundwater in the Sonoma Valley occurs in the Alluvial Deposits, the Glen Ellen and Huichica Formations and the Sonoma Volcanics. The aquifer system in Sonoma Valley is generally defined as follows:

- A shallow alluvial aquifer system generally present from the water table to depths ranging from 100 to 220 feet. The shallow aquifer is comprised of heterogeneous deposits of sand, silt, clay and gravel deposited along alluvial fans, stream channels and floodplains. In areas where Quaternary alluvial deposits are absent, the shallow aquifer locally occurs within sedimentary deposits of the Glen Ellen and Huichica Formations.

- An intermediate aquifer system primarily comprised of sand and gravel interspersed within variable amounts of clay and occurs within sedimentary deposits of the Glen Ellen and Huichica Formations. Locally, the intermediate aquifer system occurs within volcaniclastic sediments, tuffs and fractured volcanic rocks of the Sonoma Volcanics where the volcanic units present within the hills extend beneath the alluvial fill of the valley floor, such as in the project area. Aquitards comprised of clay deposits or volcanic flow rocks typically separate the shallow and intermediate aquifer systems and serve to locally confine the intermediate aquifer system. The thickness of the intermediate aquifer ranges between 90 and 210 feet. In some areas, such as in the project area, the shallow alluvial aquifer system is absent and the intermediate aquifer system represents the uppermost aquifer.
- A deep aquifer system generally present beneath the intermediate aquifer. The lateral continuity of the deep aquifer and the separation from the intermediate aquifer are not well defined due to the limited number of wells and lithologic information for the deep aquifer system.

Several faults have been mapped in the hills bounding Sonoma Valley, including a northwest-striking fault has been mapped along the eastside of the valley floor approximately ¼-mile west of the project area. This fault, referred to as the Eastside Fault, locally provides a conduit for the upward circulation of deeper thermal waters and may act as a hydrologic barrier to horizontal groundwater flow (USGS, 2006).

2.2.1 Target Aquifer Zone Hydrogeologic Framework

The Sonoma Volcanics within the intermediate aquifer system represent the target aquifer storage zone for this ASR pilot test. A geologic map of the area is presented on **Figure 2 – Geology and Cross-Section Location Map**. A geologic cross-section showing the local hydrostratigraphy is presented on **Figure 3 – Geologic Cross-Section**, including the depths and screened intervals of the test well and other nearby wells. As shown by the geology map (CGS, 2010), the project area is located along the southern margin of the surficial outcrop of Tertiary-age volcanic units of the Sonoma Volcanics (Tsv). According to the California Geologic Survey (CGS, 2010), these rocks are mapped as andesitic flows (Msvas – Andesite of Shocken Hill) with intercalated tuff and sediments (Tsvt) of the Sonoma Volcanics with units that locally strike northwest – southeast and dip approximately 25 degrees to the southwest in the vicinity of the wells. The Eastside Fault is mapped approximately ¼-mile to the west of the well site, as indicated on Figure 2.

As described, the Sonoma Volcanics are comprised of mixtures of thick sequences of extrusive lava beds (flows), ash, and unwelded tuffs. The volcanic rocks appear to have been erupted predominantly from local volcanic vents that were located east of the valley. The Sonoma Volcanics have a large variation in water-bearing properties, with a mixture of fractured lava beds, unwelded tuffs and interbedded volcaniclastic sedimentary deposits providing the best aquifer materials. Lava beds have extremely low primary permeability and only fractures yield significant water. Unwelded tuffs can yield water similar to high porosity, high permeability alluvial sediments. The Sonoma Volcanics are highly variable in lithology and their subsurface distribution is often difficult to discern from well drillers logs in the Sonoma Valley. For reference and additional details on the hydrogeology of the area, the reader is referred to the Groundwater Banking Feasibility Study (GEI, 2013); Geohydrological Characterization, Water-Chemistry, and Ground-Water Flow Simulation Model of the Sonoma Valley Area, Sonoma County, California (Farrar, 2006); and Sonoma Valley Groundwater Management Program Five Year Review Report (SCWA, 2014).

An As-Built Drawing and Well Completion Report (driller's log) are provided in **Appendix C, Well Logs and Mineralogy, Inc. Report,** for TW-6A along with a composite well log for nearby City Well #6. A drillers log is not available for City Well #6 but some information about the local geologic conditions was available from the City of Sonoma's files, including a soil formation log for the well. TW-6A was drilled to a depth of 250 feet while City Well #6 was reportedly drilled to 270 feet. Both wells produce groundwater from the Sonoma Volcanics, as interpreted by this project and previous work (Winzler and Kelly, 2009).

The log of the recently drilled TW-6A shows that the borehole primarily encountered hard volcanic rocks (andesite, andesitic breccias, volcanic mudflows, and welded tuff) and volcaniclastic sediments of the Sonoma Volcanics from near the ground surface to the total 250-foot depth of the borehole. The andesite and andesitic breccia is present from approximately 12 to 100 feet and was found to be hard, dark gray, with orange hydrothermal deposits in fillings and surface coatings. The poorly graded medium- to coarse-grained volcaniclastic sands representing the target aquifer zone were encountered between about 100 and 215 feet below ground surface (bgs), with an interbedded sequence of sandy clay occurring between 160 and 170 feet bgs. The composition of the sands varied from mostly intermediate/mafic volcanic origin from 100 to 120 feet bgs to more felsic/intermediate (predominantly feldspars with a small percent of quartz) composition from 120 to 215 feet bgs. A red to dark gray welded volcanic tuff was encountered at 215 feet bgs and continued to the bottom of the borehole.

Samples of the volcaniclastic sands from 150 feet and 210 feet were collected from the borehole and analyzed for x-ray diffraction mineralogical analysis with Rietveld refinement, x-ray fluorescence analysis, acid insoluble residue analysis, cation exchange capacity analysis, thin section petrography, and scanning electron microscopy analysis to provide mineralogical and geochemical data to support the geochemical modeling described in Section 2.6.2. The mineralogical analysis indicate that the target aquifer zone is comprised of unconsolidated, medium to coarse grained, poorly sorted, glass-rich, volcanic litharenitic sands. The sands contain an abundance of rhyolitic tuff and scoria rock fragments coupled with rhyolite rock fragments, plagioclase feldspar crystals, obsidian rock fragments, and rare litharenitic sandstone and diorite rock fragment materials. A detailed description and results of the mineralogical and geochemical analysis is included in Appendix C.

The 'composite' log of City Well #6 shows the boring to have penetrated mostly "rock" with a small percentage of rough gravels between approximately 185 and 215 feet and a few thin layers of "loose volcanic matter" between approximately 90 and 145 feet. A 1999 video survey of City Well #6 (open hole) found some fractures between 140 and 165 feet bgs that may contribute water to the well. The differences in the logs of the nearby wells area is likely due to the different drilling methods, differences in interpretation of borehole cuttings (i.e., the City

Well #6 was logged by the well driller, while Test Well 6A was logged by a geologist), and the 60-foot distance between the locations.

Based on a comparison between the logs and completion details for the two wells, and on a review of well logs from other nearby City municipal wells, volcaniclastic sediments (identified as “rough gravel” and “loose volcanic matter” at the existing City Well #6) appear to be the target aquifer zone for the wells. As shown in cross-section A-A’, the target aquifer zone appears to locally be confined by the andesitic flow/flow breccia present between approximately 10 and 100 feet at the well site.

2.2.2 Target Aquifer Zone Hydraulic Characteristics

An aquifer test was performed at the adjacent City Well #6 in 2009 and the transmissivity was estimated to be 4,950 gallons per day per foot (gpd/ft). Aquifer testing performed in 2012 at the nearby Field of Dreams well (City Well #8), inferred to be perforated within the target aquifer zone, yielded a significantly higher estimate of transmissivity of 30,324 gpd/ft (GHD, 2014). This range of transmissivity estimates would yield a hydraulic conductivity range of 5.5 to 34 ft/d for the approximate 120-foot thick sequence of volcaniclastic sediments (target aquifer zone) observed at TW-6A, which is consistent with typical values for a clean fine sand, a silty sand, or fractured volcanic rock (Heath, 1983). While a storativity value of 0.01 was originally assumed by previous investigators for City Well #6, based solely on the depth of the screen (Winzler & Kelly, 2009), data from the subsequent aquifer test at the nearby Field of Dreams well (#8) that included analysis of data from nearby observation wells in addition to the pumping well, yielded an estimated storativity of 0.0007, which is consistent with confined aquifer conditions and considered more representative of the target aquifer zone. Aquifer properties will be further evaluated by conducting a 24-hour constant-rate test at TW-6A prior to initiating the pilot test.

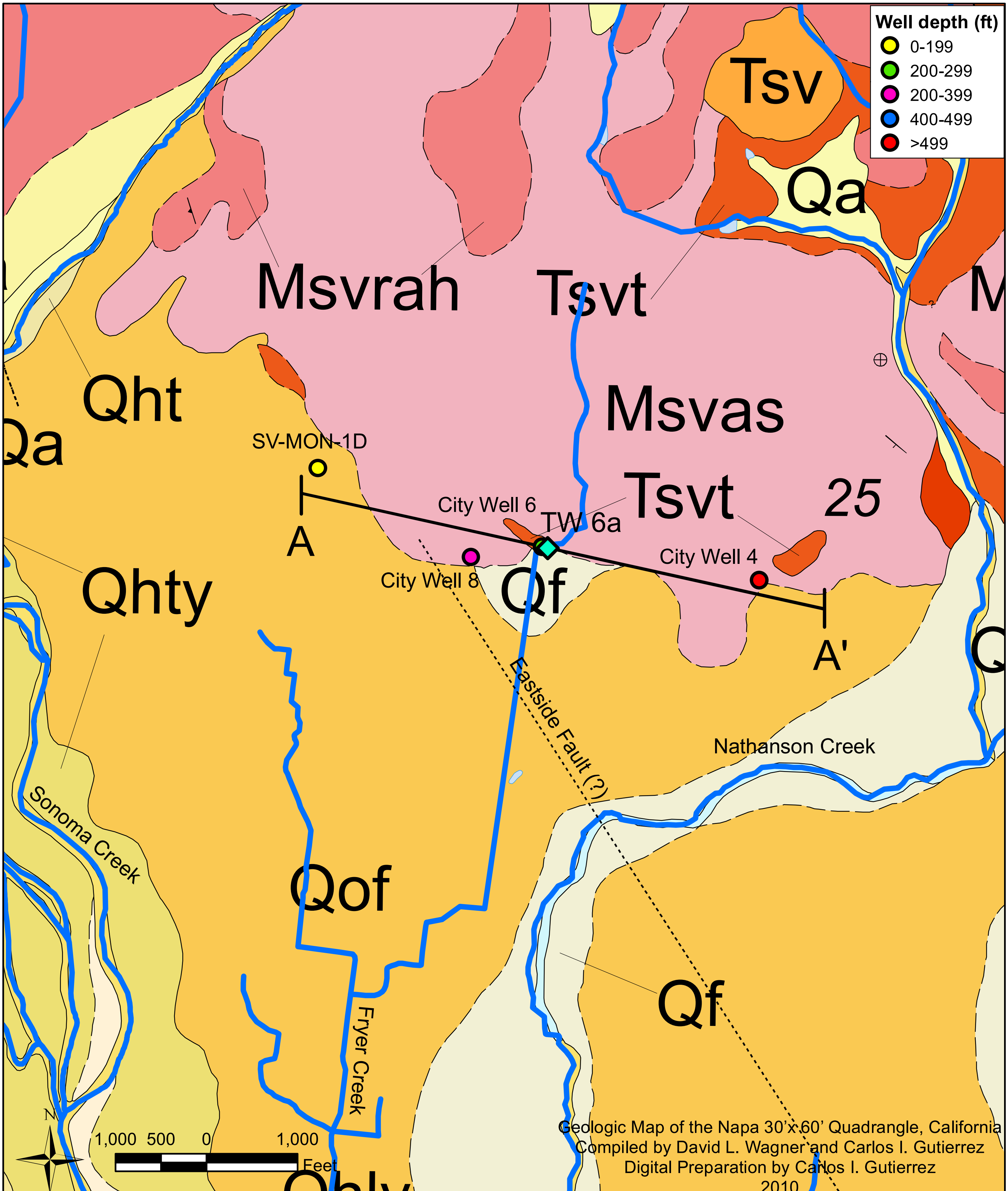


Figure 2. Geology and Cross Section Location Map

Sonoma Valley ASR Pilot Study
Sonoma County, CA

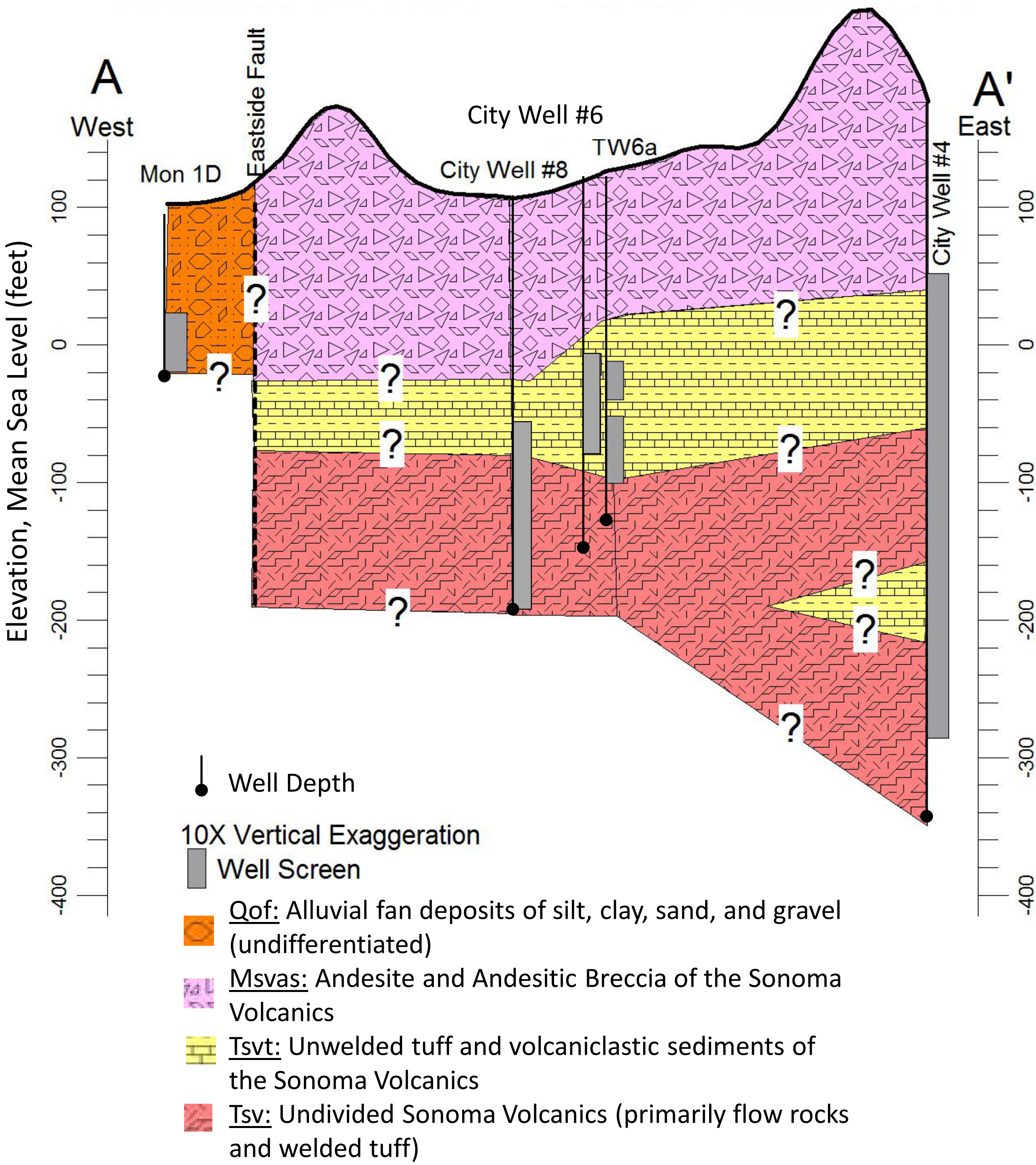


Figure 3. Generalized Geologic Cross Section A-A'

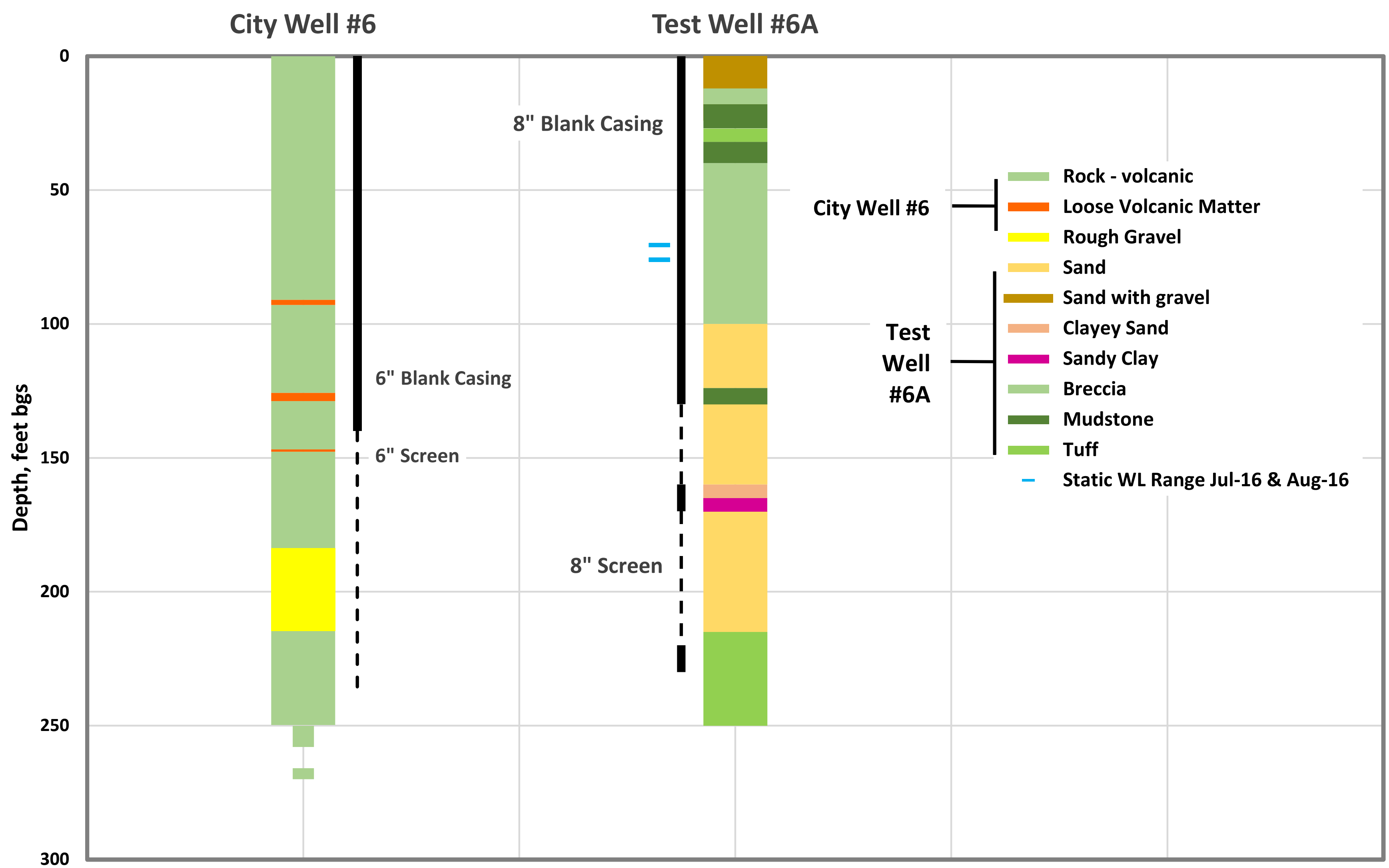
Provided by Sonoma County Water Agency

2.3 Well Construction Details

An as-built drawing of TW-6A is presented in Appendix C. The test well was drilled to 250 feet bgs using mud rotary drilling methods. The well was constructed with 8-inch, schedule 80, polyvinyl chloride (PVC) casing and 40-slot PVC screen from 130 to 160 feet bgs and from 170 to 230 feet bgs. An 8x16 filter sand was installed in the annular space around the 80-foot screen interval (total), from 119 to 250 feet bgs. A neat cement sanitary seal was installed from land surface to 109 feet bgs on top of a 10-foot thick bentonite transition seal.

City Well #6 will be used as a monitoring well during the pilot test and was reportedly drilled to a depth of 250 feet bgs (lithologic log, City of Sonoma), or possibly 270 feet, according to a record from the Department of Public Health. The well was constructed with a 10-inch diameter steel casing to a depth of 131 feet, based on a video survey of the well (Winzler & Kelly, 2010). The remaining portions of the well was found to be open hole, which indicates the drilling method was cable tool. The original sanitary seal was reportedly installed to a depth of 3 feet bgs (Winzler & Kelly, 2010). City Well #6 was rebuilt in 1999 with 6-inch, Class 200, PVC casing to a total well of 236 feet bgs. The PVC screen is reported to be 30-slot and extends from 140 to 236 feet bgs. The open hole was backfilled with pea gravel to 134 feet bgs – 3 feet from the bottom of the steel casing, and cement was installed in the annular space between the steel and PVC casings, from 134 feet bgs to the land surface (Winzler & Kelly, 2010).

The available construction details of TW-6A and City Well #6 are summarized in **Table 1** and illustrated by **Figure 4 – Comparison of Well Construction and Lithology**.



ASR Pilot Project Sonoma County, California	GEI Consultants	Illustration of Well Construction and Lithology
City of Sonoma and Sonoma County Water Agency		May 2017 — Figure 4

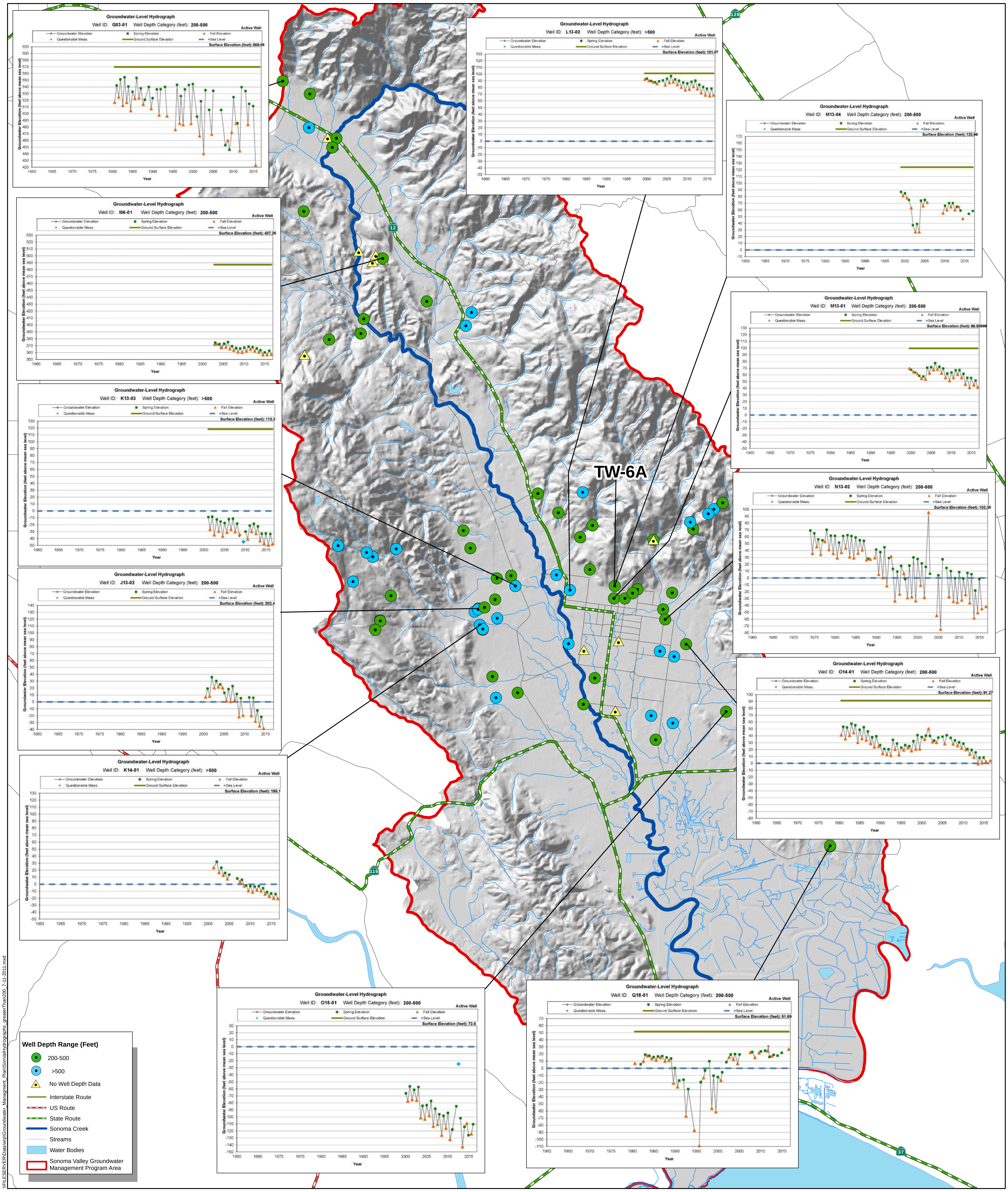
Table 1. Summary of Well Construction Information

Well Name	TW-6A	City Well #6 (Post-Lining Details)
Well Casing Elevation	123.8' msl	130' msl
Total Depth	230'	236'
Casing Diameter	8"	6"
Casing Material	PVC	PVC
Annular Seal Depth	109' cement 119' bentonite	3' around steel conductor 131-134' beneath conductor and within annulus
Screened Intervals	130-160' 170-220'	140-236'
Total Screen Length	80'	96'
Geologic Formation	Sonoma Volcanics	Sonoma Volcanics

2.4 Groundwater-Level Conditions

As described in the Sonoma Valley Groundwater Management Program Five Year Review Report (SCWA, 2014) and Sonoma Valley Groundwater Management Program 2016 Annual Report (SCWA, 2017), declining groundwater levels occur in many intermediate and deep aquifer system wells, with groundwater-levels in the El Verano Area and southeast of the City of Sonoma trending below sea level. Numerous well hydrographs shown on **Figure 5 – Selected Hydrographs** exhibit groundwater level declines ranging up to 80 feet over the last 30 years. In the vicinity of the City of Sonoma, many intermediate and deep aquifer system wells exhibit groundwater level declines, ranging from 20 to 30 feet over the past 15 years. Conversely, groundwater levels in shallow aquifer system wells are generally stable and predominantly remain above sea level.

At City Well #6, the static depth to groundwater was 64 feet bgs in May 2014 compared with static depths of approximately 15 feet in March 1977 and 38 feet in April 1999. In May 2011 (a wet year), depth to groundwater at City Well #6 was 54.8 feet bgs. The static depth of water at TW-6A has varied seasonally from approximately 61 to 78 feet bgs between June 2016 and November 2017 as shown on **Figure 6 –Hydrograph for TW-6A**. These groundwater levels were recorded from TW-6A at 15-minute intervals via a pressure transducer/data logger system.



Selected Hydrographs Intermediate/Deep Aquifer System

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Miles

N S E W

December 6, 2017

Figure 5

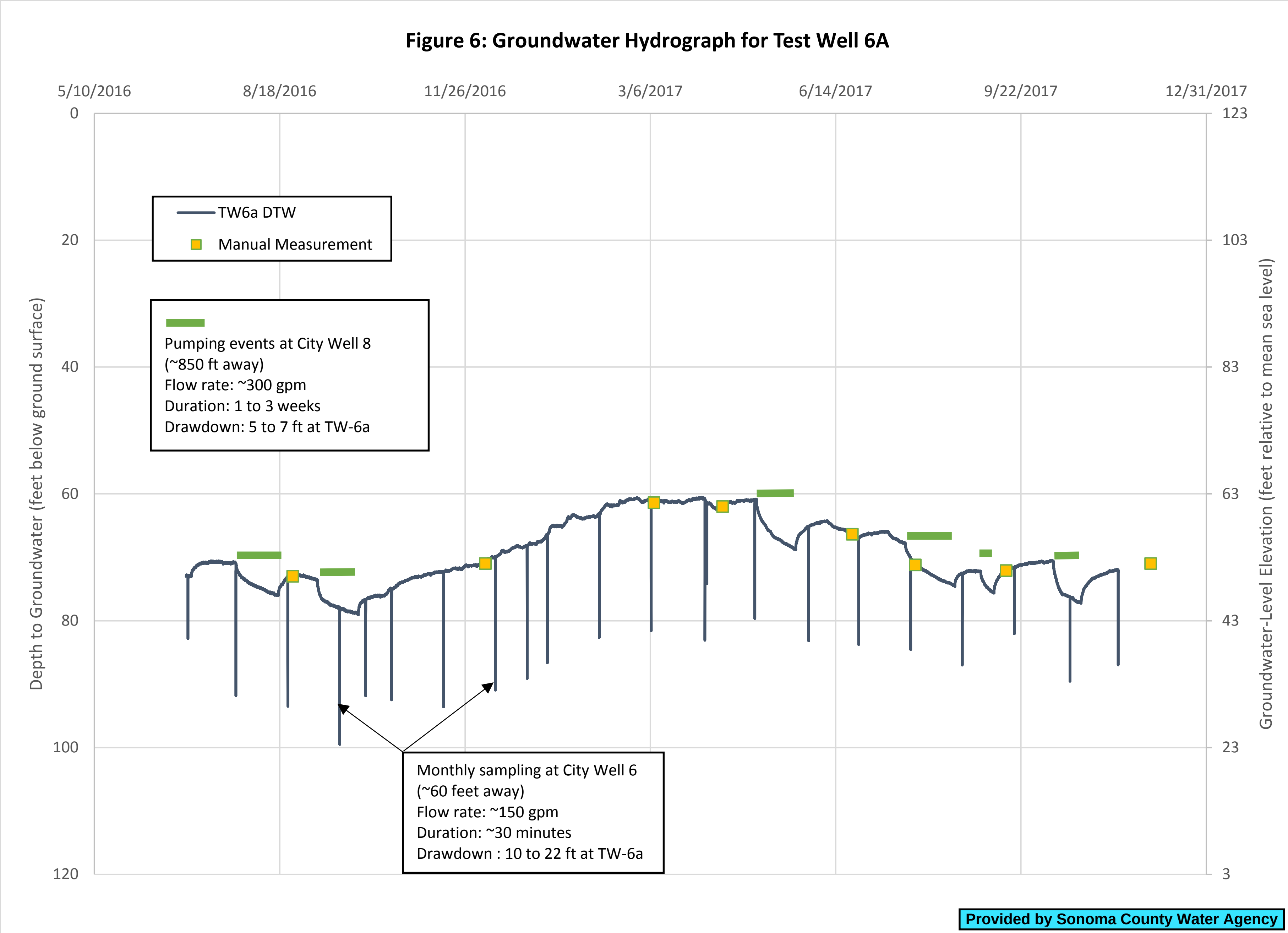


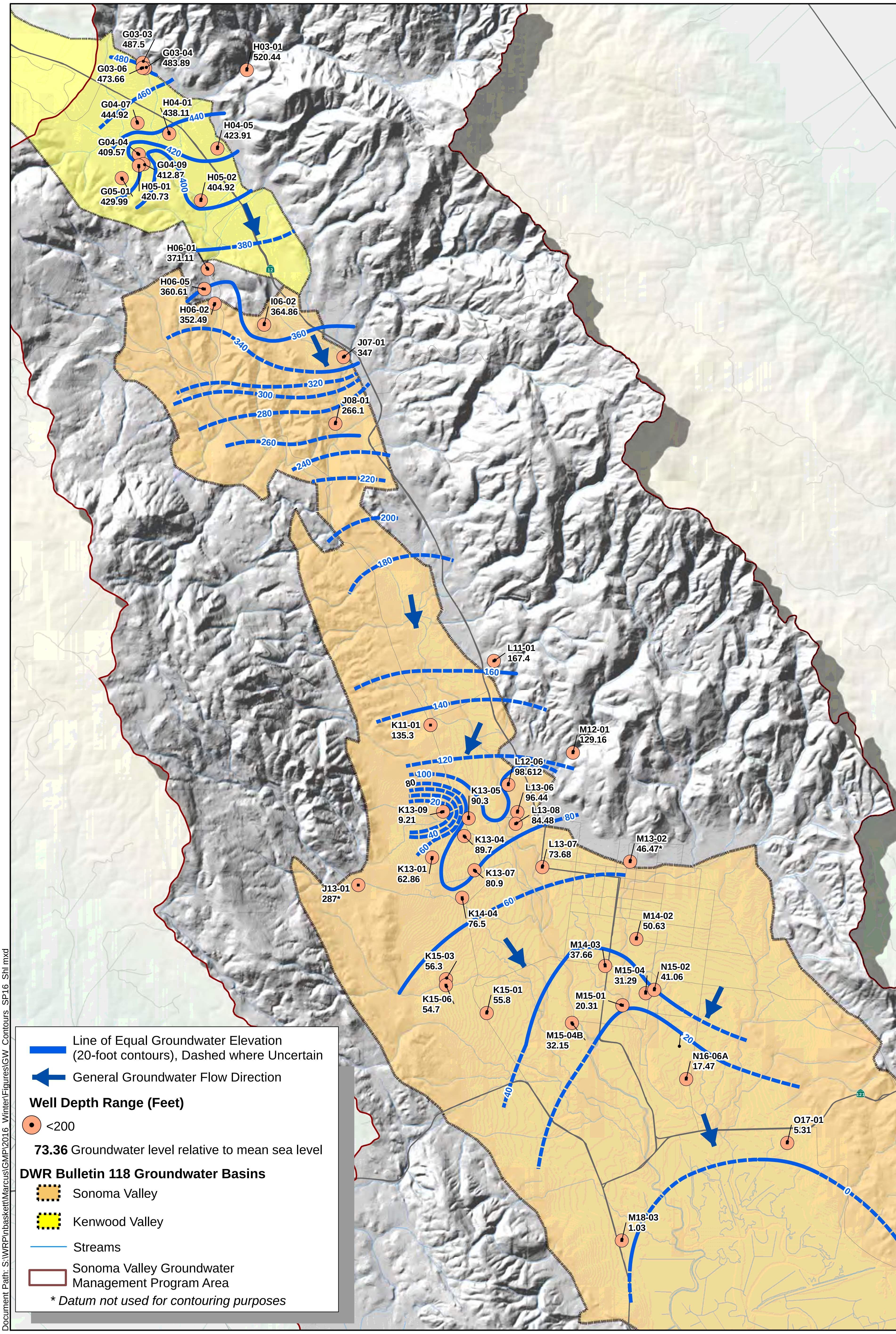
Figure 6: Groundwater Hydrograph for Test Well 6A
5/10/2016
8/18/2016
11/26/2016
3/6/2017
6/14/2017
9/22/2017
12/31/2017
0
20
40
60
80
100
120
123
103
83
63
43
23
3
Depth to Groundwater (feet below ground surface)
Groundwater-Level Elevation (feet relative to mean sea level)
TW6a DTW
Manual Measurement
Pumping events at City Well 8
(~850 ft away)
Flow rate: ~300 gpm
Duration: 1 to 3 weeks
Drawdown: 5 to 7 ft at TW-6a
Monthly sampling at City Well 6
(~60 feet away)
Flow rate: ~150 gpm
Duration: ~30 minutes
Drawdown : 10 to 22 ft at TW-6a
Provided by Sonoma County Water Agency

The following groundwater-level drawdown responses are observed in the hydrograph for TW-6A due to periodic pumping events at the adjacent City Well #6 and nearby City Well #8:

- Short-term drawdown ranging from approximately 10 to 22 feet is observed on a monthly basis due to short duration pumping of the City Well #6 (located approximately 60 feet from the test well) during water quality sampling events.
- Drawdown ranging from approximately 5.0 to 6.5 feet is observed for longer periods of time (three to four weeks in duration) during production pumping of City Well #8 at approximately 300 gpm (located approximately 850 feet to the west of the test well).

Contours of Spring 2016 groundwater elevations are shown on respective **Figures 7 and 8 – Groundwater Elevation Contours** for the shallow and intermediate/deep aquifer systems primarily within the alluvial/sedimentary portions of the basin. City Well #6 is shown as M13-04. The shallow zone contours show that groundwater flowed in a south to south-southeasterly direction. The intermediate/deep aquifer system contours show a pumping depression is located on the southeast side of the City. As shown on Figure 8, the contour map shows a relatively steep gradient in the vicinity of the project area with groundwater flowing to the south to southeast toward the groundwater pumping depression. The degree to which the Eastside Fault forms a barrier to horizontal groundwater movement west of the project area is uncertain based on available data.

A comparison of shallow and intermediate/deep aquifer system groundwater elevations south of the project area indicates that shallow groundwater elevations are 10 to 20 feet higher than intermediate/deep groundwater elevations, indicating a downward vertical hydraulic gradient in that area.



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Sonoma Valley
Groundwater Management Program

Generalized Groundwater Level Contour Map
Shallow Aquifer System
Spring 2016

January 09, 2017

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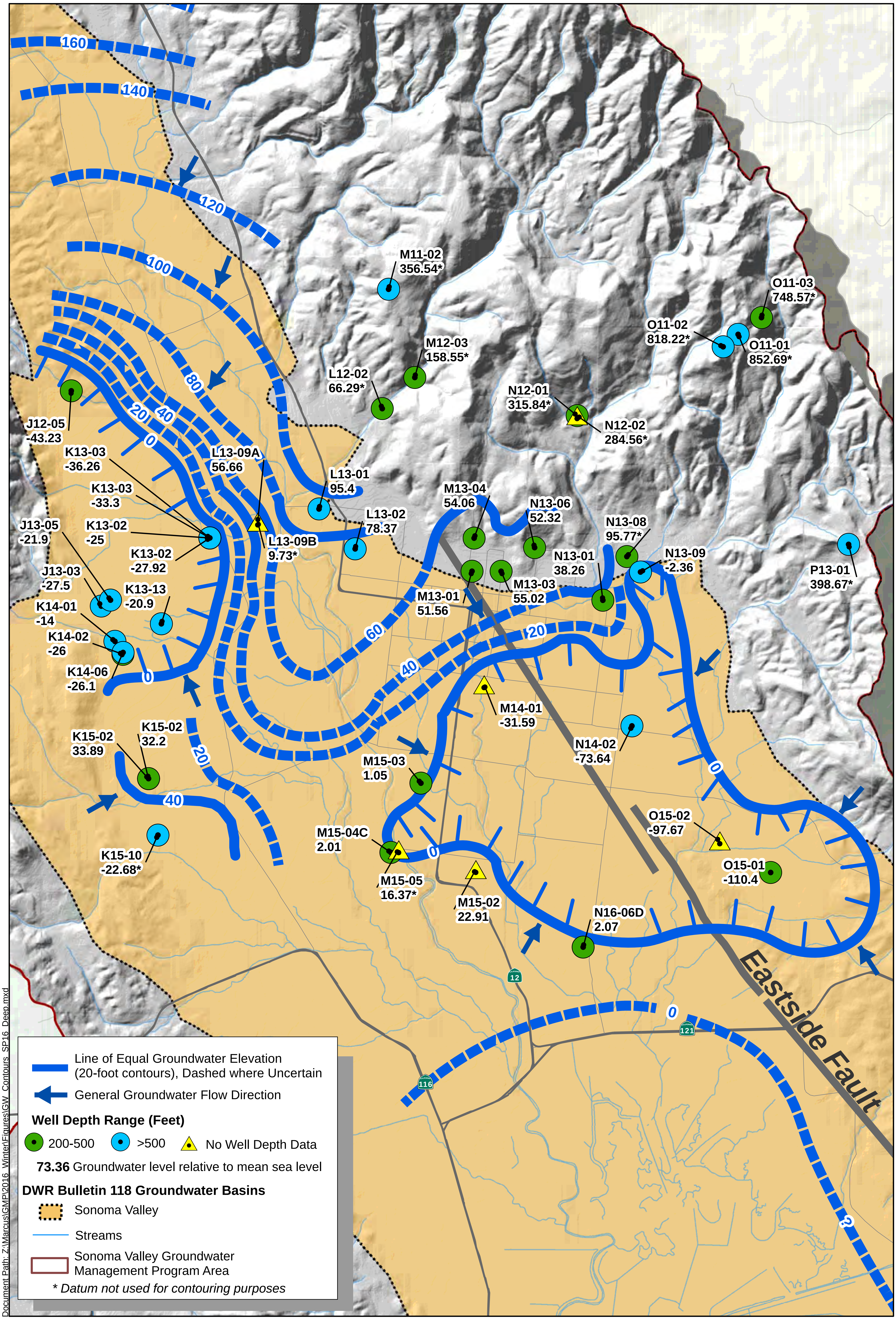
N S W E

Figure 7



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Sonoma Valley
Groundwater Management Program
Generalized Groundwater Level Contour Map
Intermediate/Deep Aquifer System
Spring 2016

December 22, 2016

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Figure 8

2.5 Recharge Capacity and Area of Hydrologic Influence

2.5.1 Recharge Capacity Assessment

A detailed assessment of physical and hydraulic constraints associated with recharge at City Well #6 (as well as other candidate pilot ASR wells) was performed in June 2014 to determine the operational criteria for a pilot demonstration program. Details of the analysis are documented in the Technical Memorandum contained in **Appendix B**. As discussed, the recharge capacity of any given ASR well is dependent on a variety of site-specific factors, which can be generally categorized into issues associated with; 1) well response to recharge, and 2) aquifer response to recharge. Examples of well response issues include allowable "draw-up" within the well casing before some head limitation is reached (e.g., water level reaching ground surface), and the available drawdown for well backflushing. Aquifer response issues include the available "freeboard" in the aquifer for water levels (piezometric head) to be increased without inducing problematic results (e.g., water "daylighting" at the ground surface). To the extent possible, ASR wells should be operated to maximize recharge and production rates while operating within the constraints of these site-specific factors. The results of the recharge capacity constraints analysis for City Well #6 are summarized in **Table 2**.

Table 2. Recharge Capacity Constraints Summary

Well	Recharge Capacity (gpm) vs. Constraint					
	Well Response (gpm)				Aquifer Response	
	Min.	Max.	Backflushing Capacity (gpm)	Downhole Velocity (gpm)	Hydro-Fracturing (gpm)	Offsite Impacts (gpm)
City Well #6	120	251	93	**88**	100	670

Notes:
Primary limiting factor shown in **bold** type.

Well response analysis indicated that a recharge rate of 120 gpm would create draw-up within the well casing that would raise water levels to ground surface after 183 days of continuous recharge. The well's internal diameter is another limiting factor on recharge capacity. Downhole velocities should not exceed the rate at which average size air bubbles rise (1ft/sec) and this resulted in a flow limit of 88 gpm, so a recharge rate of 90 gpm was originally recommended for City Well #6. This analysis indicated that adverse aquifer responses, such as hydro-fracturing of the aquifer by over pressuring the formation during recharge or raising water levels to the ground surface (offsite impacts), are not limiting factors since these responses would result from higher flows than the downhole velocity constraint. This recommended recharge rate is also applied as an assumption in evaluating the area of hydrologic influence for the proposed pilot test using TW-6A as the recharge/recovery well. The recharge rate will be further evaluated during the planned additional well development and aquifer testing described below in Section 3.2 and any potential changes to the recharge rate will be provided to the California Regional Water Quality Control Board, San Francisco Bay Region, (RWQCB) prior to initiating the pilot test.

2.5.2 Evaluation of the Area of Hydrologic Influence

The ASR General Order requires the identification of the area of hydrologic influence for the pilot test, along with identification of land uses (including known water-supply wells) and potential contaminating activities within the area.

Calculation of Area of Hydrologic Influence. For the proposed pilot test, three full cycles of recharge, storage, and recovery are proposed after one pre-test with less than 1 day of recharge. ASR Cycle 1 will include a 5- to 7-day recharge cycle while ASR Cycles 2 and 3 will each target 21-day recharge cycles, each with subsequent storage and recovery phases. Applying a proposed recharge rate of 90 gpm for each of these cycles would result in a total recharge volume of approximately 20 acre-feet for the pilot test.

To develop information required by the ASR General Order and to assist in identifying potential impacts, the area surrounding TW-6A likely to be influenced during pilot testing activities was estimated by the following two methods. The ASR General Order defines the area of hydrologic influence as:

> *"The area of the aquifer which is affected chemically or physically by the ASR project (the storage zone plus any additional area affect by the ASR project)"*

Given this definition, the two basic elements of the area of hydrologic influence include 1) the area affected hydraulically by recharge operations (i.e., groundwater-level draw-up) on the aquifer system (area of hydraulic effect) and 2) the area physically underlain by recharged water (area of water quality mixing).

For the proposed pilot test program, the maximum hydraulic effect will occur at the end of the 21-day recharge tests (ASR Cycles 2 and 3). This area of hydraulic effect or radius of influence was estimated from the Theis Non-Equilibrium Equation (Lohman, 1972; Heath, 1983) and the following assumptions:

- Transmissivity (T) = range of 4,950 to 30,324 gallons per day per foot (gpd/ft)
- Storativity (S) = 0.0007 (dimensionless)
- Time (t) = 21 days
- Recharge Rate (Q) = 90 gpm

The Theis-predicted theoretical draw up vs. distance is presented graphically on **Figure 9 – Theis-Predicted Draw up vs. Distance**. As shown, the estimated water-level draw-up within the aquifer at the well could vary from approximately 41 to 6 feet at the well (casing radius of 0.33 feet), depending upon the transmissivity. At the nearest well (City Well #8), water-level draw-up could range from approximately 1 to 8 feet depending upon the transmissivity. Water-level draw-up is estimated to be less than 5 feet at a distance of 2,000 feet from TW-6A based on the lowest and more conservative estimate of transmissivity. Given static water levels in the aquifer of approximately 60 feet bgs, water levels within the aquifer system are anticipated to remain approximately 20 feet or more below the ground surface immediately adjacent to TW-6A.

The area physically underlain by the recharged water (area of water quality mixing) was estimated utilizing the Calculated Fixed Radius equation[1] and the following assumptions:

- Recharge Volume after 21 days (V) = 2.7 million gallons (8.3 acre-feet)
- Effective Porosity (n) = 15 to 30 percent
- Aquifer Thickness (b) = 120 feet

Based on the above assumptions, the radius of recharged water from the TW-6A could vary between 80 and 57 feet, respective of the estimated porosity range, at the end of the 21-day recharge test, excluding any flow gradient effects. To account for potential flow gradient effects, the distance that the recharged water could migrate during the longest planned storage phase of 30 days for the pilot test is approximately 30 feet south-southeast (downgradient), assuming a flow velocity of 1 foot per day. This calculation incorporates conservative assumptions based on the higher hydraulic conductivity (K) estimate (34 feet per day), the gradient (i) value (23 feet per mile) for Spring 2016 deep zone, and the lower porosity (n) estimate (15%). Lower hydraulic conductivity and gradient values and higher porosity values would produce a slower velocity and reduce the potential migration distance. The predicted area physically underlain by recharged water (area of water quality mixing), including the estimated extent of migration during the longest planned storage phase is delineated on **Figure 10 – Predicted Area Underlain by Recharged Water**.

Land uses within the Area of Hydrologic Influence. The two basic elements of the area of hydrologic influence (described above) were both evaluated with respect to potential impacts to land uses. The area underlain by the recharged water (area of water quality mixing) is predicted to be very limited (within approximately 110 feet of the test well) and the land uses consist of the City-owned municipal well facility and parking areas for community buildings and hiking trails. The only well within the area of water quality mixing is City Well #6, which will be used as a monitoring well during the pilot test. Other private agricultural, industrial, or domestic water supply wells are not located within the predicted area of water quality mixing (the closest reported location for a private water well is approximately 1,000 feet downgradient of the test well).

Land uses within the more expansive area of hydraulic effect (i.e., area expected to experience groundwater level fluctuations) consist of open space, cemetery, recreational sports, commercial and residential. The pilot test would not, however, have any foreseeable negative impact on the land uses within the area of hydraulic effect, as offsite groundwater levels are predicted to be more than 20 feet below ground surface during the entire test program. An inventory of known water wells located within and near the area of hydraulic effect is shown in **Figure 11** and presented in **Appendix D**. As shown in Figure 11, eight potential water wells are located within 2,000 feet of the project, where water-level draw-up is predicted to exceed approximately 5 feet using the more conservative (i.e., lower) estimate of transmissivity. These locations include five of the City's other municipal supply wells (Wells #1, #2, #3, #6 and #8), plus three private

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[1] For purposes of these short duration pilot tests, the relatively simple Calculated Fixed Radius equation is considered appropriate. For any full-scale permanent project, the calibrated USGS MODFLOW groundwater model of the basin would likely be used to delineate the area(s) of hydrologic influence.

domestic wells. The status of the private wells is unknown at this time, however, prior to initiating the pilot test the Water Agency and City will initiate an outreach dialogue with these potential private well owners to inform them of the ASR pilot study and determine whether a well actually exists and document the well status. It is likely that all of these wells have historically experienced fluctuations related to the City's municipal wellfield. Therefore, negative impacts to any private well owners within the area of hydraulic effect are not anticipated because the private well owners are likely to experience positive effects during the pilot test, as water levels will rise during the recharge cycles. Moreover, overall drawdown will likely be less than normally experienced since the nearby City wells will not be operated during the pilot test period.

Assessment of Potential Contaminating Activities. Potential contaminating activities (PCAs) within the area of hydrologic influence were assessed by reviewing the SWRCB's GeoTracker website and nearby land uses. The nearest active contaminant site (identified by GeoTracker) is located approximately 3,000 feet to the south of TW-6A (Royal Crown Cleaners at 568 Broadway), and, based on land use, the nearest PCAs are cemeteries (Mountain and Veterans Cemeteries) located immediately to the north and east (cross- and up-gradient) of the site. Groundwater levels at TW-6A are anticipated to be maintained approximately 20 feet (or more) below ground surface and are not projected to raise more than three feet within the confined target aquifer zone at a distance of 3,000 feet. As shown on Figure 3**,** the target aquifer zone is overlain by low permeability volcanic flows which confine or partially confine water within the target aquifer zone. Additionally, groundwater-level fluctuations during the pilot study would be less than those experienced during routine operation of the City's wellfield. As such, the ASR pilot test will not likely cause groundwater to come in contact with contaminated soil or otherwise affect PCAs in the area.

2.6 Water Quality Assessment

The ASR General Order requires that the recharge water complies with both primary and secondary maximum contaminant levels (MCLs), plus the identification of constituents of concern and the demonstration that proposed ASR operations will not cause groundwater to exceed any of the following for the identified constituents of concern:

- Primary or secondary MCLs
- Numeric water quality objectives in the Basin Plan for beneficial uses within the project's area of hydrologic influence
- Any Basin Plan water quality objective for the beneficial uses of groundwater.

To address these requirements, this section presents a comparison of the Water Agency's recharge water quality and native groundwater from TW-6A and City Well #6, a description of geochemical modeling completed to facilitate design of the pilot test, and a groundwater degradation assessment.

2.6.1 Source Water and Groundwater Quality Comparison

Table 3 presents a comparison of the Water Agency's recharge water quality and native groundwater from TW-6A and City Well #6. The recharge water sample was collected from the Water Agency's transmission system near the City of Sonoma turnouts during February 2011 while the City Well #6 native groundwater sample was collected during March 2014 during a performance and ASR screening test. TW-6A was sampled during June 2016, shortly after constructing the well. The samples were analyzed for various constituents, as shown by Table 2 which also compares the analytical results to applicable drinking water standards: Primary and Secondary Maximum Contaminant Levels (MCLs). As shown in **Table 3,** the Russian River recharge water and native groundwater (City Well #6 and TW-6A) meet all State and Federal MCLs.

The quality of the Russian River water exhibits some favorable characteristic in comparison to native groundwater in the Sonoma Volcanics, including a somewhat lower concentration of total dissolved solids (TDS) and the absence (not-detected) of aluminum, arsenic, iron, and manganese. In general, City Well #6 and TW-6A produced a sodium-potassium bicarbonate groundwater while the Russian River water has a mixed-cation bicarbonate character. Calcium and magnesium concentrations are slightly higher in the river water which increases the hardness value and associated alkalinity. Russian River water also exhibits a slightly higher pH and barium, boron and sulfate concentrations. As further described in Section 2.6.3, below, low levels of disinfection byproducts are also present in the Russian River water and are absent in the native groundwater.

For the above-described constituents present in Russian River water but not present in the native groundwater (or present at slightly higher concentrations), the concentrations of those constituents are well below any State or Federal MCLs (where established).

Table 3. Recharge Water and Groundwater Quality Summary

Analytical Constituent	Units	Proposed Recharge Water	Native Groundwater		Maximum Contaminat Level	
		SCWA Treated Surface Water Sample Date 02 / 2011	Pilot Test Well #6A Sample Date 06-16-16	City of Sonoma Well #6 Sample Date 05-07-14	CDPH	USEPA
Primary Standards						
Aluminum	ug/L	ND	22	<50	2,000 [1]	1,000
Arsenic	ug/L	ND	7.8	8.2	10	10
Barium	ug/L	92	6	<100	1,000	1,000
Chromium (Total)	ug/L	0.69	<1	<10	50	100
Copper	ug/L	ND	<1	<10	1,300	1,000 (AL)
Flouride	mg/L	ND	0.5	0.5	2	2
Lead	ug/L	ND	<0.5	<5	15	15 (AL)
Mercury	ug/L	ND	<0.2	<1	2	2
Nickel	ug/L	ND	<5	<10	100	100
Nitrate (as NO_3)	mg/L	1.9	1.6	1.9	45	45
Nitrite (as N)	mgL	0.43	<0.05	0.44	10	10
Selenium	ug/L	ND	<5	ND	50	50
Secondary Standards						
Alkalinity ($CaCO_3$)	mg/L	158	NA	86	NS	NS
Boron	mg/L	0.19	0.17	0.12	NS	NS
Bromine	mg/L	ND	NA	<50	NS	NS
Calcium	mg/L	24	10	11	NS	NS
Chloride	mg/L	6.5	6.4	6.9	500 (upper limit)	500 (upper limit)
Iron	ug/L	ND	<20	<100	300	300
Manganese	ug/L	ND	2	<10	50	50
Magnesium	mg/L	16	6.2	6.4	NS	NS
Potassium	mg/L	1.0	3.4	3.3	NS	NS
Sodium	mg/L	22	24	24	NS	NS
Sulfate	mg/L	17	5	3.9	500 (upper limit)	500 (upper limit)
Total Dissolved Solids (TDS)	mg/L	164	210	173	1,000 (upper limit)	1,000 (upper limit)
Conductivity	umhos/cm	323	200	171	1,600 (upper limit)	1,600 (upper limit)
pH unit	pH units	8.2	7.0	7.1	6.5 - 8.5	6.5 - 8.5
Disinfection Byproducts (DBP's)						
Total Trihalomethane (THM's)	ug/L	16	<0.5	N/A	80	80
Total Haloacetic Acids (HAA's)	ug/L	3.3	<2	N/A	60	60

Notes:
N/A = No analysis / Not available
ND = Non-detect
NS = No standard
[1] = Secondary MCL

2.6.2 Geochemical Assessment and Modeling

The pilot test program will monitor the potential for undesirable geochemical impacts from the interaction of Russian River recharge water with native groundwater and/or the aquifer minerals of the Sonoma Volcanics. Such impacts could include the leaching of undesirable minerals from the aquifer matrix or the creation of gasses or precipitates in the aquifer or well screen.

Quantitative geochemical modeling was performed for the proposed pilot program to evaluate the potential for adverse water quality interactions as described above (Pueblo, 2014b and

Pueblo, 2016). The modeling included evaluation of both the Water Agency's recharge water (Russian River) and the native groundwater at Sonoma Well #6 and at TW-6A. The modeling was performed individually with respect to the two waters' aqueous stability, and then further modeling was performed on the mixing of the two waters in 25:75, 50:50, and 75:25 ratios to assess the potential for adverse reactions. The results of the modeling indicated that significant adverse reactions are not likely under the proposed test conditions. The geochemical evaluation and modeling results are included as **Appendix A – Technical Memoranda: Geochemical Interaction Assessment for Recharge of SCWA Waters into City Well #6 and Test Well 6A**. The assessment of TW-6A indicates a slightly higher potential, in comparison to City Well 6, for precipitation of ferric oxide and fluorapatite but less potential for precipitation of amorphous silica. Additionally, the modeling indicated that substantial leaching reactions of undesirable minerals are unlikely due to: (1) the adequate pH buffering capacity in the target aquifer zone mineralogy; and (2) the relatively oxidized nature of the native groundwater and strongly oxidized nature of the recharge water, which makes the onset of reducing conditions unlikely.

2.6.3 Groundwater Degradation Assessment

The ASR General Order requires the completion of a Groundwater Degradation Assessment, which includes a list of constituents of concern, basin plan water quality objectives, identification of water resources that may be affected, and forecasted extent of degradation.

Constituents of Concern. The ASR General Order addresses specific Constituents of Concern (COCs) for all ASR projects (Findings 24 through 28 of the ASR General Order). Additional COCs include any Basin Plan water quality objectives that may be affected by recharge. **Table 4** below lists the applicable COCs for the proposed ASR pilot test. As shown in Table 4, the Russian River recharge water meets the MCLs and basin objectives for all COCs.

The only COCs present in the Russian River recharge water that were not present (or present at higher concentrations than the native groundwater) were chlorine and disinfection byproducts (DBPs). Chlorine is present as a CA Division of Drinking Water (DDW) requirement for disinfection of drinking water, and DBPs are a reaction byproduct of chlorine and organic matter in Russian River water (DBPs include THM and HAA[2] compounds). It is important to note, however, that the concentrations of all constituents in the Russian River water are well below the DDW MCLs for drinking water. Although the presence of the three disinfection compounds noted above may constitute a condition of "degradation" under RWQCB policy, they do not impair any beneficial uses of the basin.

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[2] Trihalomethane and Haloacetic acid

Table 4. Constituents of Concern

Constituent of Concern	Source of Concern	Russian River WQ Value	MCL / Basin Plan Water Quality Objective	Average Difference (WQ/MCL)-1 (%)
Cl_2 Residual	Findings 24 - 25	1.5 mg/L	4.0 mg/L / NA	-63% / NA
TTHMs	Findings 25 - 26	16 ug/L	80 ug/L / 100 ug/L	-80% / -84%
HAA 5	Findings 25 - 26	4 ug/L	60 ug/L / NA	-93% / NA
Arsenic	Finding 28	ND ug/L	10 ug/L /50 ug/L	NA / NA
Iron	Finding 28	ND ug/L	300 ug/L / 300 ug/L	NA / NA
Manganese	Finding 28	ND ug/L	300 ug/L / 50 ug/L	NA / NA
Nitrate as NO_3	Finding 28	1.8 mg/L	45 mg/L / 45 mg/L	-96% / -96%
Selenium	Finding 28	ND ug/L	50 ug/L / 50 ug/L	NA / NA
Sulfur	Finding 28	NA	NA / NA	NA / NA

Notes:
Cl_2 – Chlorine (disinfectant).
TTHMs – Total Trihalomethanes.
HAA 5 – Haloacetic Acids.
ND – Not Detected.
NA – Not Applicable.

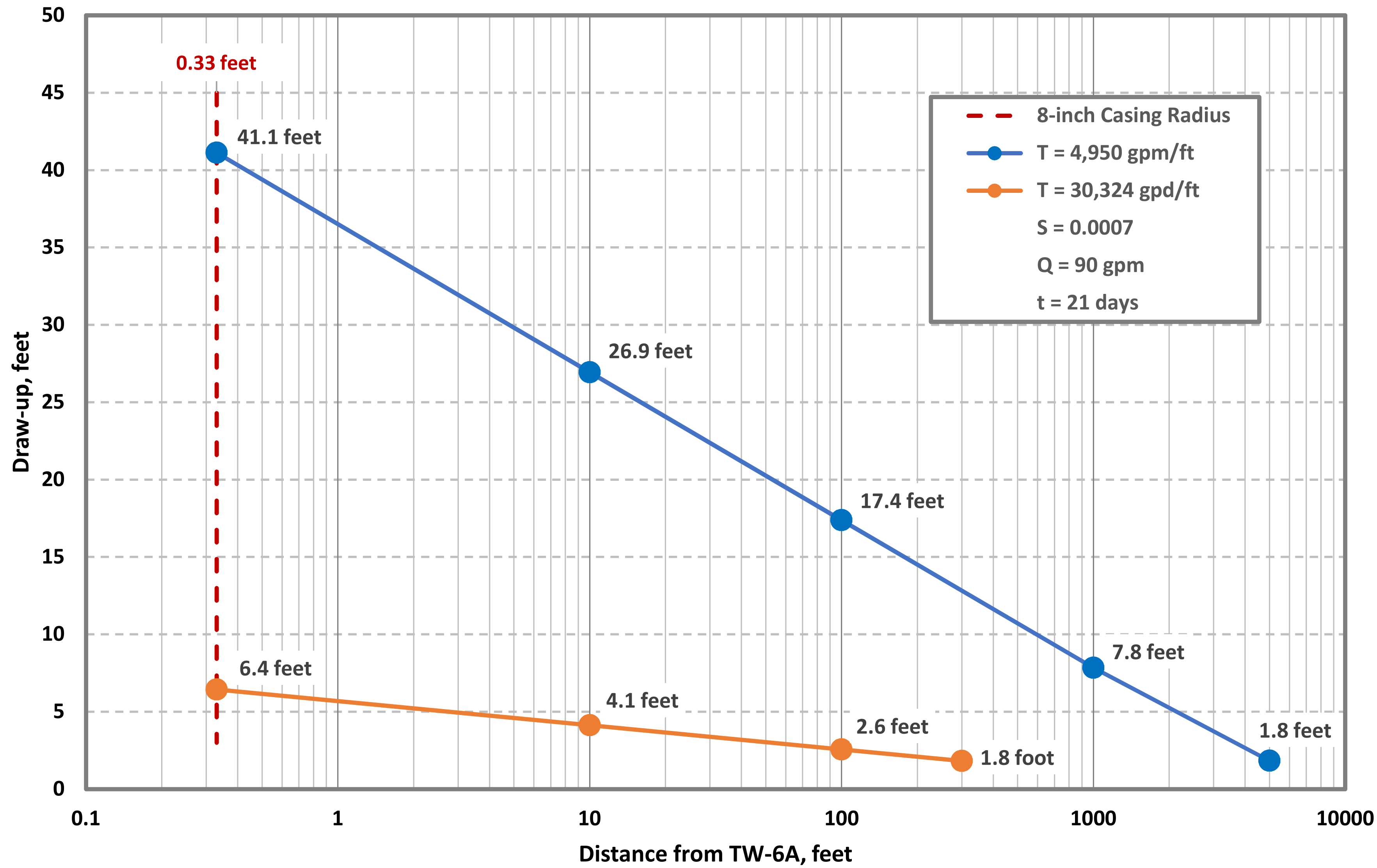
Water Resources That May Be Affected by Recharge and Extent of Degradation

As described in Section 2.5.2, the estimated area underlain by water quality mixing within the target aquifer zone is not predicted to affect any existing private or public water supply wells other than City Well #6, which is being monitored during the pilot test. In the remote possibility that the next nearest well (City Well #8, which is located 850 feet east – cross-gradient) were to capture any of the recharge water, the presence of any trace amounts of DBPs and other constituents would not adversely affect the Agricultural, Municipal, Industrial, or Process Beneficial Uses of the groundwater, in accordance with Finding 32 of the Order.

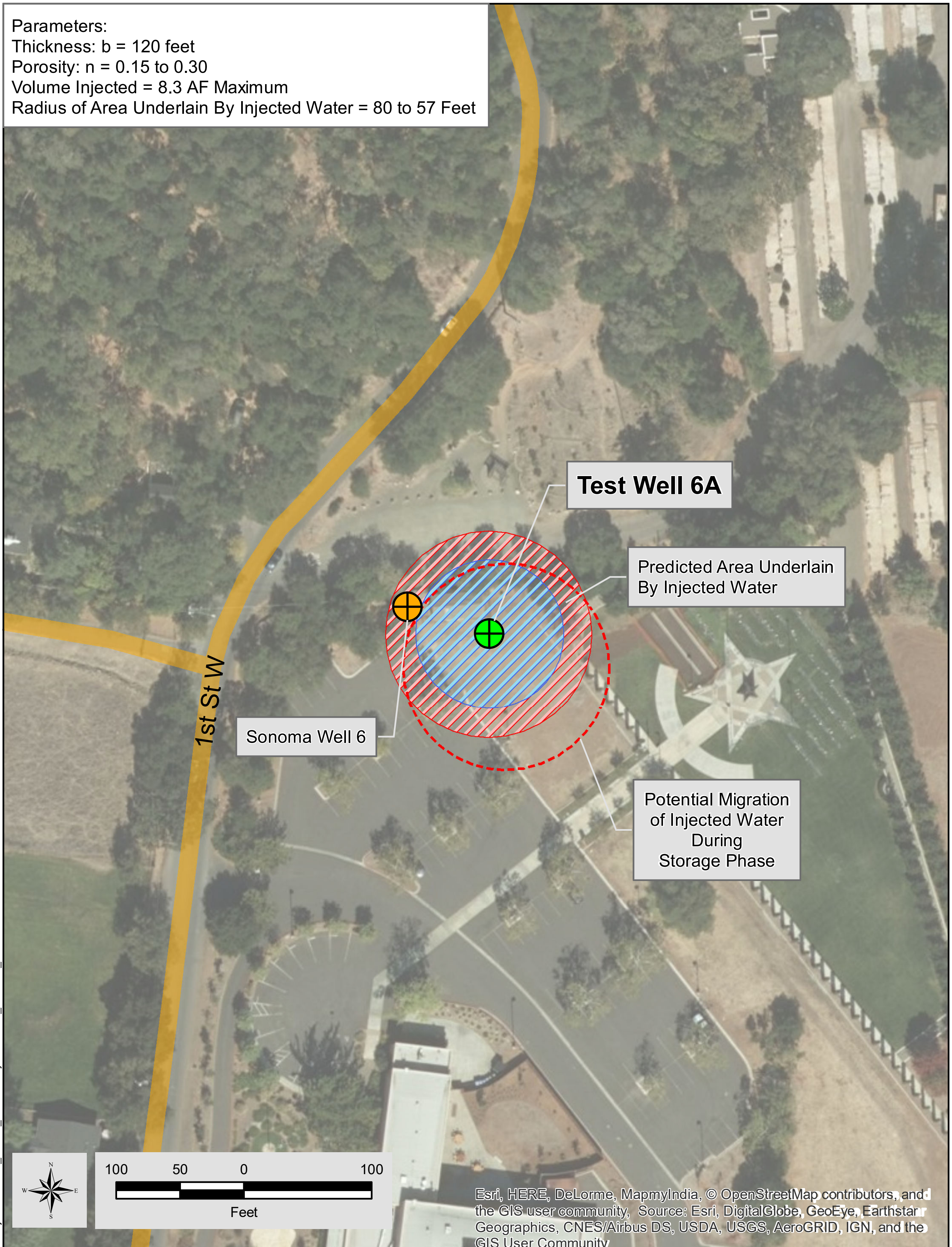
Sonoma Creek is the nearest perennial surface water feature and is located more than a mile away to the west-southwest. An ephemeral drainage ditch is located immediately north of City Well #6 and flows into the City's underground storm water drainage system. This drainage system discharges into Fryer Creek over 4,800 feet south-southwest of TW-6A, near the intersection of Bennecourt Street and Second Street West. Based on the predicted groundwater draw-up, relatively low volumes of water to be recharged during the pilot test (approximately 20 AF total volume), the depth of the target aquifer storage zone (100 to 220 feet below ground surface), and the presence of the confining volcanic rock that inhibits the potential for upward migration into any surface water bodies (as shown in Figure 3), the potential to adversely affect any other water resources beyond the target aquifer storage zone is considered highly unlikely.

During recovery phases of the pilot test, recovered water will be discharged to the drainage ditch under the City of Sonoma's existing permit with the National Pollutant Discharge Elimination System (NPDES). Any potential impacts to surface water during the recovery phase will be avoided by complying with discharge requirements for the NPDES permit, as further described in Section 3 of this report.

Degradation of the water resources is not expected in the localized area of the target aquifer zone due to the ASR pilot test.



ASR Pilot Project Sonoma County, California	GEI Consultants	Theis-Predicted Draw-up versus Distance
City of Sonoma and Sonoma County Water Agency		September 2017 Figure 9



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ASR Pilot Project Sonoma County, California	GEI Consultants	Test Well 6A Predicted Area Underlain by Injected Water
Sonoma County Water Agency		DECEMBER 2017 FIGURE 10

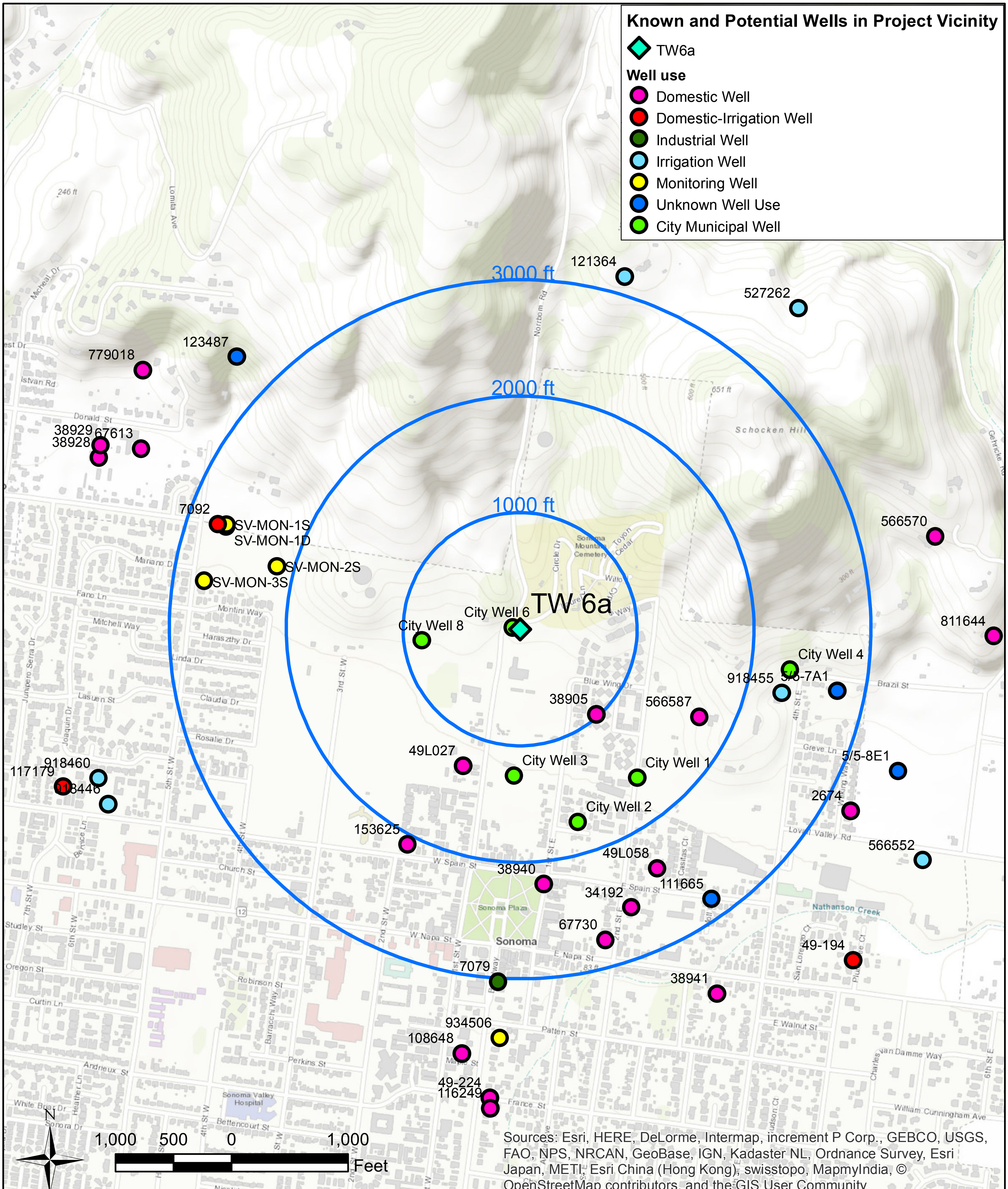


Figure 11. Test Well 6a with Known and Potential Wells in Project Vicinity

Sonoma Valley, ASR Pilot Study

December 2017

Provided by Sonoma County Water Agency

3 Proposed Pilot Test

This section describes the proposed scope of work for the ASR Pilot Test, which includes:

- Permitting
- Site Preparation
- Pilot Test Performance and Schedule
- Monitoring and Reporting

3.1 Permitting

3.1.1 Regional Water Quality Control Board

Prior to initiating the ASR Pilot Test, the San Francisco Bay RWQCB will need to issue a Notice of Applicability to include the ASR pilot test under the ASR General Order, based on the information provided in this Technical Report and NOI.

3.1.2 CEQA Compliance

The ASR General Order requires a project-level analysis of potentially significant environmental impacts prior to issuance of a NOA. The General Order allows that a pilot test may be exempt from provisions of 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. On September 13, 2017, the Water Agency's General Manager filed a Notice of Exemption for the pilot study, which is included as **Appendix E**.

3.1.3 State Water Resources Control Board

Prior to performing the pilot test, documentation that TW-6A has been registered with the US EPA Underground Injection Control Program will be provided to the SWRCB via the on-line Injection Well Inventory Form.

3.2 Site Preparation

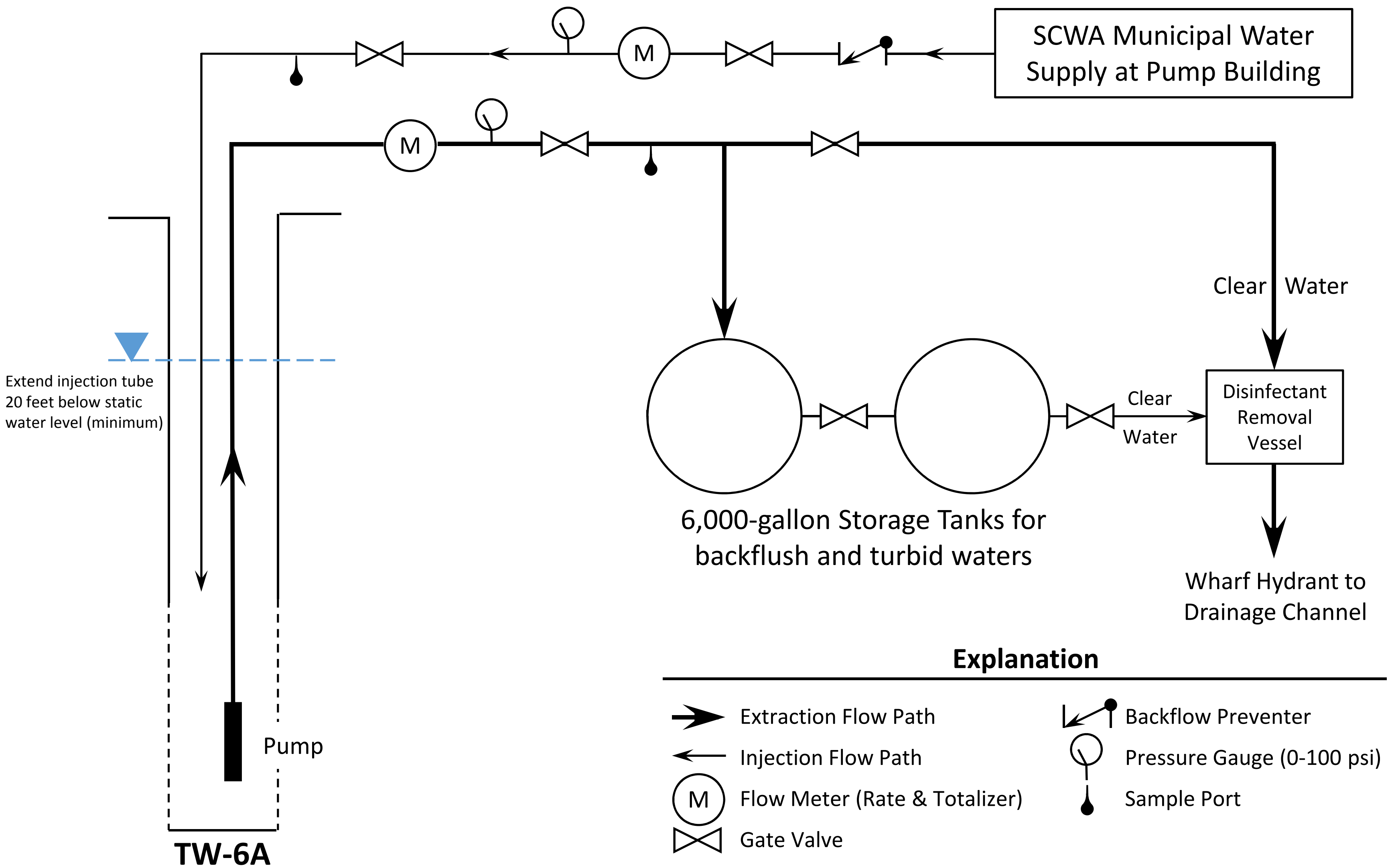
TW-6A was designed and constructed as an ASR test well with City Well #6 acting as a monitoring well at a distance of approximately 60 feet. Several temporary modifications will be necessary at the site for the implementation of the pilot test, including the following:

- Removal of the submersible pump from City Well #6 for the installation of a water level transducer. A small pump will also be installed in the well to allow for periodic sampling of water quality conditions.
- Connection of TW-6A to the City's potable water pipe line as the source of the recharge water.
- Setup of the City's two 6,000-gallon portable storage tanks to hold periodic well backflush water and recovered test waters, to ensure these waters meet applicable

discharge standards prior to release to the City's storm drain required by the City's NPDES permit.

- Connection to the City wharf hydrant for discharge of recovered water and backflush water to the drainage ditch to Fryer Creek.
- Instrumentation of City Wells #6 and #8 with pressure transducer/data loggers.

A schematic piping plan is presented on **Figure 12 – ASR Piping Diagram** which also shows the relative location of valves and meters in addition to the flow direction of water during the recharge and pumping phases of the testing.



Not to scale.

ASR Work Plan

City of Sonoma & Sonoma County Water Agency

TW-6A ASR Piping Diagram

December 2017

FIGURE 12

3.3 ASR Pilot Test Performance and Schedule

ASR operations generally consist of three steps or cycles: (1) recharge of high-quality drinking water into the aquifer; (2) storage of the recharged water within the aquifer; and, (3) recovery of the stored water. More detail on each of these steps is provided in **Work Plan Details Appendix F**.

The primary purpose of this ASR Pilot Test is to evaluate potential application in the Sonoma Volcanics. The data will be used to assess both the economic and logistical viability of ASR and will provide a basis for environmental planning and permitting documentation for a long-term, full-scale ASR project. Primary issues to be investigated in this pilot test include:

- Determination of recharge well efficiency and specific capacity
- Evaluation of recharge well plugging rates (both active and residual)
- Determination of optimal rates, frequency, and duration of backflushing to maintain long-term recharge capacity
- Determination of long-term sustainable recharge rates
- Determination of local aquifer response to recharge at the TW-6A / City Well #6 site
- Monitor ion exchange and redox reactions
- Evaluate water-quality changes during aquifer storage
- Monitor trihalomethanes (THM) and hydroacilic acid (HAA) degradation
- Monitor recovery efficiencies

The structure of the proposed pilot demonstration program also includes numerous incremental steps of ASR operations to provide multiple check-points and stopping-points in the event that pilot operations deviate significantly from the predicted responses. The test program will involve a pre-test, followed by three repeated steps of operations and monitoring, each of larger volume and/or longer duration than the preceding step, so that if adverse conditions are encountered the program can be revisited and adjusted or terminated, if needed.

The test program generally consists of a preliminary 1-day pre-test, followed by three repeated steps/cycles of Aquifer Recharge/Storage/Recovery; with each step of greater duration and/or capacity. By repeating the same steps under varying conditions, a robust dataset of aquifer responses and water quality information will be collected while minimizing the risk of adverse effects to the public, aquifer, or the environment.

The amount of water recharged during these cycles will vary from 2.8 acre-feet (900,000 gallons) to 8.3 acre-feet (2.7 million gallons), with aquifer storage periods ranging from 7 to 30 days before the water is recovered by pumping the well.

Water quality and water levels will be monitored throughout the pilot program, with some parameters being monitored continuously and others with periodic measurements or grab samples.

The above-described pilot ASR testing program is anticipated to require approximately five to six months and is tentatively scheduled to begin in the late winter/spring months during the 2017-18 water year.

To maintain the highest quality water for recharge purposes during the test program and limit the potential for hydraulic interference during the testing period, the City intends to operate this ASR pilot test with the Water Agency's Russian River water, which is conveyed throughout the City of Sonoma's distribution, and not operate its wellfield as needed, based on water demands and system capacity during the pilot study.

3.4 Monitoring and Reporting Program

Monitoring and reporting for the pilot test will comply with the requirements of the ASR General Order's Monitoring and Reporting Program (MRP) for the recharged and extracted water. However, a more extensive analytic list and frequency of sampling will be implemented to serve as a basis for both future CEQA documentation and evaluation of a full-scale, permanent ASR program.

In conjunction with the Groundwater Banking Program Feasibility Study, substantial levels of analysis have already been performed recently using existing historical and site-specific water quality sampling data, modeling of geochemical interactions between the Russian River source water (treated drinking water) and native groundwater during aquifer storage operations. Although no significant adverse water quality effects were predicted by the geochemical modeling, additional data collection will further verify and explain some of the beneficial and "net-neutral" water quality changes that may occur during ASR operations.

In addition to the specific constituents of concern (COCs) identified in Section 2.6.3, including THMs, HAAs, chlorine residual, numerous other water quality constituents will be routinely monitored during the pilot study to assess the occurrence of aquifer reactions, such as reduced species oxidation and disinfection byproduct degradation. A list of all constituents to be monitored is included in the **Sampling and Analysis Plan** provided as **Appendix G.**

A report will be prepared following completion of the pilot test and will present the methodology, results, and recommendations for next steps along with an assessment of potential full-scale operations.

4 Conclusions

Based on an evaluation of the available information for the ASR Pilot Test and our understanding of the ASR General Order, GEI offers the following conclusions:

- The target aquifer storage zone into which the drinking water will be recharged and stored consists of a confined aquifer comprised of volcaniclastic sediments of the Sonoma Volcanics along the margin of the Sonoma Valley Groundwater subbasin underlying the City.
- The pilot test will utilize less than 20 acre-feet of treated, potable surface water from the Water Agency's transmission network. This water will be recharged and recovered through a recently constructed test well (TW-6A) at various rates up to a maximum of 90 gpm during the planned 6-month testing period.
- Water levels are predicted to remain about 20 feet below ground surface at all times during recharge testing.
- The area of hydrologic influence underlain by recharged water is estimated to extend a distance of approximately 60 to 80 feet from the well, depending on porosity and could migrate up to 110 feet from the well during the longest planned storage cycle of 30 days, depending on hydraulic conductivity, gradient, and porosity. The pilot test will not affect the water quality of other existing water supply wells since these wells are located outside of the immediate area (greater than 800 feet).
- Based on analysis of well and aquifer response, groundwater levels in the target aquifer zone could rise as much as five feet within 2,000 feet of the test well. A survey of nearby water wells, an inventory of land uses and potentially contaminating activities in the vicinity indicates there are no identifiable negative impacts associated with operation of the pilot study.
- The Water Agency's potable water is derived from the Russian River and meets all MCLs and does not exceed the RWQCB's Basin Plan water quality objectives. Therefore, the ASR pilot test is not anticipated to violate the Injected Water and the Groundwater Limitations of the Order.

5 Closure

This technical report was prepared exclusively for the Sonoma County Water Agency and City of Sonoma for the specific application to Test Well #6A ASR Pilot Test. The findings, conclusions, and recommendations presented herein were prepared in accordance with generally accepted engineering and hydrogeologic practices. No other warranty, express or implied, is made.

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Appendix A – Technical Memoranda: Geochemical Interaction Assessment for Recharge of SCWA Waters into City Well #6 and Test Well 6A

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

To:	Stephen Tanner, PE, Pueblo	Date:	September 28, 2016
Copy to:	Marcus Trotta, PG, CHg , SCWA	Project No:	14-0031
From:	Dr. Stephen A Short, PhD		
Subject:	Geochemical Interaction Assessment of ASR Feasibility for Sonoma Well #6A		

In 2014, the Sonoma County Water Agency (Water Agency), received grant funding from the California State Department of Water Resources (DWR), though the Proposition 84, Integrated Regional Water Management, Local Groundwater Management Assistance Act of 2000, Agreement No 4600010354, for the Sonoma Valley Enhanced Groundwater Recharge Project. The Agreement was amended on November 6, 2015 to extend the completion date from December 30, 2015 to September 30, 2016. DWR initially solicited grant applications for viable projects with a maximum grant funded amount of $250,000. DWR selected this project for funding but revised the total grant funding to $158,314. The Water Agency agreed to fund the difference and complete the project. The Project Work Plan included five tasks which included permitting and construction of depth discrete monitoring wells at two locations in Sonoma Valley, collect both soil and water quality samples, perform a geochemical analysis to assess the compatibility of treated surface water produced by the Water Agency and native groundwater and aquifer sediments to assess whether the aquifers in the area would be suitable to develop aquifer storage and recovery (ASR) wells and program.

The Water Agency competitively bid for hydrogeologic services to complete the work and selected GEI Consultants, Inc. to complete the work. GEI Consultants teamed with Pueblo Water Resources, Inc. (Pueblo). GEI personnel provided project management, preparation of plans and specifications to solicit a drilling contractor, on-site technical monitoring for the drilling, construction, and water quality sampling of the wells. Pueblo provided assistance during the well design, water quality sampling and to prepare a geochemical analysis (analysis and findings to be provided under a separate report). Pueblo personnel also acquired water quality samples as well as one air-gas sample from the wells. This report provides the geochemical analysis of the water and soil chemistry.

We principally conducted these assessments using the latest version of the open source USGS model PHREEQC version 3.3 and the PHREEQC compatible French Geological Survey (BRGM) THERMODDEM database (file name phreeqc_thermoddemv1.10_11 dec2014.dat) dated 11 December 2014. All modeling is generally based on the chemothermodynamic full equilibrium assumption i.e. Saturation Indices (SIs) of 0.00 indicate saturation

We also checked our model runs using another extensive PHREEQC-compatible database being the Lawrence Livermore National Laboratory (LLNL) database llnl.dat 9461 dated 2 April 2015 and found no significant discrepancies.

It is noted that in a few instances, concentrations of some minor elements were listed as Not Detected (ND) at the laboratory Practical Quantitation Limit (PQL) - principally barium (Ba; in Well #6 NGW only), aluminum (Al), iron (Fe) and manganese (Mn). These elements were conservatively estimated and input into the model at one half of the listed PQL in order to enable determination of some of the below listed parameters – principally Saturation Indices (SIs) of minerals of interest for estimating potential precipitation, scaling or biofouling potential. We regard this conservative approach as standard practice as concentrations of Al, Fe and Mn in particular are almost always strongly variable both in groundwaters and in waters conveyed through iron or steel pipelines.

The principal features of geochemical importance (with respect to ASR operations) of the SCWA Recharge Water Summary Analysis and of the NGW encountered in Well #6A are as tabulated below.

Before conducting any further model simulations of admixtures of SCWA Recharge Water with native groundwater (NGW) in these wells the principal issues which arise from an inspection of the analyses of these two waters and specifically the core values listed in Table 1 below are as follows.

- The recharge water is relatively alkaline at a pH of ~8.6 and this means that admixtures with lower pH groundwaters such as found in Sonoma Well #6A (pH ~7.0) might lead, in principle, to a potential for siliceous scaling especially during the early stage of ASR operations, due to the reduced solubility of silica at lower pHs.

- Hydrous (amorphous) ferric hydroxide (also known as Ferrihydrite2L) is highly undersaturated in the proposed SCWA recharge water (as is to be expected), but is also significantly supersaturated in the Well #6A Natural Ground Water (NGW). A potential for late stage ferruginous precipitates and associated ferruginous biofouling due to the growth of iron related bacteria (IRBs) is therefore expected *remote from the recharge well.*

- Barite is only just saturated in the proposed Recharge Water and significantly undersaturated in the Well #6A NGW and admixture, and is therefore unlikely to have a potential for Barite scaling during early through late stages of recharge.

Table 1 – Geochemical Stability of Initial Recharge and Native Ground Waters

Key water parameters (measured or model-determined)	SCWA Xmission Chlorinated Water (Proposed Recharge Water)	Well #6A NGW
Measured pH	8.55	7.02
Measured Temperature (C)	13.6	24.8
Measured Specific Conductivity @ 25 C (µS/cm)	323	161
Measured Oxidation Reduction Potential (ORP) (mV)	+670	+268
Analysis Cation/Anion Balance (%)	-3.13	+2.71
Model-determined Specific Conductivity @ measured water temperature (µS/cm)	253	206
CO_2 partial pressure (%)	0.0437	1.02
Methane (CH_4) partial pressure (%)	0.0	0.0
Hydrogen Sulfide (H_2S) partial pressure (ppmv)	0.0	0.0
Barite SI	0.00	-1.89
Calcite SI	+0.60	-1.32
Magnesite(synth) SI	+0.08	-1.68
Amorphous Silica	-0.78	0.00
Chalcedony SI	+0.01	+0.75
Hydrous Ferric Oxide (HFO) SI	-4.56	+2.28
Gibbsite (microcrystalline) SI	-0.56	+0.01
Fluorapatite SI	+7.29	+2.92
Whitlockite (tricalcium phosphate) SI	-0.74	-2.71

Next, we conducted a model mixing scenario in which we mixed the proposed recharge water (ie Sonoma Xmission) with Well #6A and allowed full thermodynamic equilibration to simulate the effects of well recharge. The mixing scenario evaluated *in situ* water quality of in-ground mixtures in the volumetric ratios of 25:75. 50:50 and 75:25 of Recharge Water to NGW in the aquifer around the well.

However, no allowance was made for full equilibration of the mixtures with the NGW partial pressure of CO_2 as is likely to occur *during prolonged storage* of such mixtures in order to produce more conservative outcomes with respect to the potential for calcareous or (oxidized) ferruginous/aluminous scaling/biofouling.

Similarly, siliceous scaling or precipitation (invariably initially of Amorphous Silica might also be slightly increased over time by equilibration with higher partial pressures of CO_2 due to the reduced solubility of silica with reduced pHs below 7.0.

Assumptions were made that if the SI of Barite ($BaSO_4$), and/or Magnesite and Calcite ($CaCO_3$), Amorphous Silica (SiO_2) and/or Hydrous Ferric Oxide ($Fe(OH)_3$), and/or microcrystalline Gibbsite ($Al(OH_3)$) and/or Fluorapatite ($Ca_5(PO_4)_3F$) exceeded a default value of 0.00 then these minerals would precipitate until the equilibrium SI was reduced to 0.00. In that case; the mass of precipitated mineral in each case was calculated to estimate, in relative terms, the masses of the key minerals involved in possible precipitation or scaling or iron bacteria-based biofouling.

No assumptions were made about the intensity of aerobic biological action during and following recharge , usually due in the first instance to consumption of Dissolved or Total Organic Carbon (DOC; TOC) from the Sonoma Xmission chlorinated water and its mixture with Well #6A NGW as these effects were assumed to be, at least initially, negligible due to the presence of a significant chlorine residual in the Recharge Water (0.71 mg/L as Cl_2) and hence in the mixtures.

The principal features of geochemical importance (with respect to ASR operations) of the mixing SCWA Recharge Water Summary Analysis with the *in situ* native groundwaters as sampled from well #6A in these three ratios are tabulated below in Table 2.

Table 2 - Summary of Principal Geochemical Reactions Under Various In Situ Mix Ratios

Key Water Parameters	**Sonoma Xmission : Well #6A NGW Ratio**		
Volumetric Mix ratio	**25:75**	**50:50**	**75:25**
Mix Temperature	22.75	19.70	16.65
Predicted pH	7.25	7.55	7.99
Predicted Eh (mV)	793	791	781
Maximum Barite Precipitated (mg/L)	0	0	0
Maximum Calcite Precipitated (mg/L)	0	0	0
Maximum Hydrous Ferric Oxide Precipitated (mg/L)	**0.038**	**0.057**	**0.077**
Maximum Amorphous Silica Precipitated (mg/L)	**0**	**0**	**0**
Maximum Fluorapatite Precipitated (mg/L)	**0.57**	**0.43**	**0.27**
Maximum Gibbsite precipitated (mg/L)	0	0	0

From this model and the data presented in Table 2 above, the following assessments and recommendations can be made.

1. Recharge of SCWA chlorinated Xmission waters into Well #6A are unlikely to lead to any significant issues of scaling or precipitation due to Barite, and/or calcareous (calcium and magnesium) minerals such as Calcite and/or Magnesite.

2. Recharge of SCWA chlorinated Xmission waters into Well #6A NGW are also unlikely to lead to any siliceous scaling in and around the well screens particularly during the early stages of recharge operations. Minor build-up of siliceous scaling on well screens may occur in the final phase of bulk replacement and storage within the aquifer of Sonoma Xmission recharge waters as the stored water slowly accumulates more dissolved CO_2 from oxidation of the DOC/TOC (and any adventitious organic carbon derived from the aquifer solids) by the chlorine residual. Such scaling, if apparent, could be eliminated by adjusting the pH of the Sonoma Xmission water to say 9.0 prior to recharge operations.

3. Recharge of SCWA chlorinated Xmission waters into Well #6A NGW are likely to lead to only minor ferruginous precipitation mostly remote from the ASR well during the later stages of recharge /storage. Some minor build-up of biogenically assisted ferruginous

precipitation of <0.1mg/L on well screens may occur during the final phase of bulk replacement and storage within the aquifer of Xmission Recharge Water assisted by the available phosphorus (noting Fluorapatite is saturated in both the Recharge Water and the NGW.

4. In the case of extended storage of Recharge Water in and around Well #6A it might therefore be prudent to periodically monitor samples extracted from the zone around the well screens for total and dissolved Al, Fe and Mn, maybe even to screen such re-extracted samples for the presence of detached stalked bacteria in particular stalked heterotrophic Iron Reducing Bacteria (IRBs) e.g. *Gallionella, Sphaerotilus, Leptothris, Pseudomonas spp* etc. This need only apply if it were observed that the pH of such re-extracted stored water had fallen significantly below 7.0 as the process of ferruginous precipitation and concurrent biological growth generates acidity in each case. It is considered unlikely this issue will prove problematic.

Potential for Leaching Undesirable Minerals from Aquifer Matrix

One issue of concern with all ASR projects is the potential for the newly introduced recharge water to react with and solubilize (ie leach) undesirable constituents from the aquifer geologic matrix.

Prediction of such occurrences is both complex and generally unreliable due to the myriad of variables that affect mineral solubilization. Aquifer residence time, subsurface mixing and transport phenomena, physical properties of aquifer grain structure, subsurface hydraulic pressure, microbially induced reactions, and many other factors can significantly alter solubility processes in the aquifer; the required level of investigation for such work is beyond the scope of this study.

The primary (and preferred) methodologies for determination of leaching potential in ASR assessments include the following:

1- Bench scale studies involving the introduction of recharge water into core and/or crushed matrix samples under controlled conditions of pressure, temperature, and residence time – followed by analysis of the extracted water.

2- Pilot Scale studies in test wells with similar assessment of pre- and post recharged waters after controlled aquifer storage periods, combined with geochemical modelling to simulate specific aqueous reaction mechanism(s) associated with the empirically observed changes in recharge water chemistry. This method is considered superior to bench scale analyses for accuracy and scalability.

It is recommended that one or both of these procedures be implemented in subsequent phases of the project investigation.

Although the above noted work will require substantial preparation and implementation costs that are beyond the scope of the current investigation, we opine the following regarding general leaching potential susceptibility from the results of our current study:

1- The aquifer geologic matrix as observed from the test well cuttings samples suggests that there is adequate pH buffering capacity in the mineralogy to mitigate any substantial changes induced by recharge water pH. The nearly neutral pH of the NGW supports this observation.

2- The relatively oxidized nature of the NGW (+ 270 mV Eh, with 5 mg/L DO), combined with the strongly oxidizing Eh of the proposed SCWA recharge water suggests that the onset of reducing conditions is unlikely, and thus significant redox reactions will be avoided.

Because most subsurface geochemical reactions are pH or Eh (ie redox) motivated, it could be inferred that substantial leaching reactions are therefore unlikely.

CLOSURE

This technical memorandum has been prepared exclusively for the Sonoma County Water Agency for the specific application to the Well #6A ASR Project. The findings, conclusions, and recommendations presented herein were prepared in accordance with generally accepted geochemical and hydrogeologic practices. No other warranty, express or implied, is made.

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Appendix B – Preliminary Injection Capacity and Constraints Analysis for City of Sonoma Well #6

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

To:	City of Sonoma	Date:	June 2, 2014
Attention:	Dan Takasugi, P.E. Public Works Director	Project No:	14-0031
Copy to:	Marcus Trotta, P.G., C.Hg. SCWA		
From:	Robert Marks, P.G., C.Hg		
Subject:	Preliminary Injection Capacity and Constraints Analysis for City of Sonoma Well #6 **DRAFT**		

INTRODUCTION

Presented in this Technical Memorandum (TM) is a preliminary analysis of the various operational and hydrogeologic constraints affecting the potential injection capacity of the City of Sonoma's Well #6. This TM is a supplement to a previous TM prepared by Pueblo Water Resources, Inc. (PWR) for the Sonoma County Water Agency (SCWA), dated November 16, 2013, as part of SCWA's investigation of the feasibility of groundwater banking in the Santa Rosa Plain and Sonoma Valley groundwater basins, which presented an analysis of several existing ASR testing candidate wells owned by various project participants (e.g., the Cities of Cotati, Rohnert Park, and Sonoma), including an analysis of the City of Sonoma's Well #7. Based on the relatively unfavorable results of the analysis of Well #7, which showed that well's theoretic injection capacity to be limited to approximately 30 gallons per minute (gpm), the City desired a comparable evaluation of Well #6. The results of the analysis of Well #6 are presented below.

FINDINGS

As-Built Well Construction

City Well #6 is located in the Sonoma Valley groundwater basin. The well was originally constructed in 1952 to a depth of 250 feet below ground surface (bgs) with a 10-inch-diameter steel casing and perforations placed below the depth of 102 feet bgs. The annular seal was reportedly placed to a depth of 92 feet bgs. The well was subsequently lined in 1999 with a 6-inch-diameter PVC casing to a total depth of 236 feet and perforations placed between the intervals of 140 to 236 feet bgs, with an inner annular seal placed to a depth of 136 feet bgs. A summary of the as-built well construction features of Well #6 is presented below in **Table 1**:

Table 1. As-Built Construction Summary

Design Feature	As-Built	Comment
Total Well Depth (ft. bgs)	236	
Static Water Level (ft. bgs)	64	May, 2014
Seal Depth (ft. bgs)	92 / 136	Outer original / Inner lined
Casing Material (original)	Carbon Steel	10-inch dia. (original)
Casing Material (as modified)	PVC	6-inch-dia. (liner)
Perforated Intervals (ft. bgs)	140 – 236	
Total Perforation Length (feet)	96	
Cellar Section (ft bgs)	None	Perforations placed to TD
Perforation Aperture	0.030-inch slots	Machine-cut horizontal
Gravel Pack (gradation)	None / Pea Gravel	Original well drilled cable-tool w/o gravel pack / Annular space between liner and original casing

INJECTION CAPACITY CONSTRAINTS ANALYSIS

The injection capacity of any given aquifer storage and recovery (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. To the extent possible, ASR wells should be operated to maximize injection and production rates while operating within the constraints of these site-specific factors. A discussion of each of these factors and their influence on the theoretical injection capacity of Well #6 based on the available data for the well site is presented below.

Well Response to Injection

One method of estimating the injection capacity limits of an ASR well is to determine the amount of drawup available within the well casing for injection, and calculate the maximum injection rate based on the theoretical water level response to injection utilizing the Theis equation (Theis, 1935).

Available Drawup. During injection, the water level (head) in the well and aquifer will increase due to mounding in the aquifer. The available 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). A wellhead pressure of 30 psi (approximately 70 feet equivalent head of water) is considered a reasonable maximum for pressurized casing injection, based on conservative estimates of the conventional grades of casing, pump seals, and instrument components. A summary of the available drawup constraints for the well based on the above limiting criteria is presented below in **Table 2**.

Table 2. Available Drawup Summary

Well	Available Drawup (ft.)	
	Minimum (DTW)[1]	Maximum (30 psi)
Well #6	64	133

Notes:
1 - Depth to Water (DTW), May 2014.

As shown in **Table 2**, the available drawup within the well casing (under current conditions) ranges between approximately 65 and 130 feet, depending on whether pressurized casing injection is considered allowable or not.

Water-Level Response to Injection. The theoretical drawup response of a well to injection can be calculated utilizing the Theis equation and aquifer parameters of transmissivity and storativity. Valid aquifer parameter data can only be developed from controlled pumping tests, and development of storativity values requires an observation well. Site specific transmissivity values were developed from a pumping test conducted at Well #6 in 2009[1]. The well performance results and derived aquifer parameters are summarized in **Table 3** below:

Table 3. Pumping Test Data Summary

Well	Aquifer[1]	Q (gpm)	s (ft)	Q/s (gpm/ft)	T (gpd/ft)[2]	S (unitless)[3]
Well #6	QTge / Th	100	40.7	2.46	4,950	1.0E-02

Notes:
1 - Glen Ellen Formation (Qtge) / Huichica Formation (Th).
2 - gallons per day per foot (gpd/ft).
3 - assumed value for semi-confined aquifer

As shown in **Table 3**, the transmissivity estimate for the aquifer system at Well #6 is approximately 4,950 gpd/ft. A storage coefficient value could not be derived from the pumping tests due to a lack of proximate monitoring wells; therefore, for purposes of this preliminary analysis, an assumed value based on available literature values for the aquifer is utilized.

For purposes of this preliminary analysis, it is assumed that essentially continuous injection operations would occur over a six-month wet / low-demand period, e.g., from December through May (183 days continuous, interrupted only briefly for periodic backflushing).

The theoretical calculations based on the Theis equation assume a perfectly efficient well without hydraulic losses in the well casing, well screen, gravel pack or well bore. In

[1] *Well #6 Step Drawdown Pumping Test*, Technical Memorandum prepared for the City of Sonoma by Winzler & Kelly, dated October 23, 2009.

practice, however, municipal water wells typically have efficiencies of approximately 60 to 80 percent[2]. Based on the results of the 2009 pumping test, Well #6 has a calculated well efficiency of approximately 75 percent. It is noted that based on pumping test data collected by PWR in May 2014, the well performance has not changed appreciably since 2009.

Based on these relationships and assumptions, the resulting injection rates that would raise water levels within the well casing to: 1) ground surface, and, 2) result in 30 psi of wellhead pressure, after 183 days of injection are presented in **Table 4** below.

Table 4. Theoretical Well Response Constraint Summary

Well	Theoretical Injection Capacity (gpm)		Injection Rate w/ Efficiency Losses[1]	
	Min (gs)	Max (30 psi)	Min (gs)	Max (30 psi)
Well #6	160	335	120	251

Notes:
1 - Well #6 hydraulic efficiency = 75% based on 2009 testing.

As shown in **Table 4**, it is estimated that a theoretical injection rate (accounting for efficiency losses) of approximately 120 gpm would create drawup within the well casing that would raise water levels up to ground surface after 183 days of continuous injection (with routine backflushing to limit plugging). Allowing for pressurized casing injection (up to 30 psi of casing pressure), an injection rate of approximately 250 gpm is theoretically feasible.

Backflushing Capacity. This constraint considers the amount of drawdown available above the perforations for backflushing. No source of injection water is completely free of particulates; therefore, backflushing (i.e., pumping) of injection wells is 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 affect particulate removal). Periodic, vigorous backflushing is absolutely necessary to maintain injection capacity. The ability to adequately backflush ASR wells while maintaining a flooded screen section is, therefore, a critically important consideration when designing and operating ASR well facilities.

Based on experience at other injection wells, it has been shown that it is desirable to backflush injection wells at rates of at least twice 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. This criterion is considered to be the most conservative and important for maintaining long-term injection performance, and is, therefore, at least initially, adopted as the limiting backflushing criteria utilized for this project. A summary of the factors related to backflushing capacity of the well is presented in **Table 5** below:

2 Well efficiency is defined as the ratio of the actual to the theoretical specific capacity (or the ratio of total hydraulic head loss to formation losses).

Table 5. Backflushing Capacity Constraint Summary

Well	SWL[1] (ft bgs)	Top of Screen (ft bgs)	Available Drawdown (ft)	Q/s (gpm/ft)	Capacity (gpm)	
					Backflush	Injection
Well #6	64	140	76	2.46	187	93

Notes:
1 - Static Water Level (SWL)

As shown in **Table 5**, the theoretical injection rate as constrained by backflushing capacity is approximately 90 gpm.

Downhole Velocity. The well's internal diameter is another limiting factor on the injection capacity. Experience at other injection wells has shown that excessive downhole velocities can lead to the entrainment of air bubbles, sweeping them into the well screen and formation, which results in air binding and plugging of the well. The downhole velocity of the injected water is directly proportional to the internal casing diameter. Limiting downhole velocities below the rate at which average size air bubbles rise (1.0 ft/sec; Olsthoorn, 1982), has been shown to be a prudent injection well operational constraint. A summary of the downhole velocity constraints for the well is presented in **Table 6** below:

Table 6. Downhole Velocity Constraint Summary

Well	Casing Diam. (in)	Injection Rate (gpm)
Well #6	6	88

Notes:

As shown in **Table 6**, the injection rate of Well #6 is limited to approximately 90 gpm by the 1.0 ft/sec downhole velocity constraint.

Aquifer Response to Injection

Utilizing the aquifer parameters presented previously, the theoretical water-level mounding response to injection within the aquifer system can also be calculated utilizing the Theis equation. These aquifer parameters relate to other potential constraints in ASR well operations, as described and analyzed below.

Hydrofracturing Limits. As discussed in the SCWA feasibility study, the target aquifer for injection is generally semi-confined. During injection, the head in the aquifer must not exceed pressures that would create vertical cracks in the confining layers (hydraulic fracturing) through which injected water may flow upward into overlying sediments (and thereby become unrecoverable by the same well) or lost to the ground surface ("daylighting"). The pressure in the confined aquifer must not exceed vertical grain pressures of the materials overlying the confining layer to avoid hydraulic fracturing. Based on soil mechanics, Huisman and Olsthoorn (1983) suggest that the maximum allowable drawup to avoid hydraulic fracturing can be calculated using the equation:

$$s < 0.22 (A+B)$$

Where: s = total drawup (ft)
A = depth from ground surface to the confining layer (ft)
B = depth from ground surface to static water level (ft).

The depth to the top of the confining layer above the completed aquifer at Well #6 was determined based on review of the lithologic log. Utilizing the Theis equation and the aquifer parameters presented previously, the estimated injection rate that would be within the hydrofracturing limits at the borehole wall (1.0 ft radius) for the subject well is presented in **Table 7** below.

Table 7. Hydrofracturing Potential Constraint Summary

Well	Depth to Confining Layer (ft)	Static Water Level (ft bgs)	Total Available Drawup (ft)	Max. Injection Rate (gpm)
Well #6	120	64	40	100

Notes:

As shown in **Table 7**, the injection rate for Well #6 as constrained by hydrofracturing potential limits is approximately 100 gpm.

Offsite Impacts Limits. This constraint is based on estimates of the maximum injection rate that can be achieved without causing water levels in the aquifer system offsite to rise above some level that would cause undesirable results. Typically, this means raising water levels above the ground surface at an offsite well and causing it to become artesian and start flowing at the surface (“daylighting”). Utilizing the Theis equation and the aquifer parameters presented above, the maximum injection rate that can be sustained for 183 days without raising water levels above ground surface at the nearest known offsite well is summarized in **Table 8** below.

Table 8. Offsite Impact Limits Constraint Summary

Well	Distance to Nearest Offsite Well (ft)[1]	Allowable Drawup (ft)[2]	Max. Injection Rate (gpm)
Well #6	760	60	670

Notes:
1 - Based on PWR field reconnaisance in May 2014.
2 - Based on estimated current depth to water.

As shown in **Table 8**, the injection rate as constrained by offsite impact limits is approximately 670 gpm.

Summary of Injection Well Capacity Constraints

A summary of all the injection capacity constraints presented above for Well #6 is presented in **Table 9** below:

Table 9. Injection Capacity Constraints Summary

Well	Injection Capacity (gpm) vs. Constraint					
	Well Response		Backflushing Capacity	Downhole Velocity	Hydro-Fracturing	Offsite Impacts
	Min (gs)	Max (30 psi)				
Well #6	120	251	93	**88**	100	670

Notes:
Primary limiting factor shown in **bold** type.

In summary, a review of the various hydrogeologic and operational factors that limit the injection capacity of Well #6 reveals that the downhole velocity criterion represents the primary constraint on the injection capacity, with an injection rate of approximately 90 gpm. It is noted that while the downhole velocity is controlled by the liner casing diameter, the theoretical injection rate constrained by downhole velocity is comparable to the rates constrained by both the backflushing capacity and hydrofracturing criteria (approximately 90 and 100 gpm, respectively). In other words, even without the small diameter casing liner, the injection capacity would still be limited to approximately 90 to 100 gpm by these other factors. Nonetheless, the 90 gpm theoretic injection capacity of Well #6 is more than two times greater than the theoretical injection rate for Well #7, where the hydro-fracturing potential and well response criteria limited the injection capacity to approximately 40 gpm[3].

Because of the modification of the well by lining the 10-inch casing with 6-inch PVC, it will be especially important to carefully track well plugging rates and the effectiveness of backflushing of the well; such modifications can limit the effectiveness of backflushing and lead to long-term loss of capacity of an ASR well.

[3] *Groundwater Banking Program Feasibility Study; Preliminary Injection Capacity and Constraints Analysis for ASR Pilot Testing Wells*, Technical Memorandum prepared by Pueblo Water Resources, Inc. for Sonoma County Water Agency, dated November 16, 2012 (draft).

CONCLUSIONS

Based on the findings from the injection capacity constraints analysis for City of Sonoma Well #6, we conclude the following:

- Based on the constraints analysis, Well #6 is estimated to have a long-term injection capacity of approximately 90 gpm. On a seasonal storage basis, this is equivalent to injecting approximately 73 acre-feet of surplus water over a 6-month injection season.
- The injection capacity of Well #6 is primarily constrained by the internal casing diameter of the liner casing and allowable downhole velocity during injection; however, secondary constraints of backflushing capacity and hydrofracturing potential also limit the theoretical injection capacity of Well #6 to 100 gpm or less.

RECOMMENDATIONS

Based on the results of the analysis of the injection capacity analysis for Well #6, and our experience with similar ASR projects, we offer the following recommendations:

- Assuming the results of the geochemical interaction modeling analysis (pending as of this writing) prove favorable, a detailed work plan for implementing a pilot ASR testing program at Well #6 should be developed based on a long-term injection rate of 90 gpm.
- Following development of an injection testing work plan, a Notice of Intent (NOI) to conduct a pilot ASR test at Well #6 under the General Waste Discharge Requirements for Aquifer Storage and Recovery Projects (SWRCB Resolution No. 2012-0010-DWQ or General ASR Order) should be prepared and submitted to the Regional Water Quality Control Board (RWQCB).
- Following receipt of a Notice of Applicability (NOA) for the project under the General ASR Order from the RWQCB, the City should proceed with implementing a pilot ASR testing program at Well #6.
- Pending the results of the pilot ASR testing, the City should decide whether pursuing a permanent ASR project at Well #6 is warranted.

CLOSURE

This technical memorandum has been prepared exclusively for the City of Sonoma for the specific application to the Well #6 ASR 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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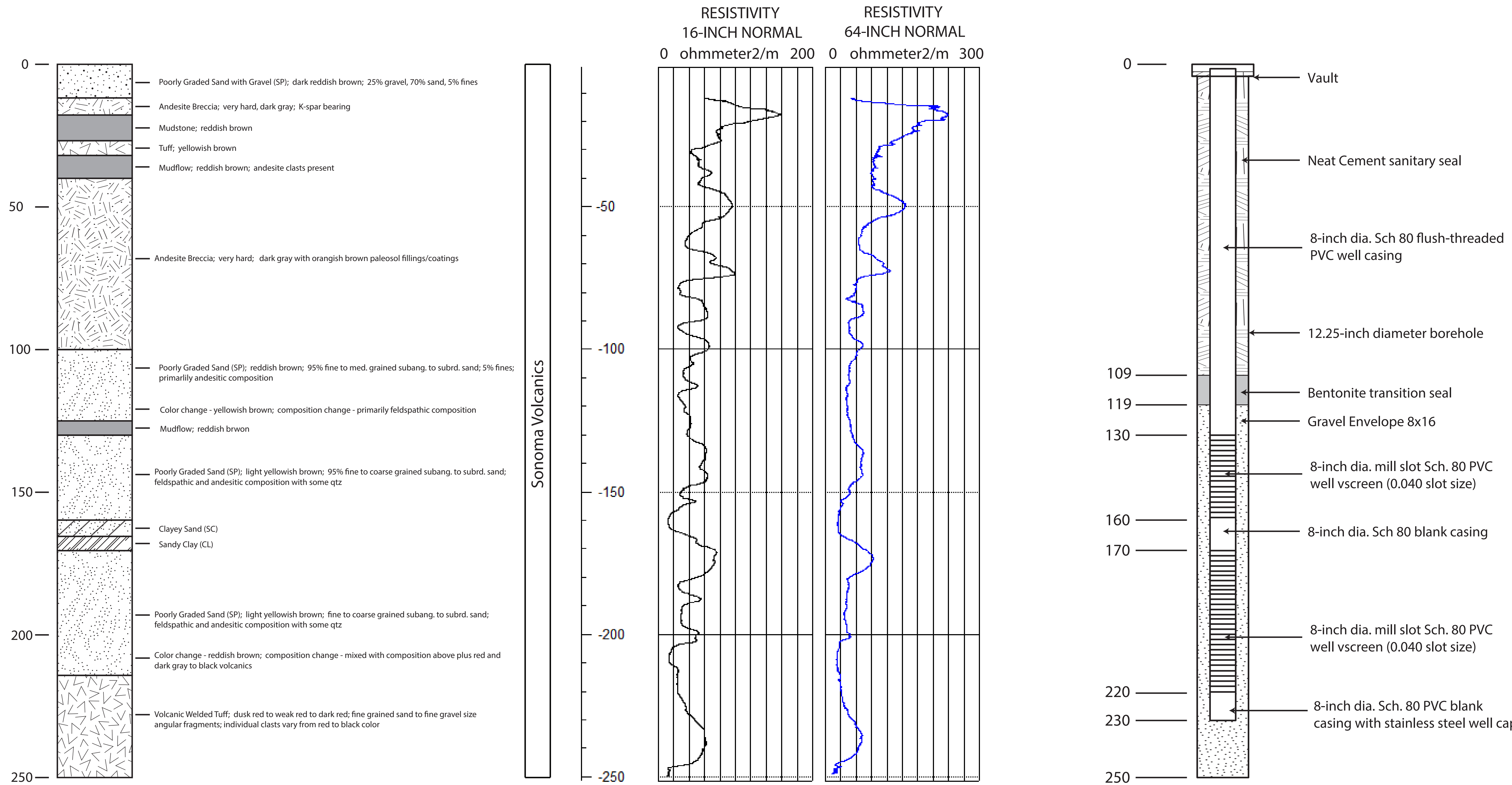
Appendix C –Well Logs for Test Well 6A and Sonoma City Well #6 and Mineralogy Inc. Report

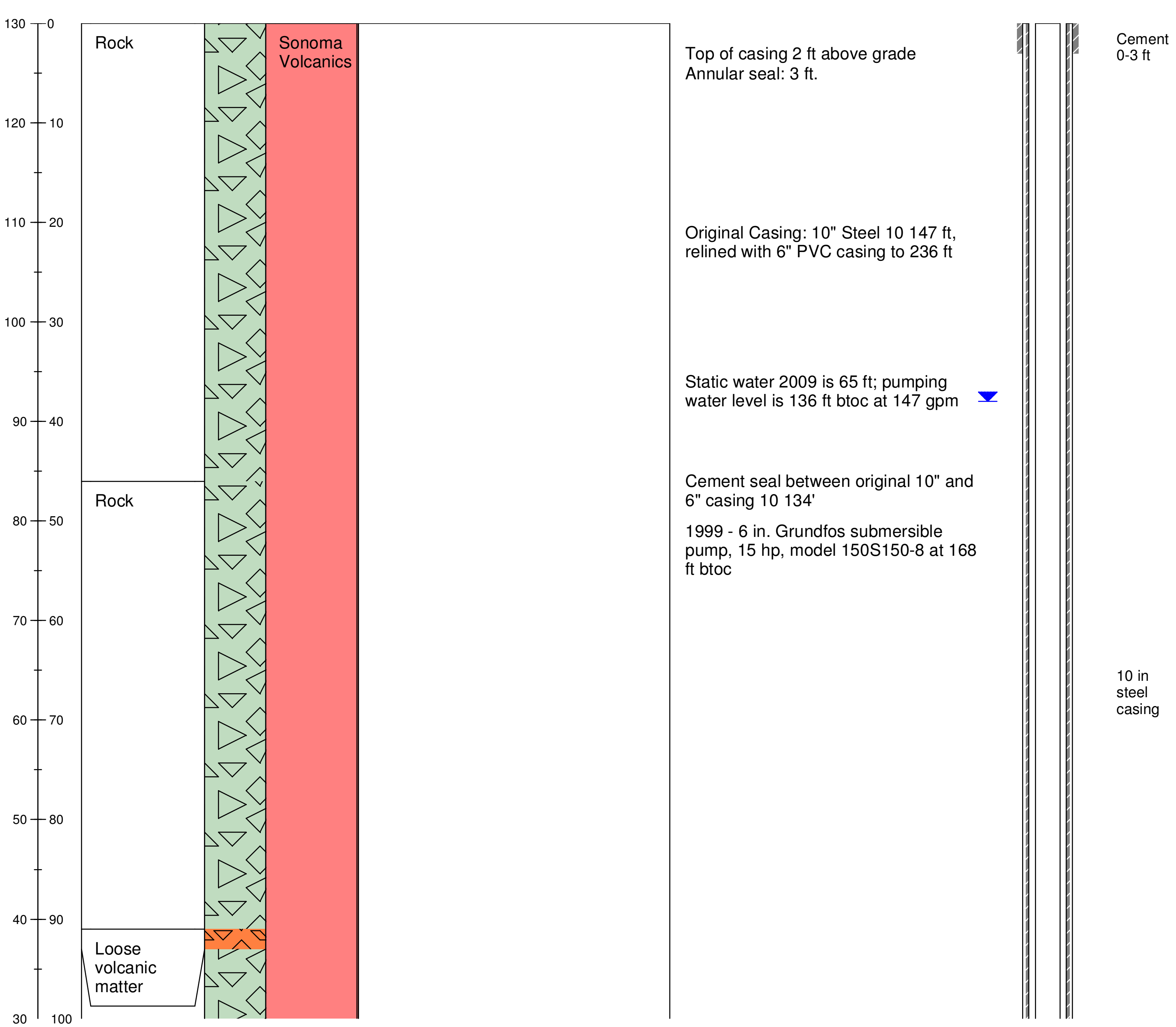


	Well Construction Sonoma County, California	GEI Consultants	Test Well - 6A
	Sonoma County Water Agency		JULY 2016 Drawing 2

COMPOSITE WELL DIAGRAM

DWR NO: 05N05W07C02M
CLIENT NAME: City of Sonoma
CITY WELL NUMBER: Well #6
DATE BEGAN: 1952
DRILLER: Lebre Well Drilling Inc.
DATE FINISHED: ~ 1952/1999
LOGGED BY: Raymond Lebre
C57 License #: 348203
LATITUDE/NORTHING: 38 17 57.87
LONGITUDE/EASTING: 122 27 26.64
GROUND ELEVATION: 130 ft-msl
DEPTH TO GW: 38
DRILLING METHOD: Air Rotary
DRILLING EQUIP: Unknown
TOC ELEVATION: 132 ft-msl

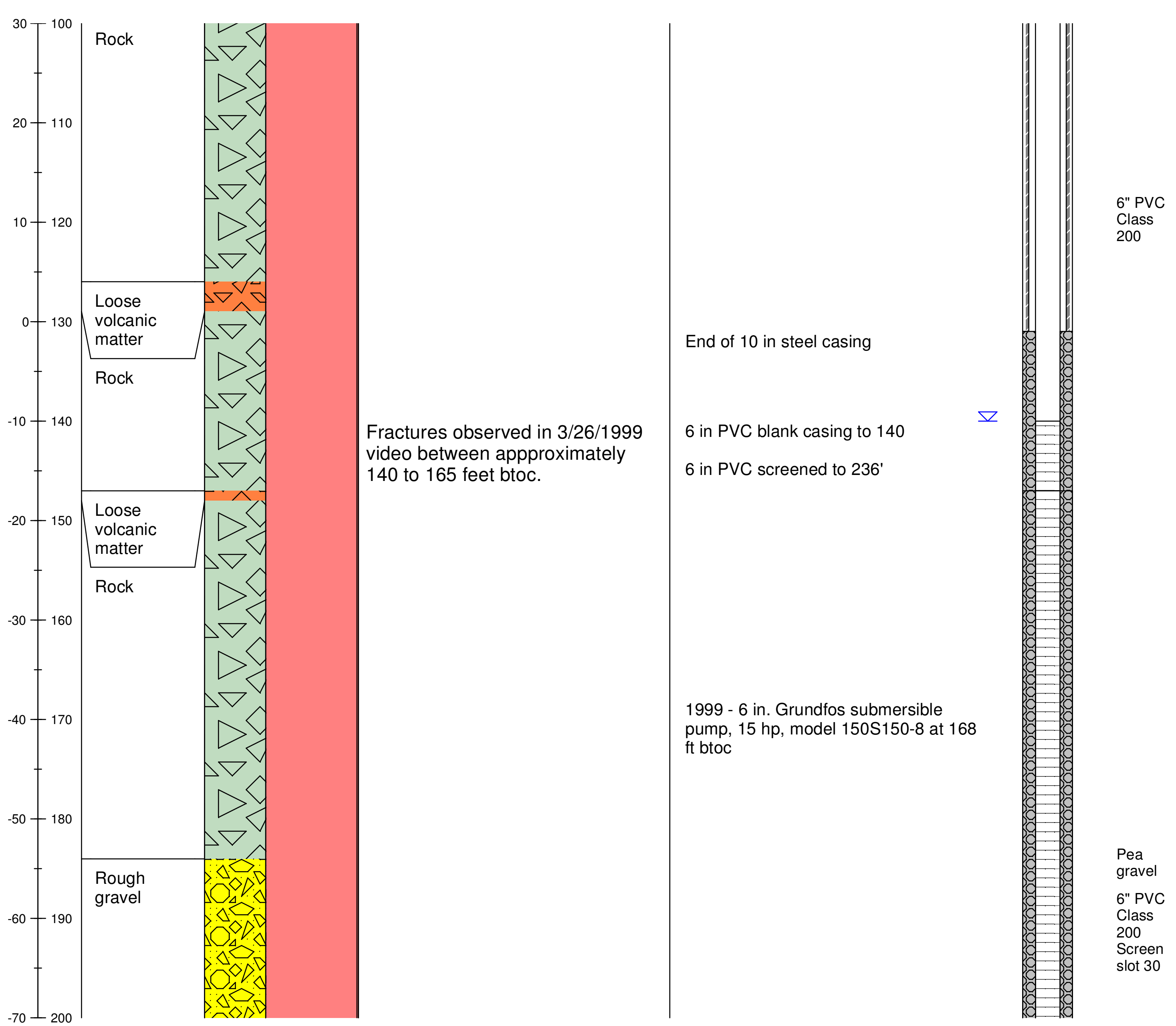
ELEVATION (ft.-msl)	DEPTH (ft.-bgs)	DRILLER'S DESC.	SOIL PROFILE	INTERPRETED STRATIGRAPHIC UNIT	NOTES FROM: 1,2,3	WELL CONSTRUCTION 1,2,3,4



COMPOSITE WELL DIAGRAM

DWR NO: 05N05W07C02M
CLIENT NAME: City of Sonoma
CITY WELL NUMBER: Well #6
DATE BEGAN: 1952
DRILLER: Lebre Well Drilling Inc.
DATE FINISHED:~ 1952/1999
LOGGED BY: Raymond Lebre
C57 License #: 348203
LATITUDE/NORTHING: 38 17 57.87
LONGITUDE/EASTING: 122 27 26.64
GROUND ELEVATION: 130 ft-msl
DEPTH TO GW: 38
DRILLING METHOD: Air Rotary
DRILLING EQUIP: Unknown
TOC ELEVATION:132 ft-msl

ELEVATION (ft.-msl)	DEPTH (ft.-bgs)	DRILLER'S DESC.	SOIL PROFILE	INTERPRETED STRATIGRAPHIC UNIT	NOTES FROM: 1,2,3	WELL CONSTRUCTION 1,2,3,4



COMPOSITE WELL DIAGRAM

DWR NO: 05N05W07C02M

CLIENT NAME: City of Sonoma

CITY WELL NUMBER: Well #6

DATE BEGAN: 1952

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C57 License #: 348203

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GROUND ELEVATION: 130 ft-msl

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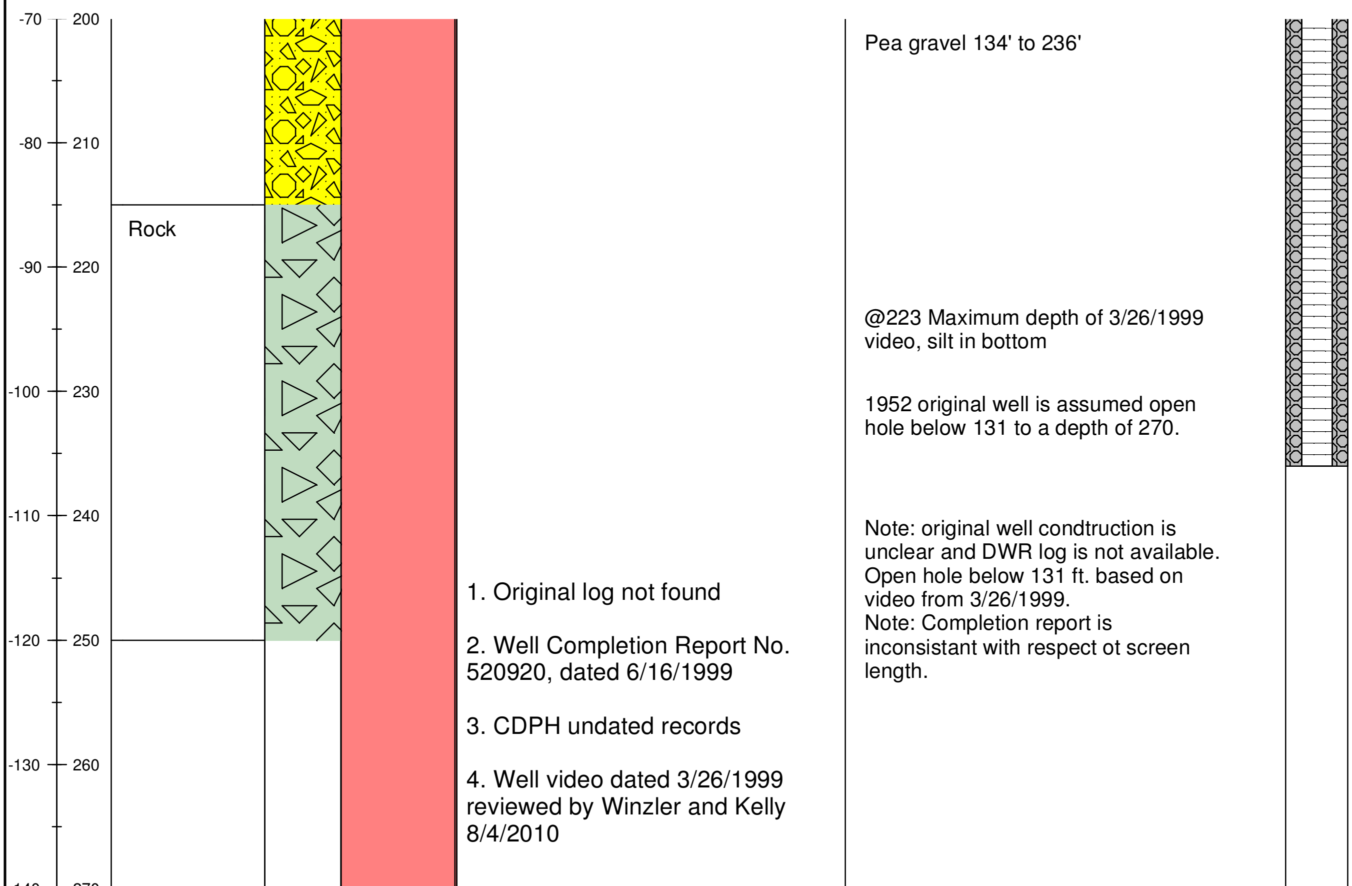
DRILLING METHOD: Air Rotary

DRILLING EQUIP: Unknown

TOC ELEVATION: 132 ft-msl

ELEVATION (ft.-msl)	DEPTH (ft.-bgs)	DRILLER'S DESC.	SOIL PROFILE	INTERPRETED STRATIGRAPHIC UNIT	NOTES FROM: 1,2,3	WELL CONSTRUCTION 1,2,3,4



DUPLICATE
Driller's Copy

Page ____ of ____

Owner's Well No. 6

Date Work Began 4-13-99, Ended 4-21-99

Local Permit Agency City of Sonoma

Permit No. 78-048, Permit Date ____

STATE OF CALIFORNIA

WELL COMPLETION REPORT

Refer to Instruction Pamphlet

No. 520920

DWR USE ONLY — DO NOT FILL IN

STATE WELL NO./STATION NO.

LATITUDE | LONGITUDE

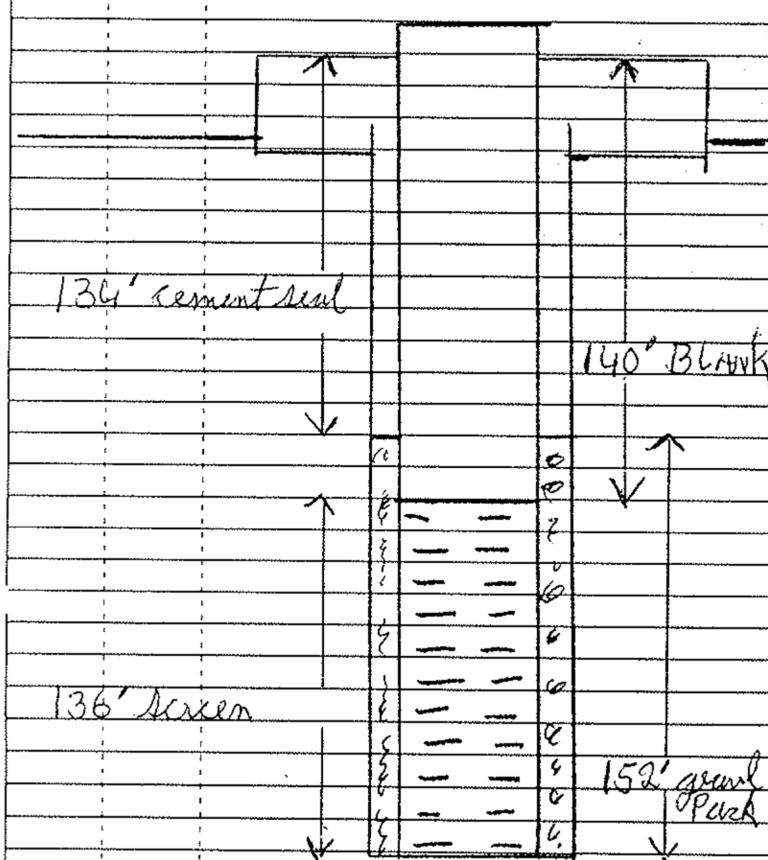
APN/TRS/OTHER

GEOLOGIC LOG

ORIENTATION (✓) ✓ VERTICAL ____ HORIZONTAL ____ ANGLE ____ (SPECIFY)

DEPTH TO FIRST WATER 140 (Ft.) BELOW SURFACE

DEPTH FROM SURFACE Ft. to Ft.	DESCRIPTION *Describe material, grain size, color, etc.*



reline existing 10" steel well

TOTAL DEPTH OF BORING 236 (Feet)

TOTAL DEPTH OF COMPLETED WELL 236 (Feet)

WELL OWNER

Name City of Sonoma

Mailing Address #1 on the Plaza

CITY Sonoma STATE Ca ZIP 95476

WELL LOCATION

Address 100 1st St West

City Sonoma

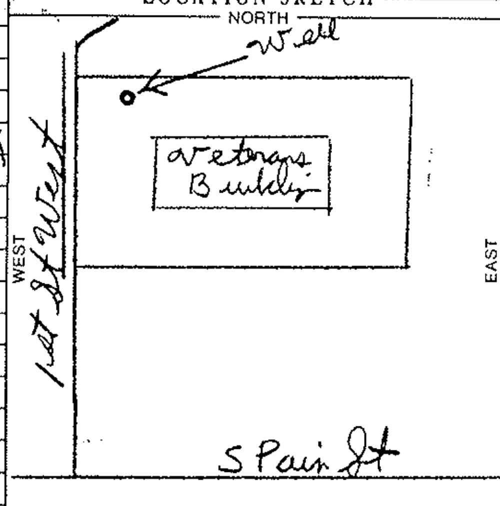
County Sonoma

APN Book 018 Page 032 Parcel 005

or Township ____ Range ____ Section ____

or Latitude ____ DEG. MIN. SEC. NORTH Longitude ____ DEG. MIN. SEC. WEST

LOCATION SKETCH



Illustrate or Describe Distance of Well from Landmarks such as Roads, Buildings, Fences, Rivers, etc. PLEASE BE ACCURATE & COMPLETE.

ACTIVITY (✓)

____ NEW WELL

MODIFICATION/REPAIR

____ Deepen

✓ Other (Specify) reline

____ DESTROY (Describe Procedures and Materials Under "GEOLOGIC LOG")

PLANNED USE(S) (✓)

____ MONITORING

WATER SUPPLY

____ Domestic

✓ Public

____ Irrigation

____ Industrial

____ "TEST WELL"

____ CATHODIC PROTECTION

____ OTHER (Specify)

DRILLING METHOD Air Rotary FLUID Air

WATER LEVEL & YIELD OF COMPLETED WELL

DEPTH OF STATIC WATER LEVEL 38' (Ft.) & DATE MEASURED 4-21-99

ESTIMATED YIELD* 200 (GPM) & TEST TYPE air

TEST LENGTH 5 (Hrs.) TOTAL DRAWDOWN 189 (Ft.)

* *May not be representative of a well's long-term yield.*

CASING(S)

DEPTH FROM SURFACE Ft. to Ft.	BORE-HOLE DIA. (Inches)	TYPE (✓) BLANK	SCREEN	CON-DUCTOR	FILL PIPE	MATERIAL / GRADE	INTERNAL DIAMETER (Inches)	GAUGE OR WALL THICKNESS	SLOT SIZE IF ANY (Inches)
0 140	10"	✓				PVC	6	200	
140 236	10"		✓			PVC	6	200	30

ANNULAR MATERIAL

DEPTH FROM SURFACE Ft. to Ft.	CE-MENT (✓)	BEN-TONITE (✓)	FILL (✓)	FILTER PACK (TYPE/SIZE)
0 134	✓			
			✓	Pea Gravel

ATTACHMENTS (✓)

____ Geologic Log

✓ Well Construction Diagram

____ Geophysical Log(s)

____ Soil/Water Chemical Analyses

____ Other ____

ATTACH ADDITIONAL INFORMATION, IF IT EXISTS.

CERTIFICATION STATEMENT

I, the undersigned, certify that this report is complete and accurate to the best of my knowledge and belief.

NAME Larbre WELL Drilling INC.
(PERSON, FIRM, OR CORPORATION) (TYPED OR PRINTED)

ADDRESS 18715 Arnold Dr CITY Sonoma STATE Ca ZIP 95476

Signed Raymond D Larbre (WELL DRILLER/AUTHORIZED REPRESENTATIVE) DATE SIGNED 6-16-99 C-57 LICENSE NUMBER 348203

DWR 188 REV. 7-90

IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

Sonoma County Water

Project No. 1601140

TW-6A

Requested by:
Robert Marks
Pueblo Water Resources, Inc.

Mineralogy, Inc. Number 16226

Date:
August 12, 2016

Submitted by:

Timothy B. Murphy

Mineralogy, Inc.
3321 East 27th Street
Tulsa, Oklahoma 74114
USA
+1 (918) 744.8284

www.mineralogy-inc.com

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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.

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Introduction

Two unconsolidated aquifer samples have been evaluated from the TW-6A Well for the Sonoma County Water Agency at the request of personnel with GEI Consultants and Pueblo Water. The samples consist of unconsolidated sands from depths of 150 ft. & 210 ft. below ground surface. Test methods utilized to evaluate these sediment samples include: x-ray diffraction mineralogical analysis with Rietveld refinement (XRD), x-ray fluorescence analysis (XRF), acid insoluble residue analysis, cation exchange capacity analysis (CEC), thin section petrography, and scanning electron microscopy analysis (SEM). The objective of this study is to provide basic mineralogical and geochemical data to assist in the development and management of these aquifer intervals.

Summary

The most significant findings of the laboratory evaluation are noted as follows:

- These sediment intervals are comprised of unconsolidated, medium to coarse grained, poorly sorted, glass-rich, volcanic litharenitic sands. The sand intervals contain an abundance of rhyolitic tuff and scoria rock fragments (RFs) coupled with rhyolite RFs, plagioclase feldspar crystals, obsidian RFs, and rare litharenitic sandstone and diorite RF materials.
- The scoria and tuffaceous RF materials commonly contain significant amounts of intra-particle gas escape vesicles. Intra-particle void volumes within selected volcanic RFs range up to 35-40%.
- Devitrification has contributed to the partial to complete replacement of glass components within selected RFs. Montmorillonite-rich clay is the dominant secondary replacement for volcanic glass, with minor amounts of chert and iron oxide cement also present as replacement mineral phases.
- The XRD mineralogical evaluation indicates the crystalline composition is dominated by plagioclase feldspar (28-37.1%), coupled with subordinate amounts of quartz (3%), magnetite (1-2.6%), and clay minerals (3-4.2%). Minor amounts of hematite were also detected in the aquifer specimen from core depth 210 ft. Amorphous glass materials are estimated to range from 50-65% of the composition within these specimens. Estimates of amorphous components were refined using an internal standard of aluminum oxide.
- The results of the XRF analysis are provided in Table II and indicate a composition dominated by silicon (SiO_2; 61.8-67.6%), and aluminum (Al_2O_3; 17.7-18.2%). Minor but significant element phases include sodium, calcium, iron, potassium, magnesium, and titanium.
- The results of the cation exchange capacity analysis are provided in Table III. The CEC analysis includes an evaluation of the leachate components to assess the relative contributions of divalent and monovalent cation types with respect to the cumulative CEC for each of the samples. The cumulative cation exchange capacity for theses sediments ranges from 17.41-19.84 meq/100g. The hierarchy of exchangeable cation species is noted as follows: sodium > calcium > magnesium > potassium.

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- The results of the acid insoluble residue analysis are provided in Table IV. Acid insoluble residue values range from 97.4-97.6% for these aquifer intervals.
- The SEM grain mount specimens consist of glass-rich volcanic litharenitic sands that are unconsolidated, medium to coarse-grained, and moderately to poorly sorted. The sand grains exhibit localized evidence of devitrification and replacement with authigenic clay, microcrystalline chert, and/or iron oxide cement. The friable nature of the tuffaceous and scoria particles has contributed to moderate amounts of silt-sized volcanic grain debris. The grain debris includes poorly sorted and microporous clusters of glass shards, phenocrysts of plagioclase feldspar, and clay matrix constituents.
- Selected volcanic RFs are partially to completely replaced with authigenic montmorillonite and/or mixed layered illite/smectite clay. Locally significant amounts of kaolinite are also present as a replacement associated with leached and altered feldspar crystals.

X-ray Diffraction Mineralogical Analysis

The results of the x-ray diffraction mineralogical analysis with Rietveld refinement are summarized in Table I. The XRD analysis reveals that amorphous material comprises ~50-65% of the bulk volume within these sediments. The amorphous fraction is attributed to volcanic glass which dominates the groundmass of the tuff, scoria, and rhyolite RF materials. Plagioclase feldspar is the most abundant crystalline mineral phase and accounts for ~28.0 - 37.1% of the sample mass. Minor but significant mineral phases detected in the XRD evaluation include quartz, magnetite, hematite, montmorillonite, mixed layered illite/smectite, and kaolinite. Quantitation of the amorphous fraction has been estimated with the benefit of an aluminum oxide internal standard.

Table I

	Cutting Depth (ft.)	150	210
	Lab ID	16226-01	16226-02
Mineral Constituents	Chemical Formula	Relative Abundance (%)	
Quartz	SiO_2	3	3
Plagioclase Feldspar	$(Na,Ca)AlSi_3O_8$	28	37.1
Magnetite	alpha-Fe_3O_4	1	2.6
Hematite	alpha-Fe_2O_3		2.1
Kaolinite	$Al_2Si_2O_5(OH)_4$	0.8	1
Montmorillonite	$Na_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 . xH_2O$	0.9	2
Mixed-Layered Illite/Smectite	$K_{0.5}Al_2(Si,Al)_4O_{10}(OH)_2 . 2H_2O$	1.3	2.2
Amorphous		65	50
TOTAL		100	100

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X-ray Fluorescence Elemental Analysis

The results of the x-ray fluorescence elemental analysis are summarized in Table II. Major elemental phases identified in the XRF evaluation are reported as oxide equivalents and include: silicon (SiO_2; 61.8-67.6%), aluminum (Al_2O_3; 17.7-18.2%), iron (Fe_2O_3; 4.26-7.57%), calcium (CaO; 2.18-4.14%), sodium (Na_2O; 3.40-3.47%), potassium (K_2O; 2.17-3.53%), titanium (TiO_2; 0.472-1.09%), and magnesium (MgO; 0.419-1.13%). Trace elements detected in the XRF evaluation include phosphorous, chlorine, manganese, zinc, barium, rubidium, strontium, yttrium, and zirconium.

Table II

	Sample ID	TW-6A; 150'	TW-6A; 210'
	M.I. Sample ID	16226-01	16226-02
Elemental Phase	Chemical Formula	Concentration (Mass %)	
Sodium	Na_2O	3.40	3.47
Magnesium	MgO	0.419	1.13
Aluminum	Al_2O_3	17.7	18.2
Silicon	SiO_2	67.6	61.8
Phosphorous	P_2O_5	0.0829	0.156
Sulfur	S	0.0149	0.0065
Chlorine	Cl	0.0469	0.0262
Potassium	K_2O	3.53	2.17
Calcium	CaO	2.18	4.14
Titanium	TiO_2	0.472	1.09
Manganese	MnO	0.0790	0.0847
Iron	Fe_2O_3	4.26	7.57
Zinc	Zn	0.0080	0.0077
Rubidium	Rb	0.0148	0.0117
Strontium	Sr	0.0206	0.0308
Yttrium	Y	0.0047	0.0039
Zirconium	Zr	0.0377	0.0295
Barium	BaO	0.106	0.0786

Cation Exchange Capacity Analysis

The results of the cation exchange capacity analysis are summarized in Table III. The CEC data summary provides discrete exchange values for common divalent & monovalent cation species which include: calcium, magnesium, potassium, and sodium. The cumulative or total CEC value for these sediments ranges from ~17.41-19.84 meq/100g. The hierarchy of exchangeable cation species as listed from greatest to least includes: sodium (Na) > calcium (Ca) > magnesium (Mg) > potassium (K).

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Table III

			Calcium		Magnesium		Potassium		Sodium		
			Results	PQL**	Results	PQL**	Results	PQL**	Results	PQL**	Cumulative
Depth (ft)	Core ID	Sample ID	(meg/100g)		(meg/100g)		(meg/100g)		(meg/100g)		CEC
150.00	TW-6A	16226-01	4.31	0.100	2.87	0.100	2.06	0.100	10.6	0.100	19.840
210.00	TW-6A	16226-02	4.21	0.100	3.39	0.100	1.41	0.100	8.40	0.100	17.410

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 Analysis

The results of the acid insoluble residue analysis are summarized in Table IV. Acid insoluble constituents account for ~97.4-97.6% of the solids within these volcanic litharenitic sand samples. The volcanic glass, feldspar, and quartz components are relatively insoluble with exposure to HCL acid solutions. Acid soluble material could include minor amounts of clay matrix material +/- carbonate cement associated with the litharenitic sand sediments.

Table IV

Lab ID	Core ID	Depth	Acid Insoluble Residue (%)
16226-01	TW-6A	150 ft	97.4
16226-02	TW-6A	210 ft	97.6

Scanning Electron Microscopy & Thin Section Petrographic Analysis

Representative images from the scanning electron microscopy (SEM) and and thin section petrographic analysis for these aquifer samples are presented in Appendix I. The following discussion provides an overview of the texture, fabric, detrital & authigenic mineralogy, matrix properties, and pore system characteristics for these aquifer intervals.

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Table V

Sample Depth (ft.)	150	210
Lab ID	16226-01	16226-02
Parameter		
Lithologic Classification	Volcanic Litharenitic Sand	Volcanic Litharenitic Sand
*Texture**	Unconsolidated,	Unconsolidated,
	mL - mU,	cU
	ps, sa	ms-ps, sa
GSA Color Designation	gray-orange	pale brown
	10YR 7/4	5YR 5/2
Major Detrital Grain Types	Tuffaceous RFs	Scoria RFs
	Rhyolite / Trachyte RFs	Tuffaceous RFs
	Plagioclase Feldspar	Rhyolite / Trachyte RFs
	Obsidian	Obsidian
	Rare Litharenitic sandstone & diorite RFs	Plagioclase Feldspar

** Note: 'cU' - coarse-grained (upper), 'mL' medium-grained (lower), 'mU - medium-grained (upper), 'ms' - moderately sorted, 'ps' - poorly sorted, 'sa' - sub-angular, 'sr' - sub-rounded, 'RF' - rock fragment*

Detrital Fabric

The unconsolidated sediments from these aquifer intervals are medium to coarse grained, moderately to poorly sorted, subangular, volcanic litharenitic sands. The grain surfaces locally exhibit encrustations of silt-sized grain debris, phenocrysts of plagioclase feldspar, and scattered clusters of authigenic clay matrix material. Tuffaceous and scoria RFs contained within these sand specimens locally contain significant amounts of intra-particle (gas escape) void space. The most porous of the volcanic RFs are relatively weak & friable, and have contributed to the common presence of silt-sized grain debris within the thin section and SEM specimens.

Framework Components

Detrital grains contained within these volcanic litharenitic sand specimens include tuffaceous RFs, scoria RFs, rhyolite RFs, plagioclase feldspar crystals, obsidian RFs, rare litharenitic sandstone RFs and diorite RFs. Gas escape voids are common within the scoria and tuffaceous RF materials. The tuff, scoria, and rhyolite RFs all exhibit amorphous volcanic glass as a ubiquitous groundmass material. The tuff and rhyolite RFs commonly exhibit phenocrysts of plagioclase feldspar suspended in the glassy

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matrix. Selected volcanic sand grains exhibit alteration halos indicative of peripheral weathering and localized devitrification of the volcanic glass.

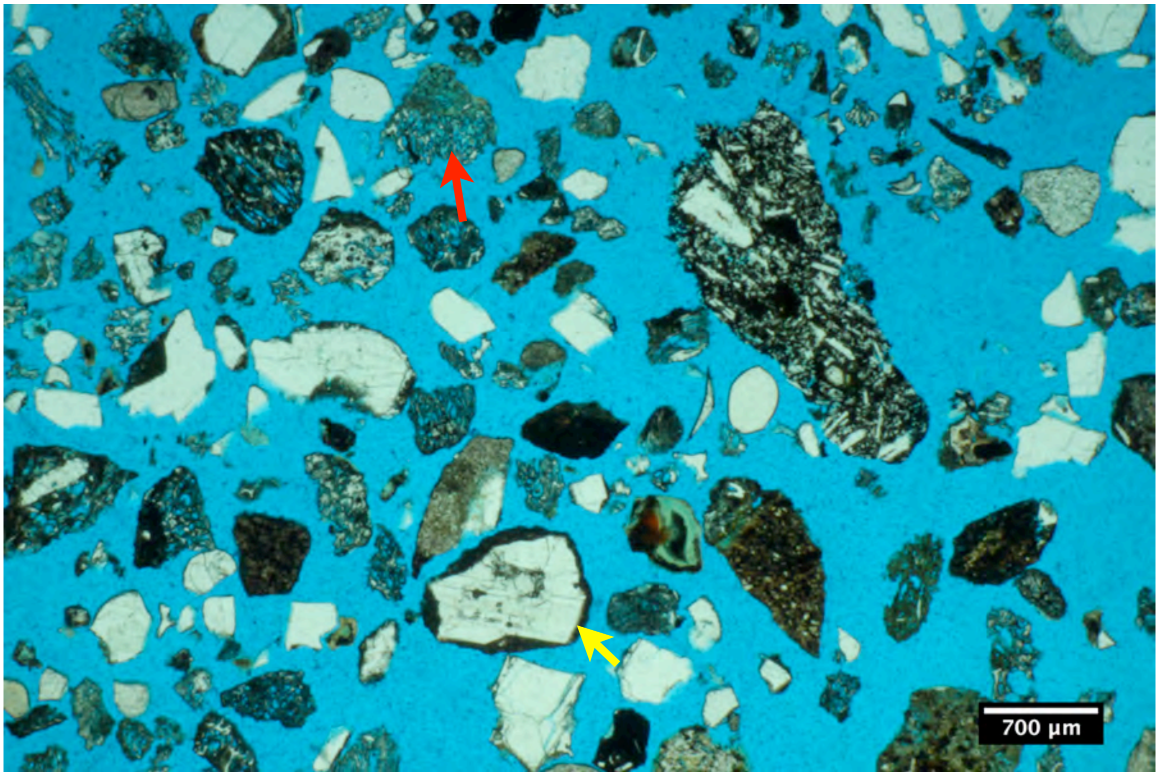
Matrix Components

Based on the XRD mineralogical analysis, clay matrix minerals account for ~3.0 - 5.2% of the total mass within these aquifer specimens. Clay matrix minerals include mixed layered illite/smectite coupled with significant amounts of montmorillonite and kaolinite. All of the clay occurs as authigenic matrix related to the localized alteration and replacement of volcanic glass and feldspar. The sand-sized framework grains are commonly encrusted with clusters of silt-sized grain debris. The grain debris typically consists of amorphous glass shards, very fine to finely crystalline phenocrysts of plagioclase feldspar, iron oxide cement crystals, and clay matrix minerals. The grain debris and authigenic materials are locally brush-piled and concentrated within selected inter-granular pore throats within the thin section & SEM grain-mounts, mimicking the likely presentation of these materials within the *in-situ* aquifer intervals.

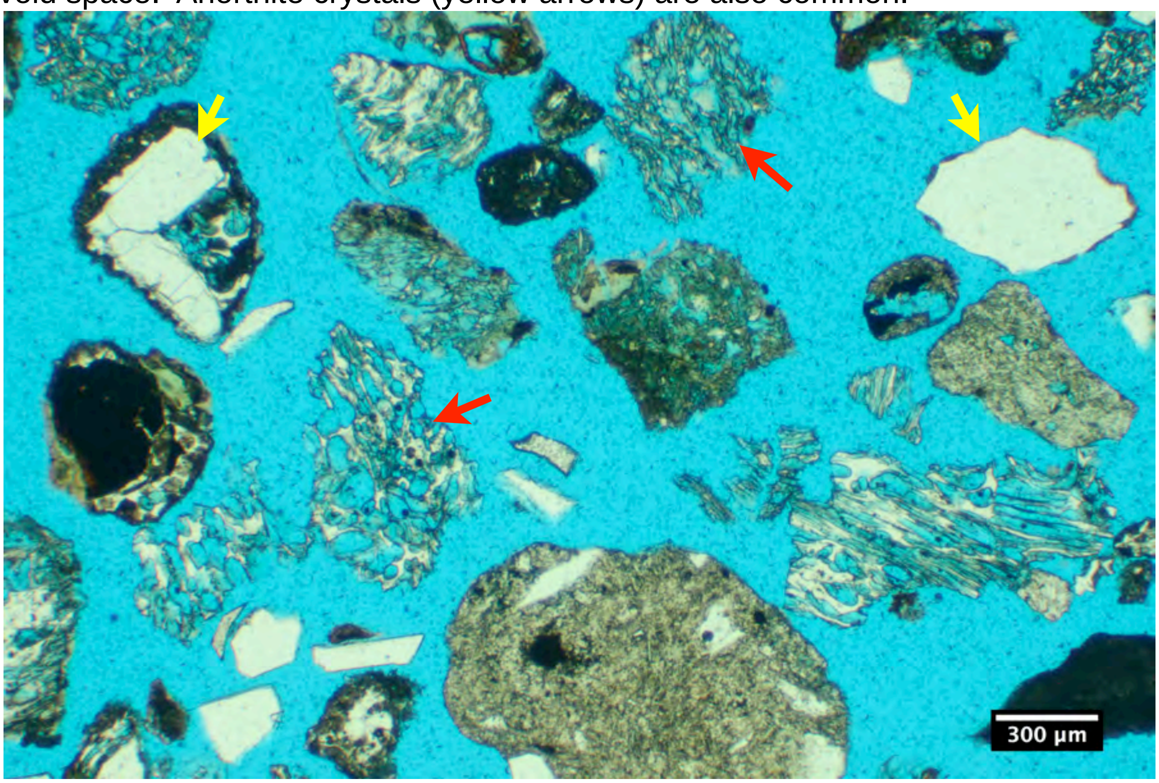
Pore System

The pore system for these specimens cannot be directly evaluated due to the unconsolidated character of the aquifer sediments. Mildly compacted, moderately to poorly sorted, medium to coarse-grained sand specimens can exhibit void volumes that range as high as 30-40% based upon experimental compaction studies (Beard & Weyl; 1973). Voids contained within the grain mounts include inter-particle (primary) voids as well as intra-particle gas escape voids associated with the tuff and scoria RFs.

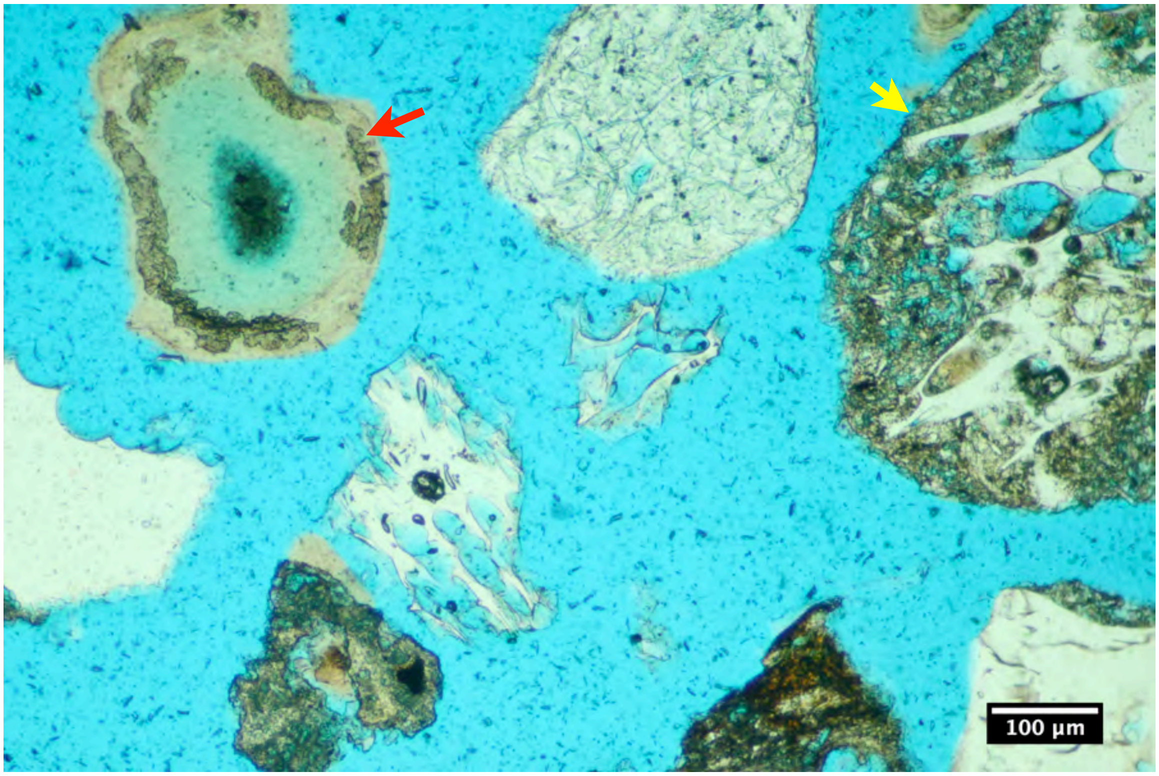
TW-6A - 150’; MI#16226-01



Scoria & tuff rock fragments (red arrows) containing abundant intraparticle cellular void space. Anorthite crystals (yellow arrows) are also common.



TW-6A - 150'; MI#16226-01



A tuff particle partially devitrified and replaced with montmorillonite clay (red arrows). Note the welded tuff RF (yellow arrows).

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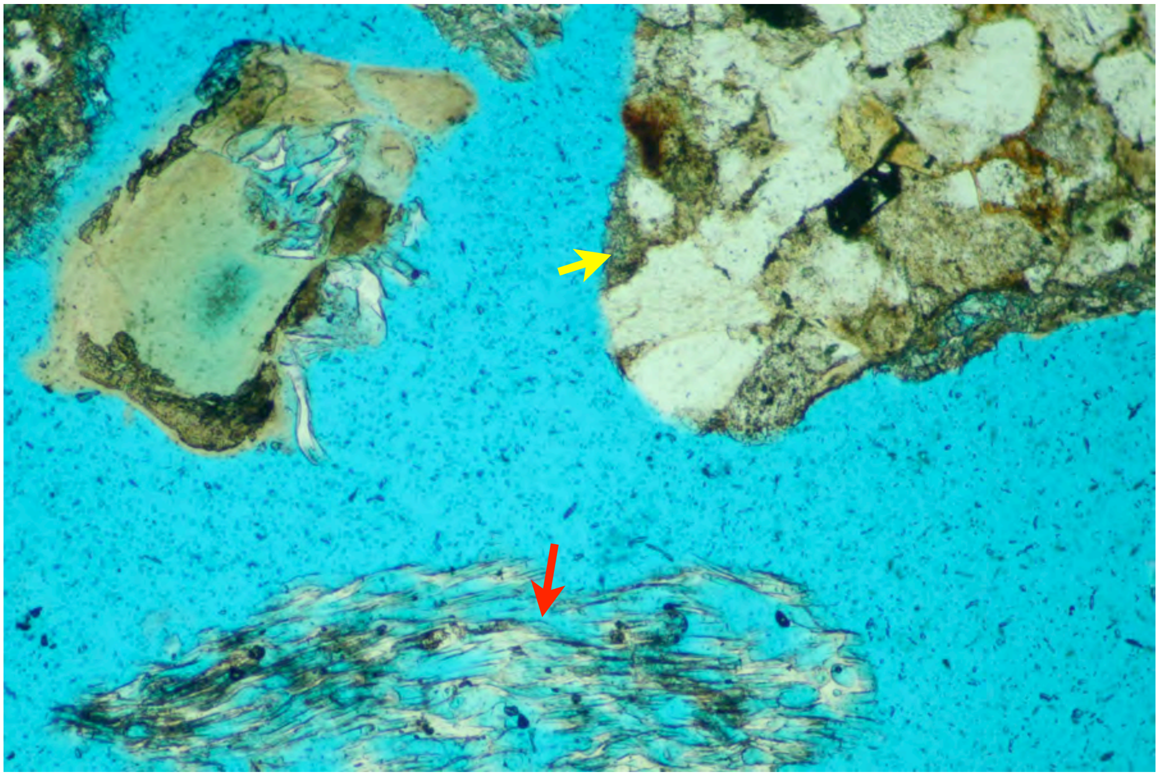
TW-6A - 150’; MI#16226-01



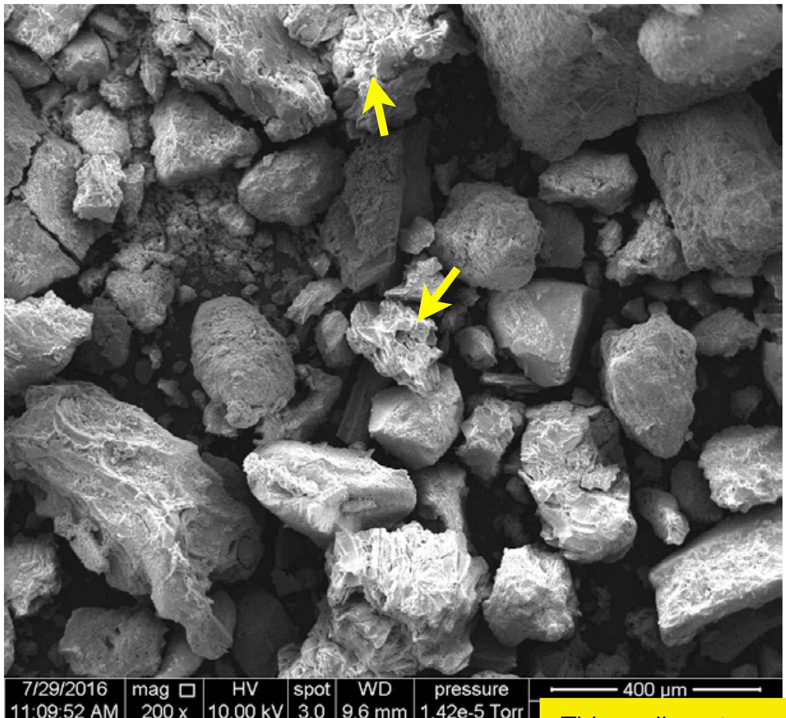
Selected scoria RFs contain >35% intraparticle porosity (red arrows). Note the granodiorite RF partially altered & replaced with authigenic clay (yellow arrows).

TW-6A - 150’ ft. - MI#16226-01 SEM

Summary: This well cutting sample is described as an unconsolidated, fine-grained, moderately to poorly sorted, subangular, volcanoclastic-rich litharenitic sand. The sand-sized grains include rhyolitic and basaltic tuff, scoria, welded tuff, gabbro & granodiorite rock fragments. The XRD analysis (see Table I) indicates a crystalline mineral composition that is largely dominated by plagioclase feldspar (anorthite), coupled with minor amounts of quartz, magnetite, and clay minerals. The clays are present as authigenic replacements for weathered volcanic RFs. Montmorillonite is the dominant clay species, with minor kaolinite and illite also present in the clay fraction.

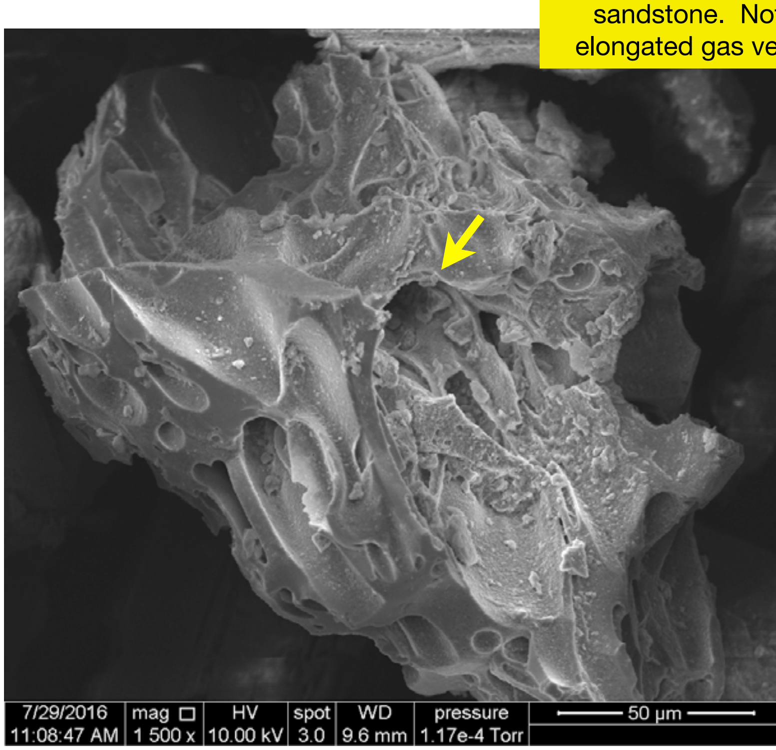
16226-01 Photo Index: (bookmarks)

16226-01A 200X



16226-01B 1500X

This sediment sample is characterized as a fine-grained, moderately sorted, subangular, volcanic-rich litharenitic sandstone. Note the scoria RF with elongated gas vesicles (yellow arrows).



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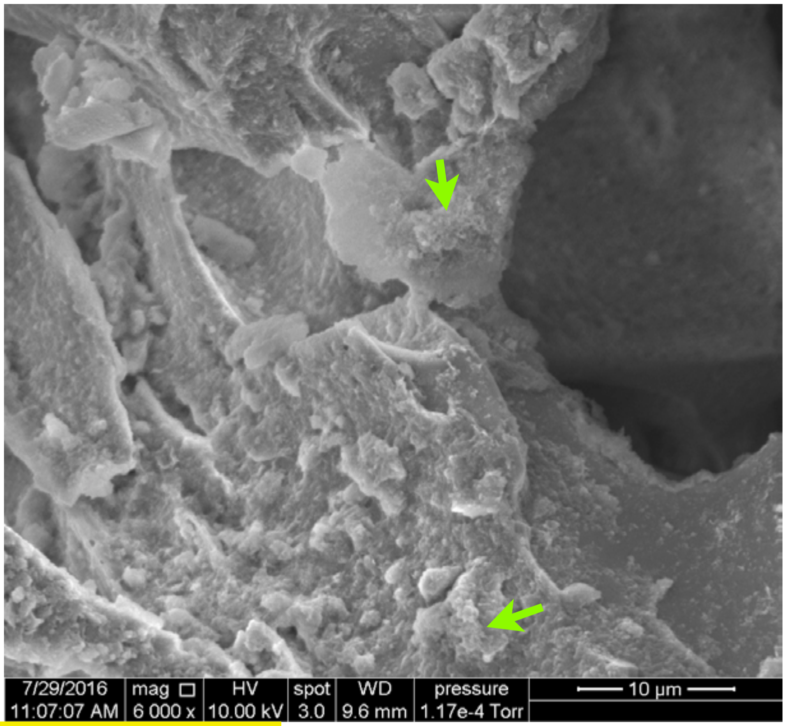
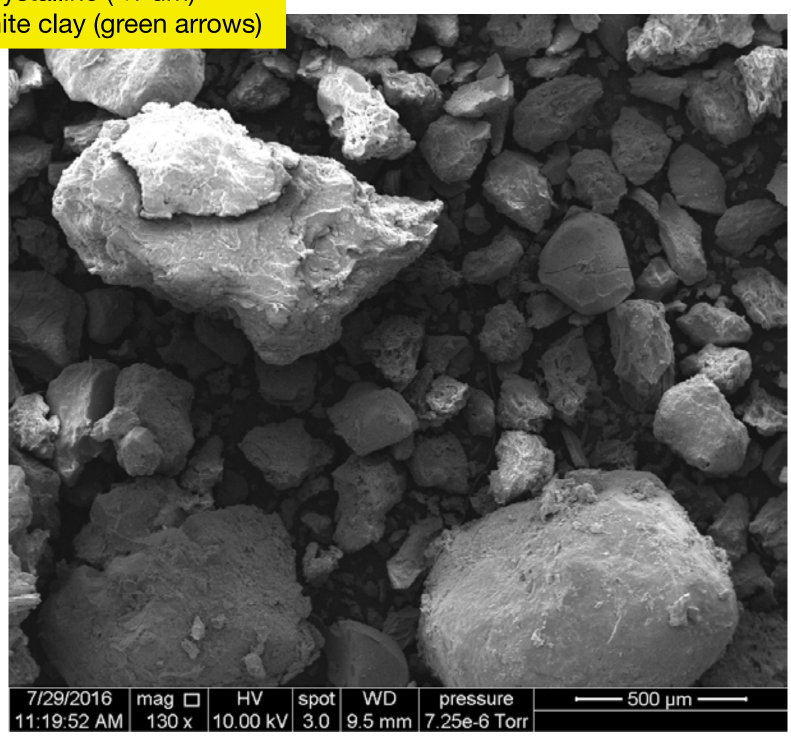
16226-01C 6000X



The glass shards of the scoria RFs are typically encrusted with microcrystalline (<1 um) montmorillonite clay (green arrows)

16226-01D 130X



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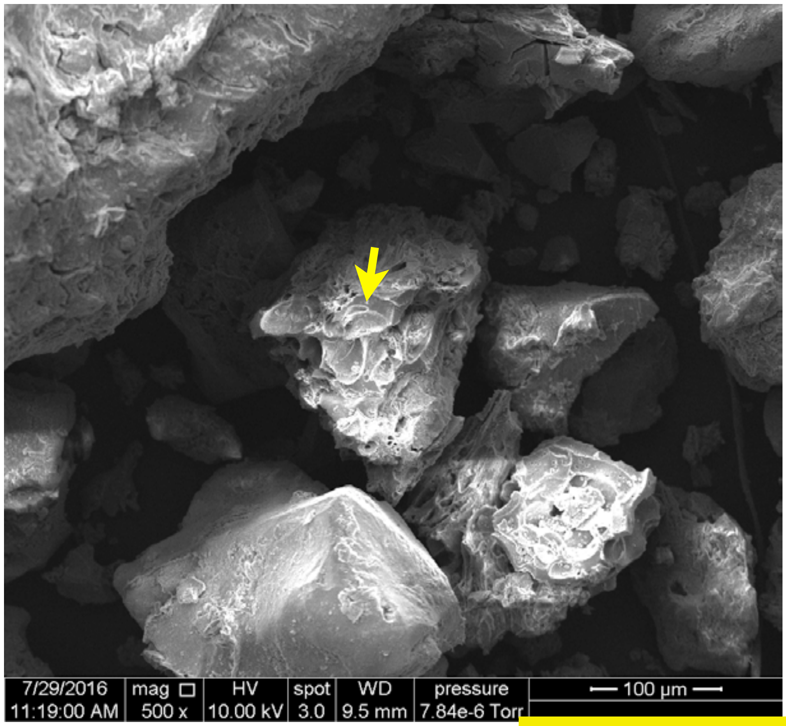
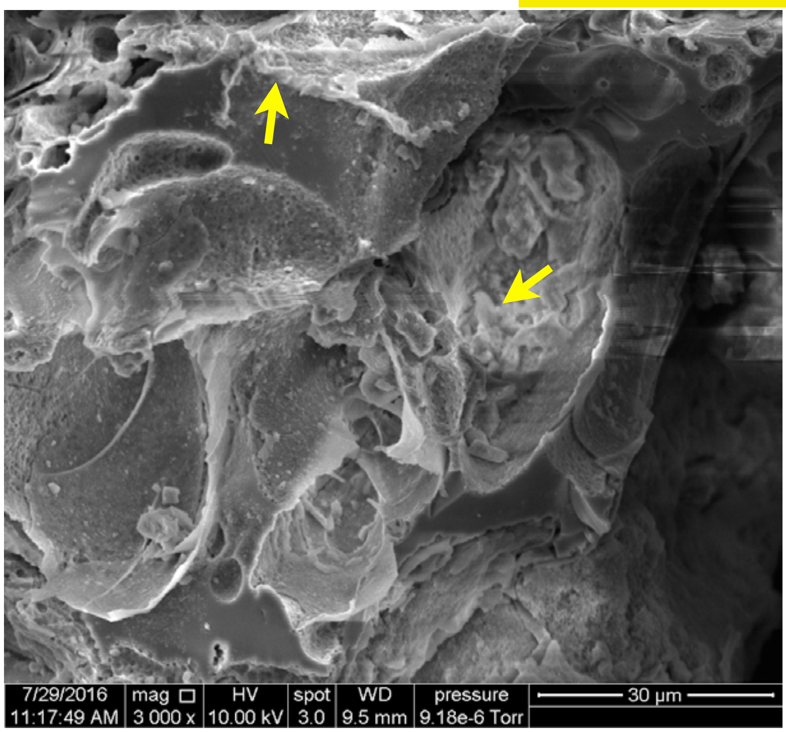
16226-01E 500X



16226-01F 3000X

Montmorillonite clay (yellow arrows) partially replacing a glass-rich scoria RF



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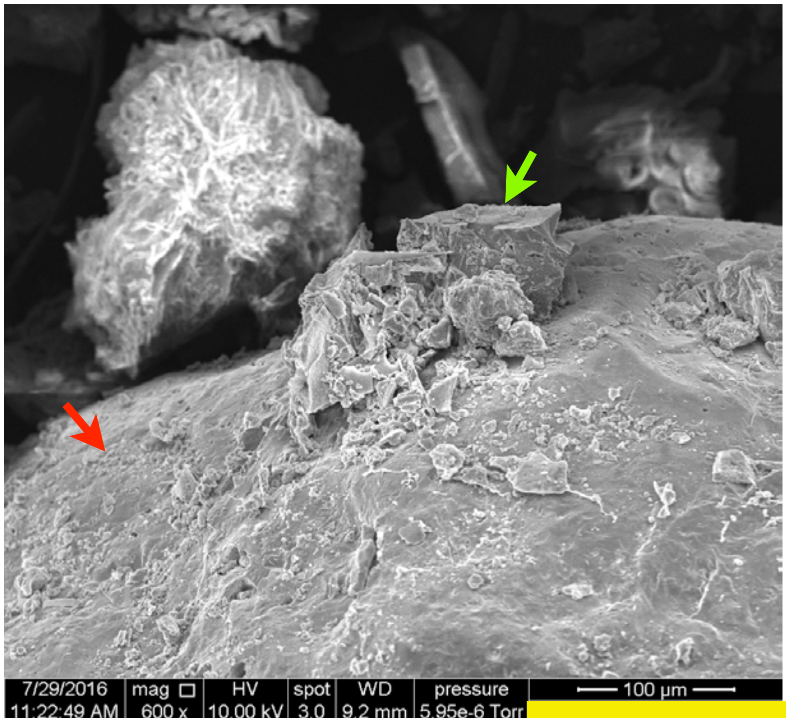
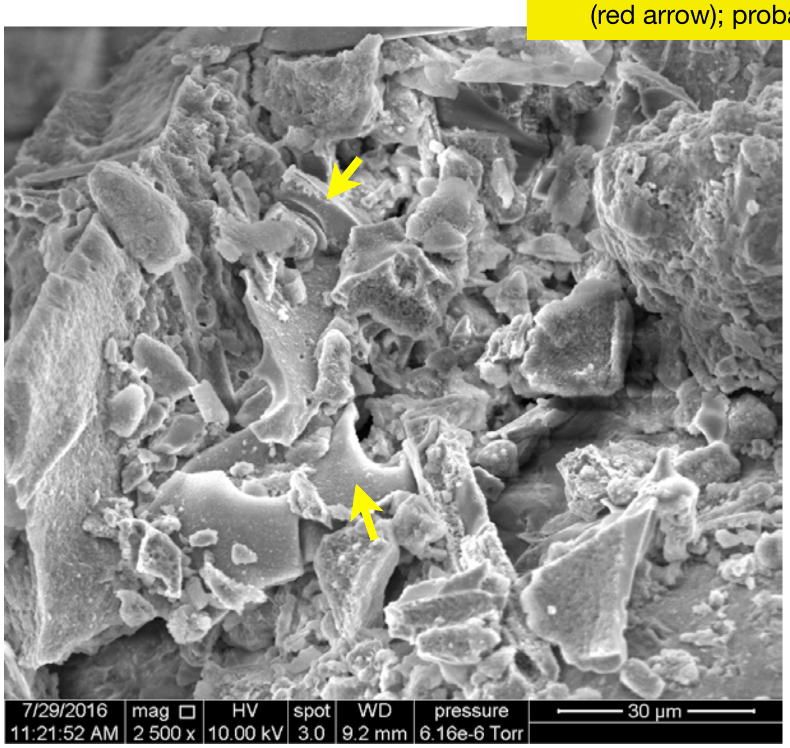
16226-01G 600X



Silt-sized glass shards (yellow arrows) & feldspar crystals (green arrows) encrusting a sand-sized detrital grain (red arrow); probably anorthite)

16226-01H 2500X



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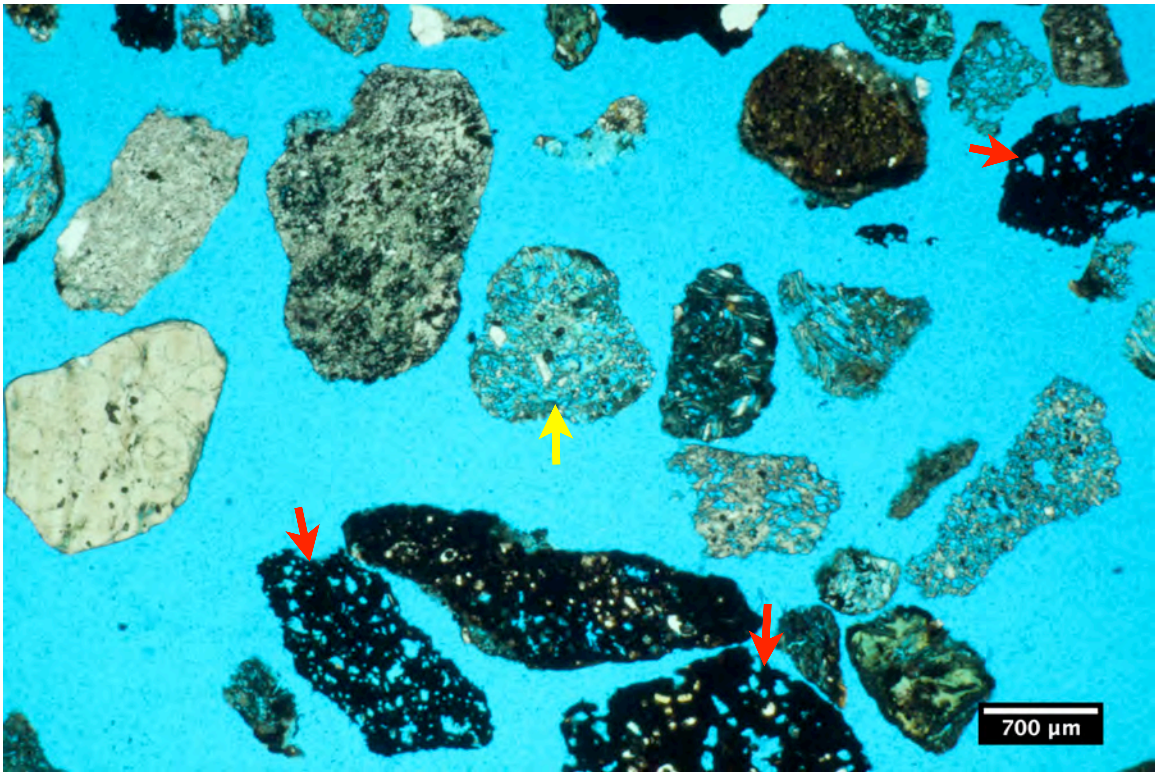
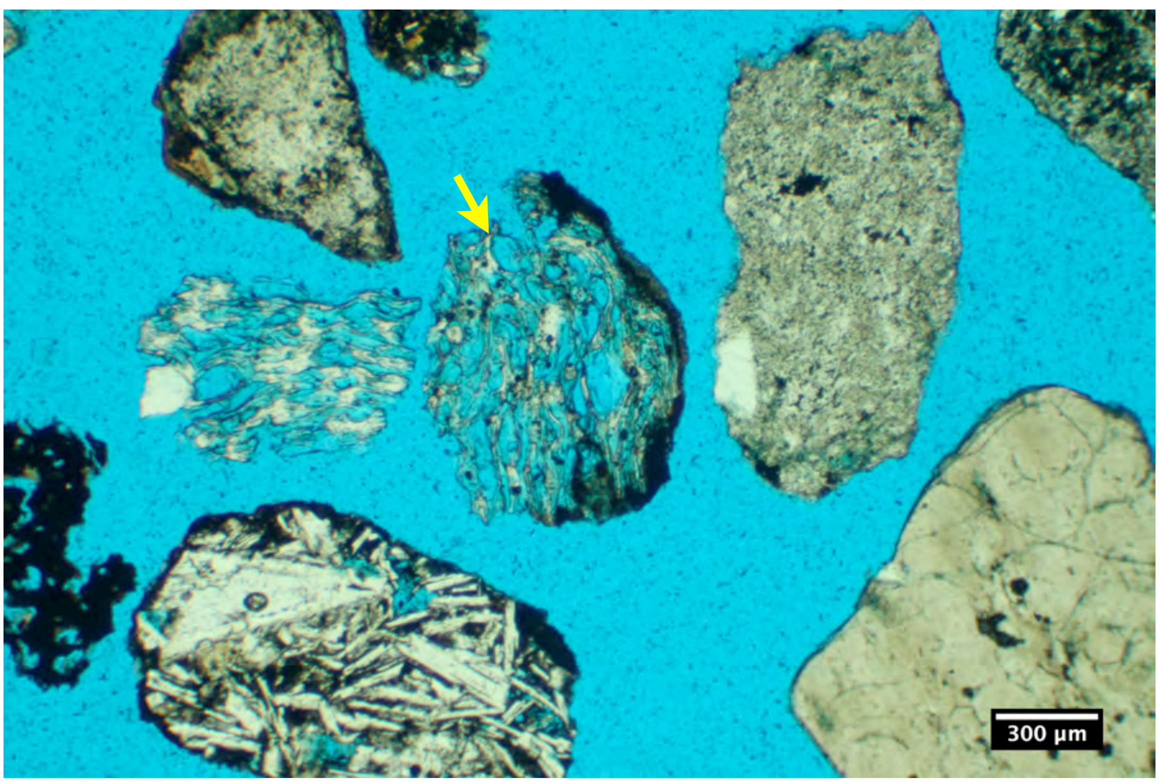
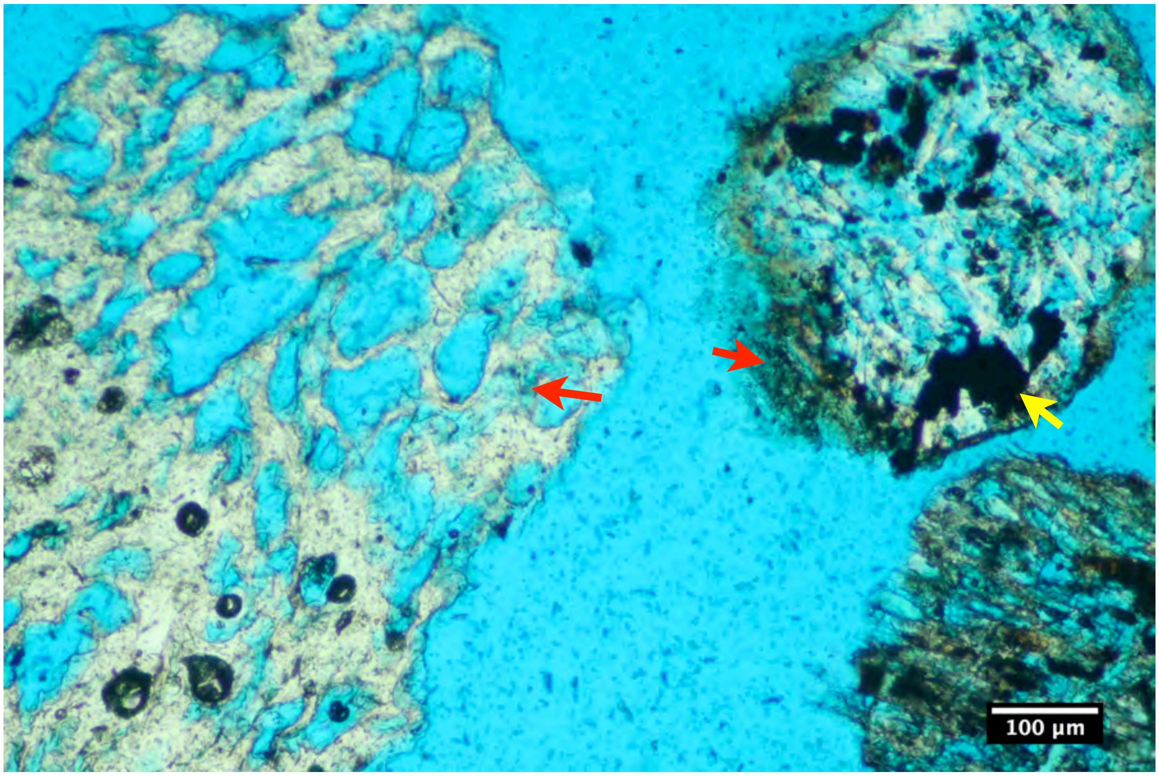
TW-6A - 210’; MI#16226-02



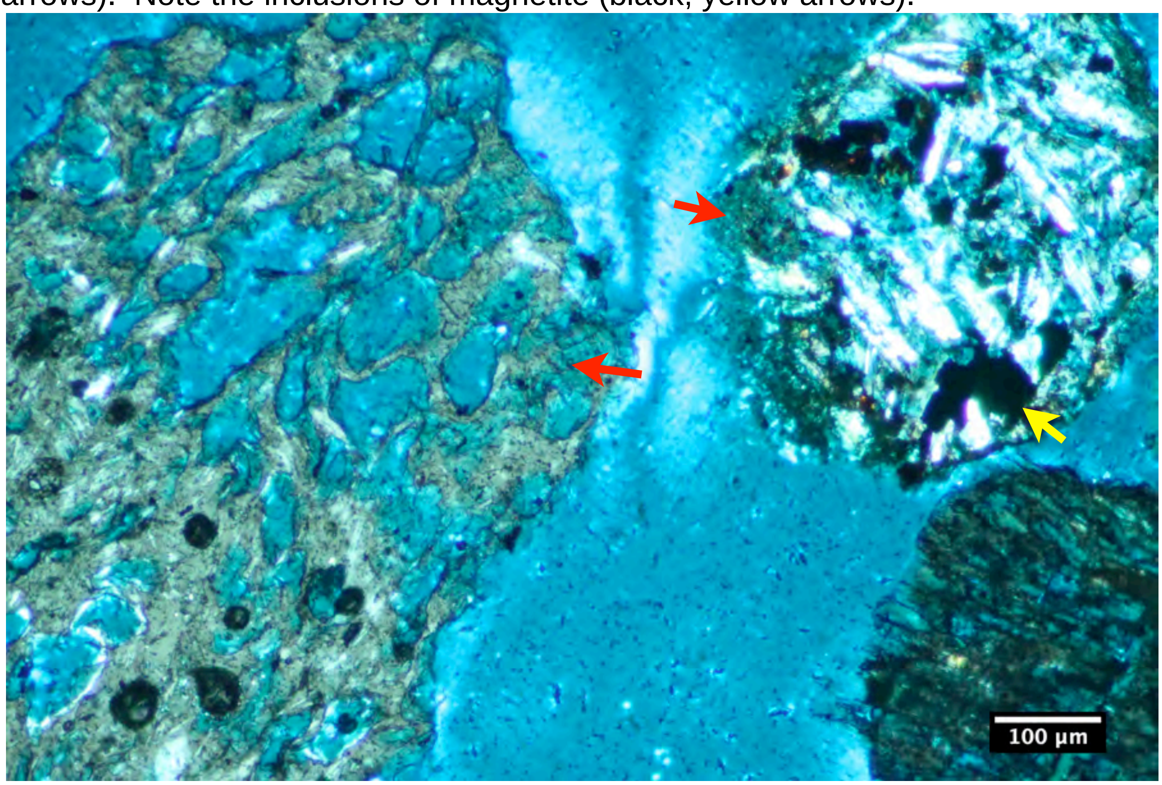
Scoria RFs (red arrows) and rhyolitic tuff RFs (yellow arrows).



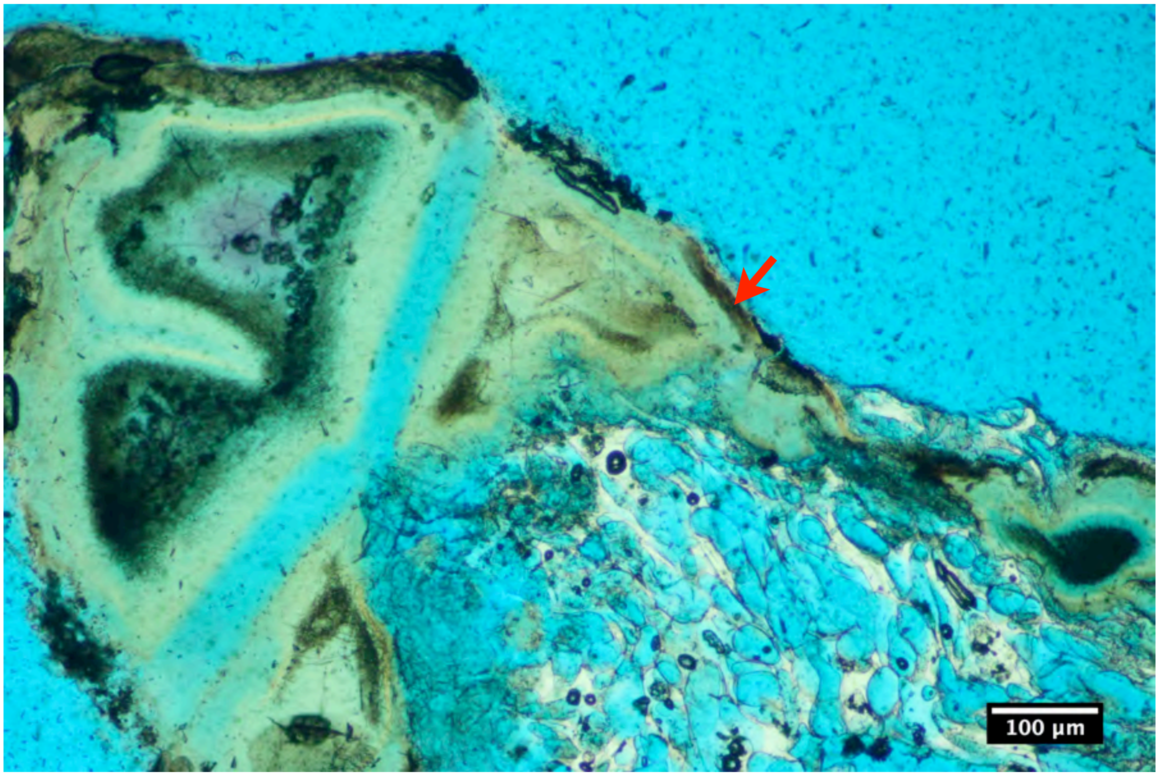
TW-6A - 210'; MI#16226-02



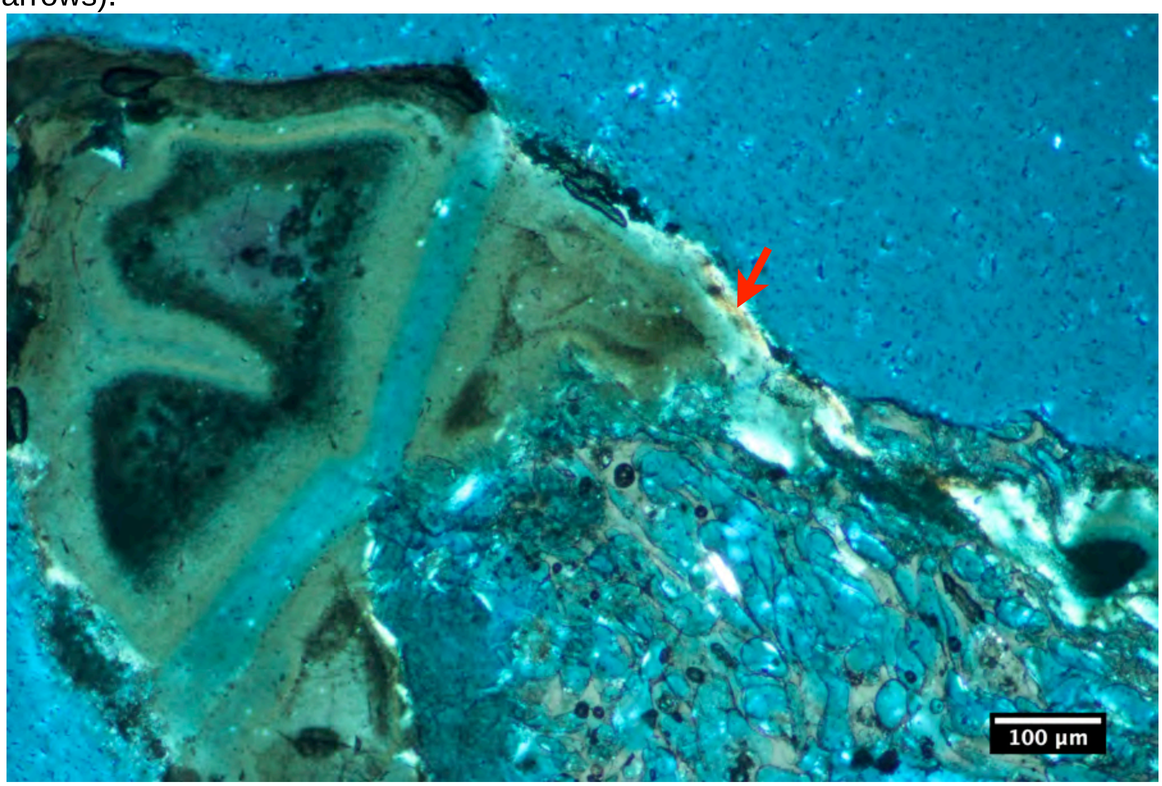
Scoria and tuffaceous RFs partially replaced with montmorillonite clay (red arrows). Note the inclusions of magnetite (black; yellow arrows).



TW-6A - 210'; MI#16226-02



A welded tuff particle marginally replaced with authigenic montmorillonite clay (red arrows).

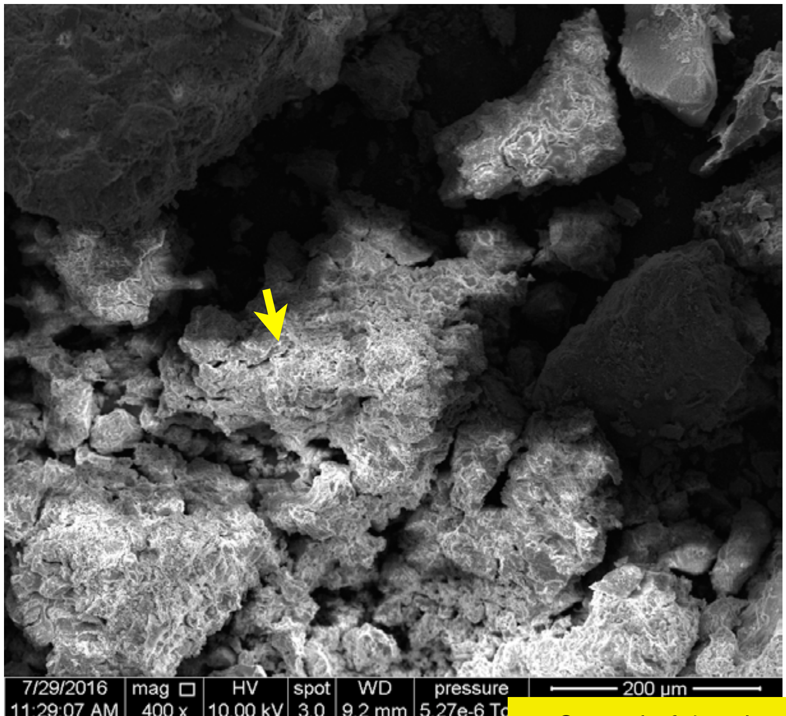


TW-6A - 210' ft. - MI#16226-02 SEM

Summary: This drill cutting sample is characterized as a coarse-grained, moderately to poorly sorted, sub-angular, unconsolidated, volcanic litharenitic sand. Detrital grain types include: scoria rock fragments (RFs), tuffaceous RFs, rhyolite / trachyte RFs, obsidian RFs, and discrete (fine to coarsely crystalline) plagioclase feldspar crystals. Selected tuffaceous RFs contain significant amounts (~5-25%) of intraparticle vesicular porosity. Scattered glass-rich RFs are locally devitrified and replaced with authigenic clay (mostly mixed-layered iliite/smectite +/- montmorillonite +/- kaolinite) and/or iron oxide (magnetite +/- hematite) cement. Scattered lithic grains exhibit marginal weathering halos.

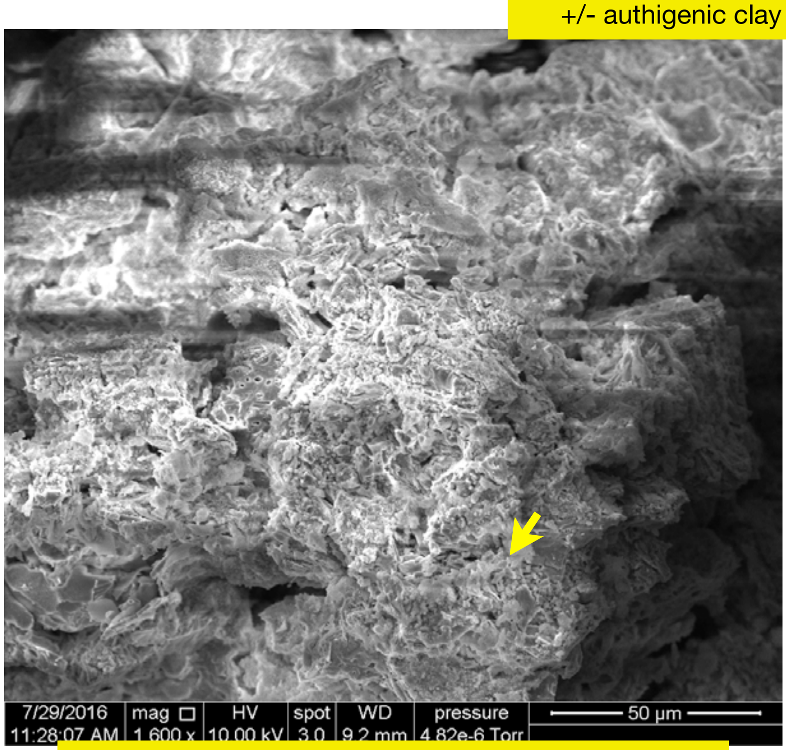
16226-02 Photo Index: (bookmarks)

16226-02A 400X



Several of the glass-rich tuffaceous RFs are partially disaggregated and locally encrusted with weakly attached clusters of silt-sized glass shards +/- authigenic clay minerals (yellow arrows)

16226-02B 1600X



The weakly attached clusters of glass-rich grain debris + clay are prone to surface charging due to poor conductivity with the Au/Pd coated sample surface.

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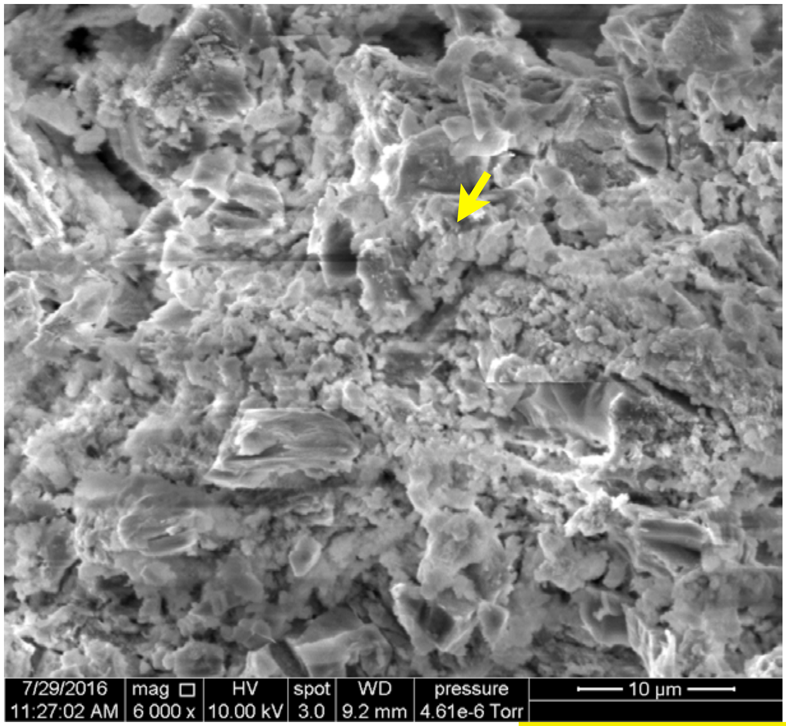
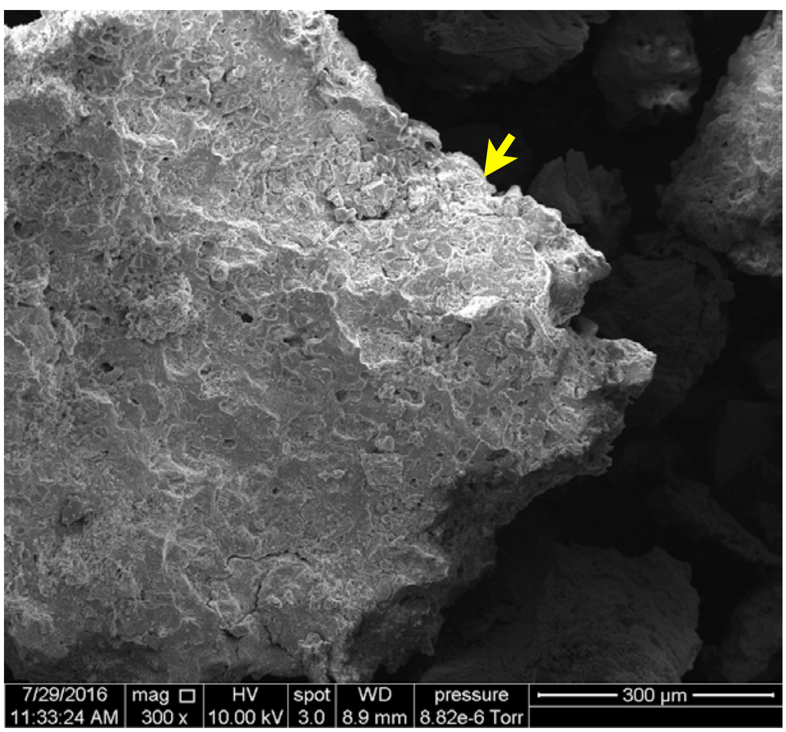
16226-02C 6000X

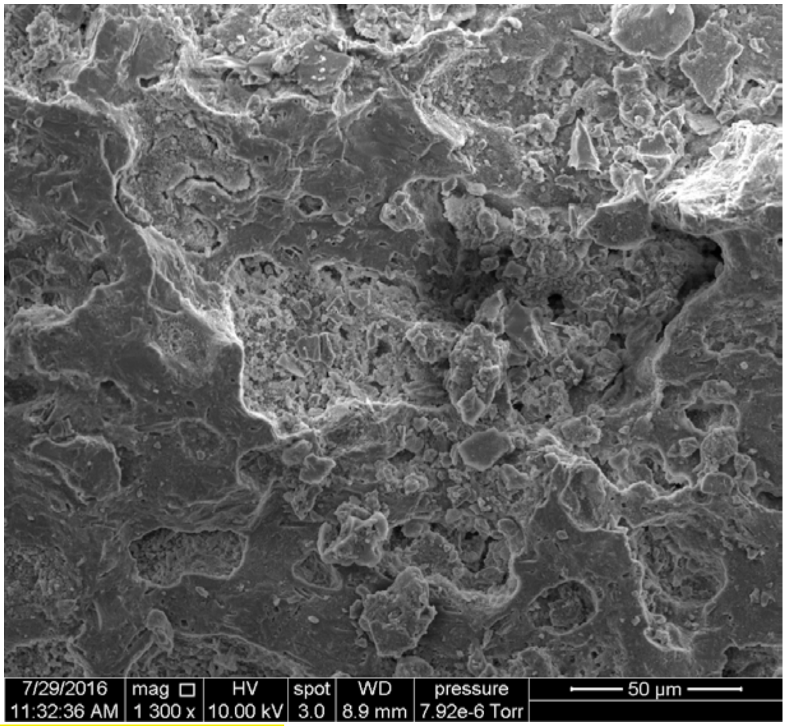


16226-02D 300X

Partially devitrified and microporous tuffaceous RFs (yellow arrows)

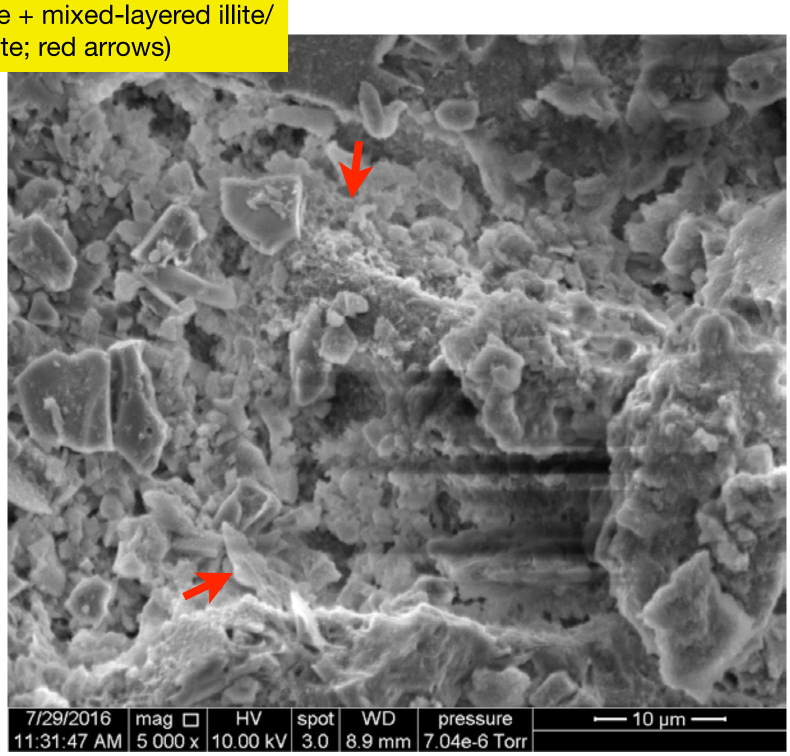


16226-02E 1300X



Vesicular intraparticle voids encrusted with poorly crystallized authigenic clay (montmorillonite + mixed-layered illite/smectite; red arrows)

16226-02F 5000X



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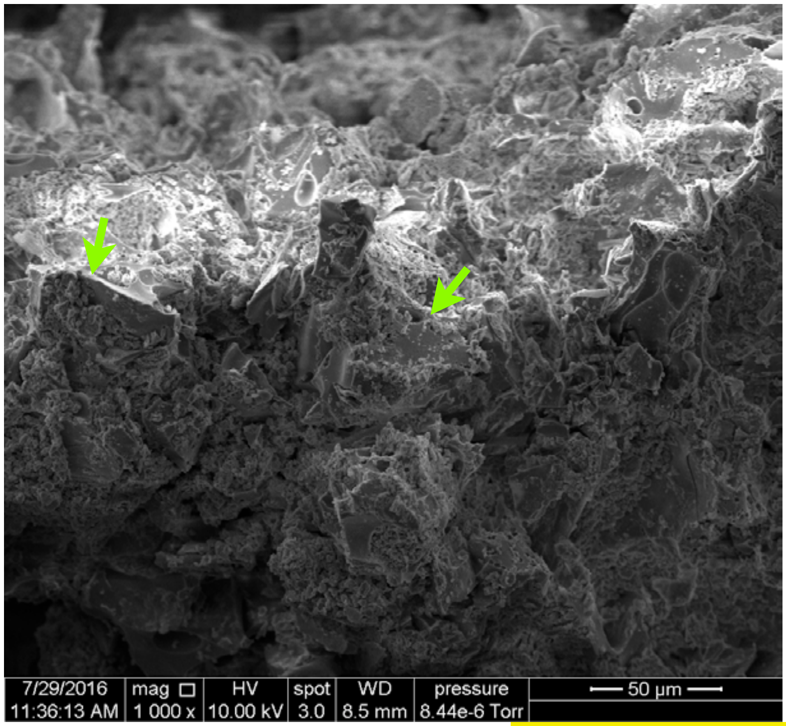
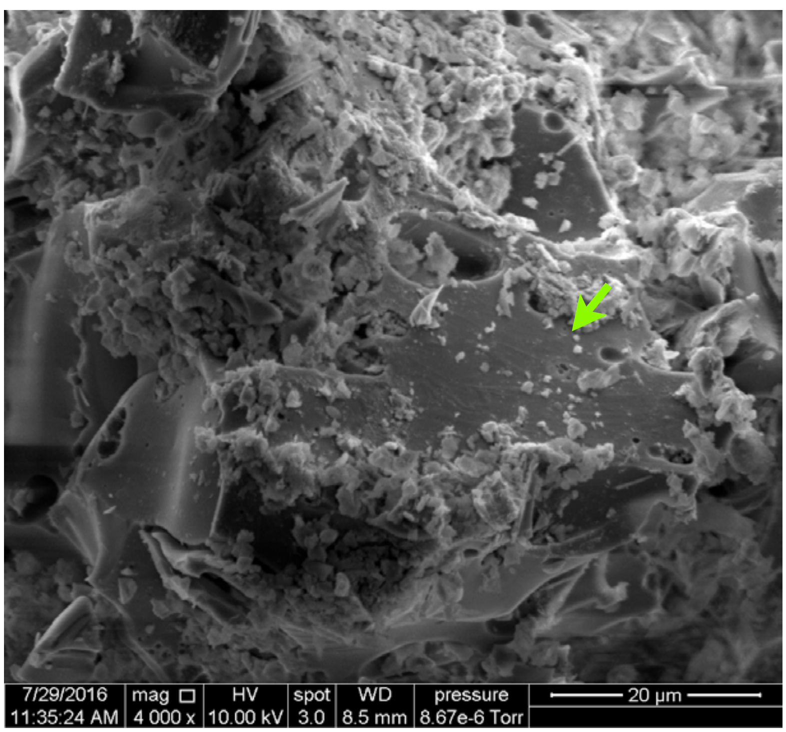
16226-02G 1000X



16226-02H 4000X

Plagioclase feldspar phenocrysts within a rhyolite / trachyte RF (green arrows)



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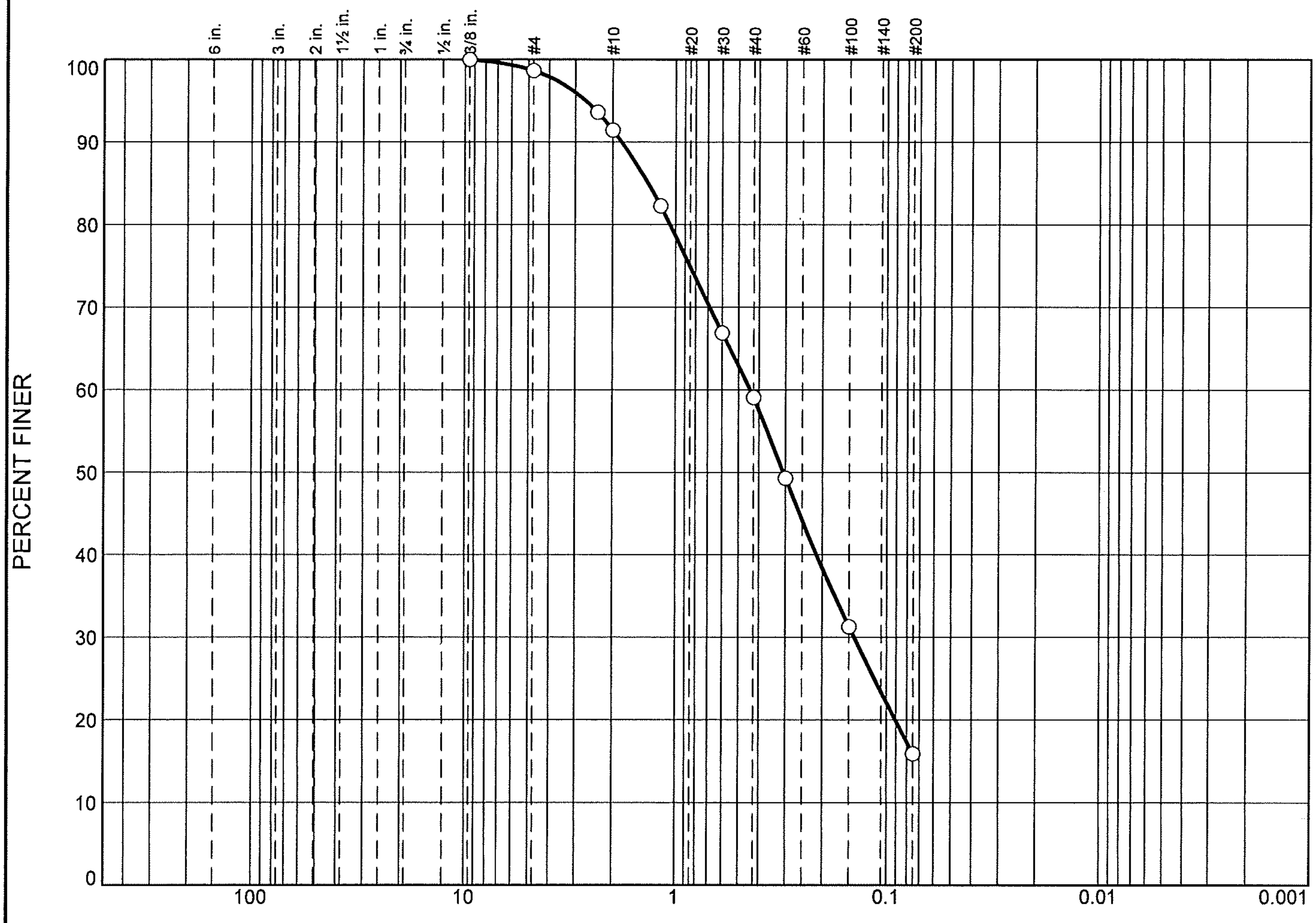
Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines
		Coarse	Fine	Coarse	Medium	Fine	
○	0.0	0.0	1.3	7.3	32.3	43.2	15.9

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	nv	np	1.3540	0.4411	0.3074	0.1419				

Material Description	USCS	AASHTO
○ Silty SAND	SM	A-2-4(0)

Project No. 1601140 **Client:** Sonoma County Water Agency

Project: SCWA - Groundwater Monitoring Well Construction

○ **Source of Sample:** TW-6A **Depth:** 140 feet

Remarks:

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

GRAIN SIZE DISTRIBUTION TEST DATA

6/29/2016

Client: Sonoma County Water Agency
Project: SCWA - Groundwater Monitoring Well Construction
Project Number: 1601140
Location: TW-6A
Depth: 140 feet
Material Description: Silty SAND
Liquid Limit: nv **Plastic Limit:** np
USCS Classification: SM **AASHTO Classification:** A-2-4(0)

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
94.84	0.00	210.22	0.375	210.22	100.0
			#4	211.50	98.7
			#8	216.28	93.6
			#10	218.33	91.4
			#16	227.04	82.3
			#30	241.63	66.9
			#40	249.03	59.1
			#50	258.31	49.3
			#100	275.38	31.3
			#200	289.95	15.9

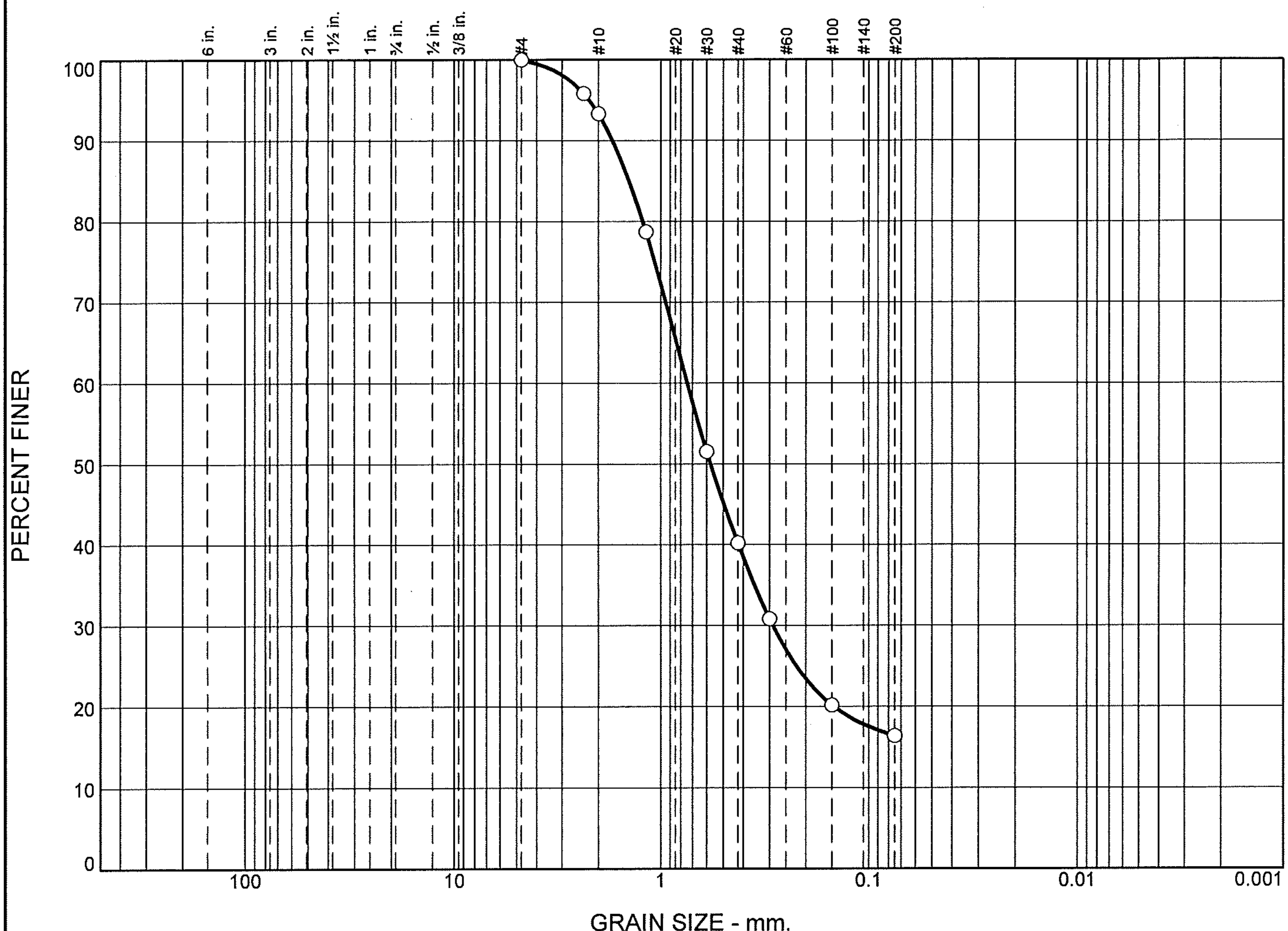
Fractional Components

Cobbles	Gravel			Sand				Fines
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	
0.0	0.0	1.3	1.3	7.3	32.3	43.2	82.8	15.9

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
			0.0906	0.1419	0.2134	0.3074	0.4411	1.0617	1.3540	1.8128	2.6831

Fineness Modulus
1.78

Particle Size Distribution Report



	% +3"	% Gravel		% Sand			% Fines
		Coarse	Fine	Coarse	Medium	Fine	
○	0.0	0.0	0.0	6.7	53.1	23.8	16.4

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	NV	NP	1.4221	0.7436	0.5750	0.2892				

Material Description	USCS	AASHTO
○ Silty SAND	SM	A-1-b

Project No. 1601140 **Client:** Sonoma County Water Agency

Project: SCWA - Groundwater Monitoring Well Construction

○ **Source of Sample:** TW-6A **Depth:** 180 feet

Remarks:

GEI Consultants, Inc.
400 Unicorn Park Drive
Woburn, MA 01801

Figure

GRAIN SIZE DISTRIBUTION TEST DATA

6/29/2016

Client: Sonoma County Water Agency
Project: SCWA - Groundwater Monitoring Well Construction
Project Number: 1601140
Location: TW-6A
Depth: 180 feet
Material Description: Silty SAND
Liquid Limit: NV
Plastic Limit: NP
USCS Classification: SM
AASHTO Classification: A-1-b

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
105.76	0.00	189.06	#4	189.06	100.0
			#8	193.49	95.8
			#10	196.12	93.3
			#16	211.56	78.7
			#30	240.31	51.5
			#40	252.27	40.2
			#50	262.21	30.8
			#100	273.45	20.2
			#200	277.46	16.4

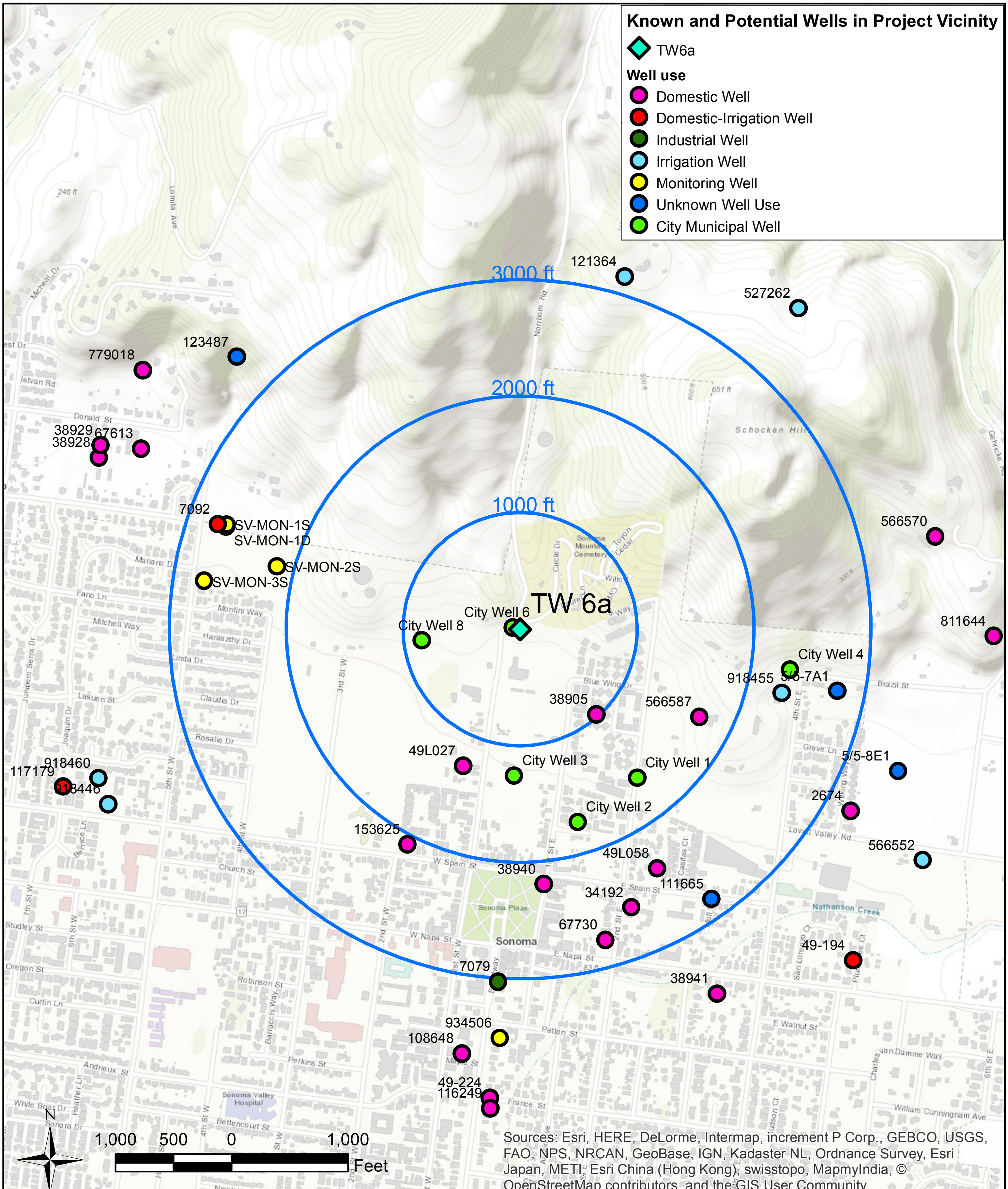
Fractional Components

Cobbles	Gravel			Sand				Fines
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	
0.0	0.0	0.0	0.0	6.7	53.1	23.8	83.6	16.4

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
			0.1465	0.2892	0.4217	0.5750	0.7436	1.2225	1.4221	1.7076	2.2203

Fineness Modulus
2.23

Appendix D – Inventory of Known Wells



Test Well 6a with Known and Potential Wells in Project Vicinity

Sonoma Valley, ASR Pilot Study

December 2017

Table A-1. Inventory of Known and Potential Wells in Project Vicinity
Sonoma Valley, ASR Pilot Study

DWR Number	APN	Depth (feet bgs)	Street Address	Reported Water Use	Distance from TW-6A (feet)
520920 (City Well 6)	018-032-005	236	100 1st Street West	City Municipal Well	62
295996 (City Well 8)	018-007-008	300	175 First Street West	City Municipal Well	849
38905	092-050-007	500	183 Guadalupe Drive	Domestic	982
5N5W-07F01M (City Well 3)	018-162-021	407	-	City Municipal Well	1,260
49L027	018-121-018	210	277 First Street West	Domestic	1,269
50057 (City Well 1)	018-141-013	405	2nd Street East	City Municipal Well	1,628
566587	016-091-010	235	140 Second Street East	Domestic	1,717
5N5W-07G01M (City Well 2)	018-600-005	220	-	City Municipal Well	1,730
153625	018-780-003	230	190 West Spain Sreet	Domestic	2,085
MON - 2S	018-011-017	60	Montini Test Site	Monitoring Well	2,153
38940	-	313	414 1st St. E, Sonoma	Domestic	2,199
918455	018-091-004	290	131 Fourth Street East	Irrigation	2,315
5N5W-07A02M (City Well 4)	018-051-007	500	4th Street East	City Municipal Well	2,347
49L058	018-172-009	235	236 East Spain Street	Domestic	2,371
34192	018-222-003	225	426 Second Street East	Domestic	2,575
MON - 1D	018-011-017	127	Montini Test Site	Monitoring Well	2,671
7092 (Montini)		208		Domestic-Irrigation	2,670
MON - 1S	018-011-017	76	Montini Test Site	Monitoring Well	2,674
MON - 3S	018-011-017	50	Montini Test Site	Monitoring Well	2,742
67730	018-221-032	315	473 Second Street East	Domestic	2,766
5/5-7A1	018-102-031	575	unknown	Unknown	2,778
111665	-	120		Unknown	2,841
7079	018-212-014	262	546 Broadway	Industrial	3,032
121364	-	435		Irrigation	3,157
2674	018-102-004	400	Sonoma Highway 12 - Turkey Ranch	Domestic	3,239
123487	-	610	End of Donald Ave, El Verano	Unknown	3,371
5/5-8E1	127-162-018	235	unknown	Unknown	3,470

Appendix E – CEQA Notice of Exemption

NOTICE OF EXEMPTION

To: ___ Office of Planning & Research
1400 Tenth Street, Room 121
Sacramento, CA 95814

X County Clerk
County of Sonoma
Santa Rosa, CA 95401

William F. Rousseau, County Clerk
BY: [signature]
Alma Roman, Deputy Clerk

From: SONOMA COUNTY WATER AGENCY
404 Aviation Boulevard
Santa Rosa, CA 95403

This notice was posted on 09/14/2017 and will remain posted for a period of thirty days through 10/15/2017

Doc No.49-09142017-253

Project Title: Sonoma Well # 6 ASR Pilot Test Project (Project)

Project Location - Specific: The project site is located at 150 First Street West in the City of Sonoma. See **Figure 1**.

Project Location - City: Sonoma **Project Location - County:** Sonoma

Description of Nature, Purpose and Beneficiaries of Project: Due to uncertainties in the reliability of regional future water supplies (both surface water and groundwater), the Water Agency, City of Sonoma, and other local partners, including the cities of Rohnert Park and Cotati, Valley of the Moon Water District, and the Town of Windsor (study participants) have conducted a feasibility study for a regional groundwater banking program to investigate the viability of enhancing the conjunctive management of surface water and groundwater resources.

The feasibility study recommended a pilot test located at Sonoma Well #6 and at Well #6A due to their operational capacity and geochemical compatibility. The overall objective of the pilot test project is to verify and empirically determine specific hydrogeologic and water-quality factors to support a technical and economic viability assessment of ASR technology for the City of Sonoma. The Project would evaluate the ability to recharge the Sonoma Volcanics, as well as verify geochemical compatibility of native and recharged waters with aquifer mineralogy and short-term water quality changes. The Project would assess basic aquifer recharge and hydraulic parameters in addition to assess well hydraulics (e.g., specific capacity, plugging rates, etc.) for ASR operations.

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 project.

The pilot test Well #6A was constructed on County property under a Permit to Enter Agreement. The Water Agency is seeking permanent property rights for continued operation and maintenance of the improvements.

Name of Public Agency Approving Project: Sonoma County Water Agency

Name of Person or Agency Carrying Out Project: Sonoma County Water Agency

Exempt Status: (Check one)

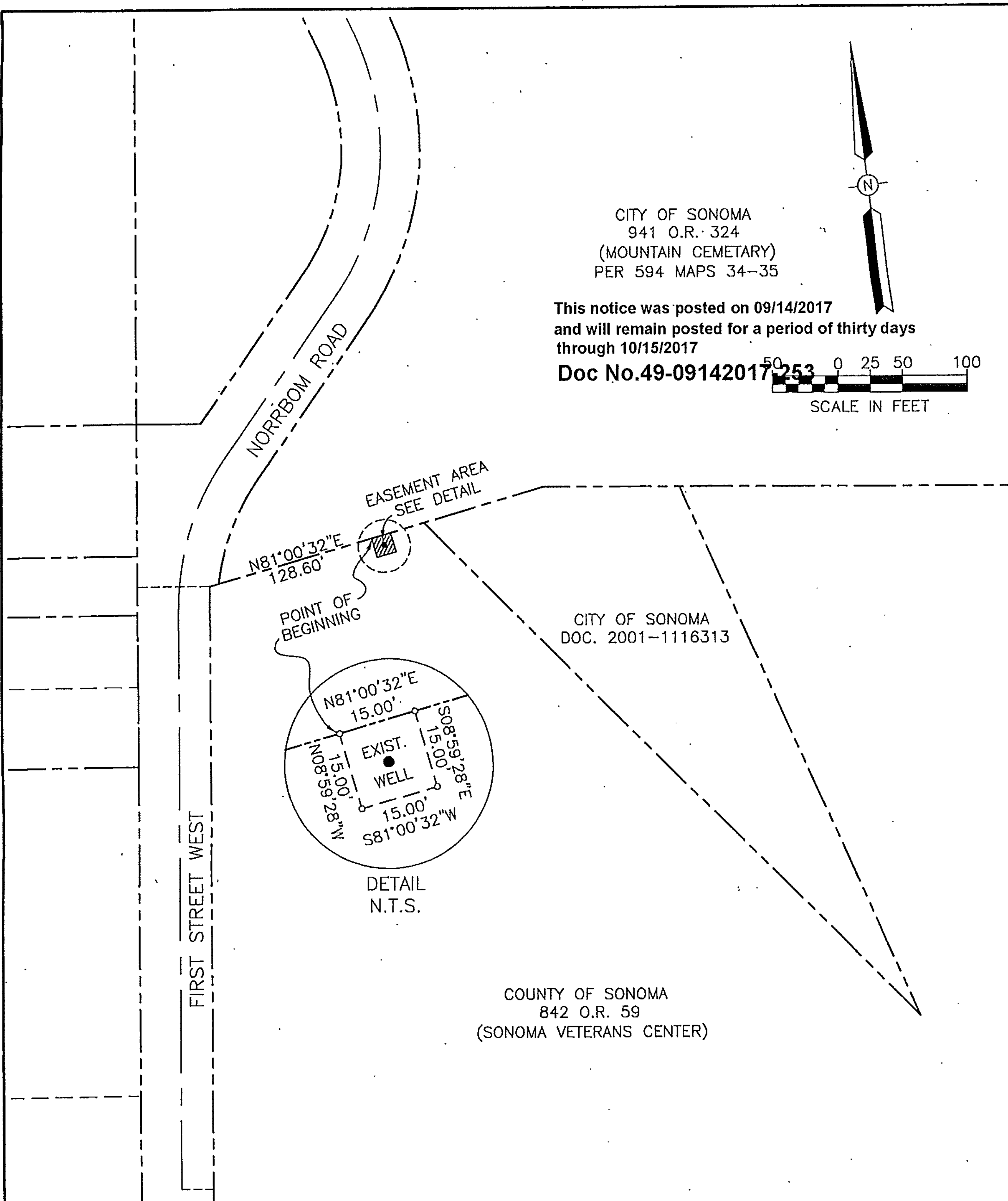
- ___ Ministerial (Sec. 21080(b)(1); 15268)
- ___ Declared Emergency (Sec. 21080(b)(3); 15269(a));
- ___ Emergency Project (Sec.21080 (b)(4); 15269(b)(c));
- X Categorical Exemption. State type and section number: CEQA Guidelines 15306: Information Collection and 15061 (b)(3) Review for Exemption
- ___ Statutory Exemptions. State Code number:

Reasons why project is exempt:
The project consists of data collection, research, and experimental management of aquifer storage and recovery. The project will not have a significant adverse effect upon an environmental resource. The project is part of a study which may result in a future project which has not yet been approved, funded, or adopted. The transfer of property rights would not result in any change in existing environmental conditions.

Lead Agency Contact Person: Connie Barton Area Code/Telephone: 707-547-1905

Signature: [signature] Date: 9/12/17 Title: General Manager

X Lead Agency ___ Applicant
Date Received for filing at OPR:



This notice was posted on 09/14/2017 and will remain posted for a period of thirty days through 10/15/2017

Doc No.49-09142017-253

SONOMA COUNTY WATER AGENCY	REVISIONS	PLAT TO ACCOMPANY LEGAL DESCRIPTION	PROJECT/TASK: T0275C012
	REV. DATE BY	EXHIBIT "A–1"	DATE : 04–10–17
		EASEMENT AREA	DRAWN BY: JM
		SONOMA VETERANS CENTER	CHECKED BY:
			SHEET NO. 1 OF 1

jm\\SD-Data\Survey\Land Projects\ASR (Sonoma Vets Center) Record Boundary.dwg

Appendix F – Work Plan Details

SUMMARY OF ASR CYCLES

CYCLE NO. 1

Injection Period: 6 days

Injection Rate: 100 gallons per minute (gpm)

Injection Volume: 0.90 million gallons (2.8 acre-feet)

Injected Water Radius: 52 feet

Storage Period: 7 days

Recovery Period: 4 days

Recovery Rate: 150 gpm

Primary Test Objectives:

- Monitor injection hydraulics
- Monitor Water Quality: Ion Exchange reactions

CYCLE NO. 2

Injection Period: 19 days
Injection Rate: 100 gpm
Injection Volume: 2.7 million gallons (8.3 acre-feet)
Injected Water Radius: 93 feet
Storage Period: 21 days
Recovery Rate: 150 gpm
Recovery Period: 13
Primary Test Objectives:

- Reconfirm injection hydraulics
- Monitor well plugging/backflushing rates
- Monitor Ion Exchange & Redox reaction mechanisms
- Monitor recovery efficiency
- Evaluate water quality changes during storage

CYCLE NO. 3

Injection Period: 19 days

Injection Rate: 100 gpm

Injection Volume: 2.7 million gallons (8.3 acre-feet)

Injected Water Radius: 93 feet

Storage Period: 30 days

Recovery Period: 13 days

Recovery Rate: 150 gpm

Primary Test Objectives:

- Monitor longer term well performance trends for injection.
- Monitor injected water quality stability and equalization in the aquifer.
- Monitor THM and HAA degradation.
- Quantify aquifer mixing/dispersion parameters.
- Determine economic factors of pumping, injection, recovery efficiency, backflush percentage.
- Monitor recovered water ‘post extraction’ for re-chlorination and THM/HAA reformation.

WORK PLAN

1. Fabricate special temporary well head seal plate and install existing electric submersible pump from Well No. 6 (15 Hp, 460 v, 150 gpm at 300 ft. TDH on 3 in. column pipe). Set pump to approx. 120 ft. Also install: 1 ea. – 1 in. PVC sounding tube to 120 ft.; 2 ea. – 1 in. PVC injection tubes; 2 ea. – 2 in. PVC injection tubes. (Note: Injection tubes shall be F480 flush-threaded, set to 20 ft. minimum below static water level. [Special orifice caps will be provided for injection flow control])
2. Install temporary, 20,000 gal. surge tank and temporary piping per **Figure 12**. Pressure and leak test piping and check operation of all meters and instrumentation.
3. Flush injection piping/supply to waste per **Injection Procedures**. Ensure injection supply has SDI < 3.0 before injecting.
4. Perform Injection Step Test to assess well performance and injection rates.
5. Commence ASR Cycle 1 Injection per **Injection and Backflushing Procedures**. Proceed through Injection/Backflush/Storage/Recovery operations cycle.
6. Based on the results of ASR Cycle 1 testing, adjust operation/monitoring parameters for ASR Cycle 2.
7. Commence ASR Cycle 2 with revised operating parameters. Proceed through Injection/Backflushing/Storage/Recovery operations cycle.
8. Adjust operations/monitoring plan as needed for Cycle 3.
9. Commence ASR Cycle 3 with revised operating parameters. Proceed through Injection/Backflushing/Storage/Recovery cycle.
10. Disassemble temporary piping/valving/storage tanks and remove pump from Well 6A. Reinstall pump assembly in Well 6 and restore site to original condition.

INJECTION PROCEDURES

1. Adjust valving to flush the potable system supply to the 20,000-gal. tank. Set dechlorination equipment as needed if water will route to storm drain or sewer.
2. Initiate system flow to tank to flush the distribution system of scale/residue/particulates. Flushing rate should be at least 150 % 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 recharge operations for the season, 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 > 4.0, immediately stop injection operations, backflush the well, and flush the distribution system to waste until SDI < 3.0 is restored.

BACKFLUSHING PROCEDURES

1. Stop injection flow to well, being careful to avoid both water hammer to the distribution system and negative pressure/cascading water conditions in the well.
2. Record all meter readings and water levels.
3. Adjust valving to 'backflush position', routing well production to the 20,000-gal tank.
4. Start well at backflush rate setpoint 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.
5. Repeat Step 4 a total of 3 times, or until the discharge water is visually clear within 1 minute of pump start-up.
6. When static water level has stabilized (15-minute minimum), start pump and set flow to normal recovery rate. Record 10-minute pumping water level and flow rate, calculate and record 10-minute specific capacity.
7. Record all meter readings and water levels.
8. Adjust valving as needed to next ASR operation (e.g., return to injection, storage, or recovery mode).

Appendix G – Sampling and Analysis Plan

SAMPLING AND ANALYSIS PLAN

INTRODUCTION

This Groundwater Sampling and Analysis Plan (SAP) has been developed for the City of Sonoma's Pilot Aquifer Storage and Recovery (ASR) Test Program. The project is being implemented by the City of Sonoma (City) with the assistance of the Sonoma County Water Agency (SCWA), and generally involves the recharge, storage and subsequent recovery of treated drinking water originating from the SCWA's Russian River production and treatment facilities into the Sonoma Volcanics within the Sonoma Valley ground water basin, which underlies the City. The SCWA treated potable drinking water will be injected into the aquifer via an existing City test well facility (TW-6A) located at 150 First Street West in the City of Sonoma. The injected water will then be stored within the aquifer for periods of several days to up to one month before being recovered, and subsequently discharged to the City storm drain or other beneficial uses as may be determined feasible. The recovered water will not be conveyed into the City potable drinking water system for the pilot test. The overall objective of the project is to verify and empirically determine specific hydrogeologic and water quality factors that will allow a technical and economic viability assessment of ASR technology. 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 project. The conjunctive use of water supplies via ASR technology will benefit the resources of both the City and SCWA water systems.

ASR operations generally consist of three steps or phases: (1) injection of drinking-quality water into the aquifer (in this case through TW-6A); (2) storage of the injected water within the target aquifer; and, (3) recovery of the stored water (in this case by TW-6A). Periodic samples of the injected, stored, and recovered waters are to be collected from the well and analyzed for a variety of water-quality constituents, some of which are pursuant to requirements of the Regional Water Quality Control Board (RWQCB) for the project. The purpose of this SAP is to identify the locations, sample collection frequency, and parameters to be monitored as part of the pilot project's water-quality data collection program. The project location is shown in **Figure 1**.

GROUNDWATER MONITORING

Project Wells. The TW-6A facility is located at 150 First Street West in the northern area of the City of Sonoma. Proximate existing City Wells 6 and 8 will also be utilized as monitoring wells during the project.

A summary of project well construction parameters is presented in **Table 1** below:

Table 1. Well Construction Summary

Well ID	Screen Intervals (ft bgs)		Aquifer Completed
TW-6A	130 - 160	170 - 220	Sonoma Volcanics
Well 6	140 - 236	--	Sonoma Volcanics
Well 8	155 - 295	--	Sonoma Volcanics

Groundwater Monitoring Equipment

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

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

TW-6A will be equipped with a 15 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.

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.

The pilot test well, as well as the two monitoring wells, will be instrumented with dedicated pressure/level transducers and dataloggers. Reference-point elevations will be established by City survey records. 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 TW-6A wellhead while active injection is occurring. During storage periods, the well will be periodically purged and sampled. During recovery periods, the well pump will be operating, therefore sample purging is continuous and sustained.

The existing pump will be used to purge a volume equivalent to a minimum of three (3) casing volumes from the well prior to sampling. Purge water from the well during backflushing and sampling is to be discharged to temporary holding tanks on site (Baker tanks) for surge suppression and analysis prior to discharge to the on-site City storm drain system. Water produced by the well during recovery operations will also be discharged to the Baker tanks prior to discharge to the City storm drain.

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.

Chain-of-Custody, Sample Handling, and Transport

All samples collected will be labeled in a clear and precise way for proper identification in the field and for tracking in the laboratory. All sample shipments for analyses will be accompanied by a chain-of-custody record. Forms will be completed and sent with the samples for each shipment. The chain-of-custody form will identify the contents of each shipment and maintain the custodial integrity of the samples. Samples will be placed in a cooler for delivery to the laboratory.

Documentation Procedures

Field data will be recorded by field personnel and routinely submitted to the Project Manager for review and QA/QC. Field data will include the completed field sampling-log form and chain-of-custody records. At a minimum, documentation of each monitoring and sampling event will include the following information:

- Sample location and description
- Sampler's name(s)
- Date and time of sample collection
- Type of sampling equipment used
- Field instrument calibration procedures and results
- Field instrument readings
- Field observations and details related to analysis or integrity of samples (e.g., weather conditions, noticeable odors, colors, etc.)
- Sample preservation
- Shipping arrangements
- Name(s) of recipient laboratory
- Any deviations from SAP procedures

Project information will be filed by sample date. The project file will contain project field data, correspondence, survey reports, laboratory reports, charts, tables, permits, and other project-related information. This information will be utilized in the preparation of the quarterly Pilot Test Program Operations Reports for the project.

LABORATORY PROGRAM

A complete list of constituents and constituent “groups” to be monitored as part of the City’s ASR Pilot Test Project for injected, stored, and recovered waters is presented in **Table 3** below. **Table 4** summarizes the planned sample constituent group frequencies for each source for the injection, storage, and recovery periods.

Table 3. Analytic Testing Program Constituent Summary

Constituent	MDL	Geochem Parameters	Disinfection Byproducts	Anion-Cation	Nutrients	Field[1]
Group ID		**G-1**	**DBP**	**S-1**	**S-2**	**F-1**
Major Cations						
Calcium (Ca)	1 mg/L	✓		✓		
Magnesium (Mg)	1 mg/L	✓		✓		
Sodium (Na)	1 mg/L	✓		✓		
Potassium (K)	0.5 mg/L	✓		✓		
Major Anions						
Total Alkalinity (as $CaCO_3$)	10 mg/L	✓		✓		
Sulfate (SO_4)	1 mg/L	✓	✓	✓		
Chloride (Cl)	1 mg/L	✓	✓	✓		
Nitrate as (NO3) **	1 mg/L	✓		✓	✓	
Nitrite as (Nitrogen)	0.1 mg/L	✓		✓	✓	
General Physical						
pH	0.1 units	✓				✓
Temperature	0.2 ^{0}C					✓
Specific Conductance (EC)	10 uS	✓				✓
ORP (redox potential / Eh)[2]	10 mV					✓
Total Dissolved Solids (TDS)	10 mg/L	✓		✓		
Metals						
Aluminum (Al)	10 ug/L	✓				
Antimony (Sb)	1 ug/L	✓				
Arsenic (As) **	1 ug/L	✓		✓		
Barium (Ba)	0.5 mg/L	✓				
Beryllium (Be)	1 ug/L	✓				
Cadmium (Cd)	0.5 ug/L	✓				
Chromium (Cr) (Total)	2 ug/L	✓				
Fluoride (F)	0.1 ug/L	✓				
Iron (Fe) (Total and Dissolved)	50 ug/L	✓		✓		
Lithium (Li)	5 ug/L	✓		✓		
Manganese (Mn) (Total and Dissolved)	10 ug/L	✓		✓		
Mercury (Hg)	0.5 ug/L	✓				
Molybdenum (Mo)	5 ug/L	✓				
Nickel (Ni)	10 ug/L	✓				
Selenium (Se)	5 ug/L	✓		✓		
Strontium (Sr)	5 ug/L	✓		✓		
Thallium (Tl)	1 ug/L	✓				

Constituent	MDL	Geochem Parameters	Disinfection Byproducts	Anion-Cation	Nutrients	Field[1]
Group ID		**G-1**	**DBP**	**S-1**	**S-2**	**F-1**
Uranium (U) **	1 pCi/L	✓		✓		
Vanadium (V)	5 ug/L	✓				
Zinc (Zn)	0.5 ug/L	✓				
Miscellaneous						
Ammonia (as N)	0.05 mg/L	✓			✓	
Boron (B)	0.05 mg/L	✓				
Chlorine residual (free)	0.1 mg/L		✓			✓
Chloramines	50 ug/L		✓			
Cyanide	5 ug/L	✓				
Dissolved Methane	0.5 ug/L	✓				
Dissolved Oxygen (DO)[2]	0.025 mg/L				✓	✓
Gross Alpha	1 pCi/L	✓				
Hydrogen Sulfide (H_2S)	0.05 mg/L					✓
Total Nitrogen (N)	0.2 mg/L	✓			✓	
Perchlorate	2 ug/L	✓				
Total Phosphorous	0.05 mg/L	✓			✓	
Orthophosphate as P	0.05 mg/L	✓			✓	
Radium 226	1 pCi/L	✓				
Silt Density Index (SDI)	0.1 units					✓
Total Kjehldahl N (TKN)	0.2 mg/L	✓			✓	
Organic Analyses						
Total Trihalomethanes **	1 ug/L		✓			
Bromodichloromethane	1 ug/L		✓			
Bromoform	1 ug/L		✓			
Chloroform	1 ug/L		✓			
Dibromochloromethane	1 ug/L		✓			
Haloacetic Acids (HAA) **	1 ug/L		✓			
Monobromoacetic Acid	1 ug/L		✓			
Monochloroacetic Acid	1 ug/L		✓			
Dibromoacetic Acid	1 ug/L		✓			
Dichloroacetic Acid	1 ug/L		✓			
Trichloroacetic Acid	1 ug/L		✓			
Total organic carbon (TOC)	0.1 mg/L	✓			✓	
Dissolved organic carbon (DOC)	0.1 mg/L	✓			✓	

Constituent	MDL	Geochem Parameters	Disinfection Byproducts	Anion-Cation	Nutrients	Field[1]
Group ID		G-1	DBP	S-1	S-2	F-1

Table 3 Notes:

MDL = Method Detection Limit

Constituents marked ** are RWQCB Constituents of Concern for the project

1 – Field Parameters (Group F-1) must be taken concurrently with collection of all laboratory samples.
2 – ORP and DO must be analyzed utilizing a flow-thru cell device.

Table 4. Analytic Testing Program Schedule

RECHARGE PERIOD (active injection)		
Analyte Group	**SCWA Recharge Water (sampled at TW-6A) ASR Cycle 1**	**ASR Cycles 2 & 3**
F-1	2 x	1 / week
DBP	1 x	1 / month
G-1	1 x	1 / month
S-1		1 x (@ end)
S-2		1 x (@ end)
STORAGE PERIOD (no recharge / system idle)		
Group	**Well 6A: ASR Cycle 1**	**Well 6A: ASR Cycles 2 & 3**
F-1	2 x	1 / week
DBP	1 x (@ end)	1 / week
G-1		1 x
S-1	1 x (@ end)	1 / week
S-2	1 x (@ end)	1 / month
RECOVERY PERIOD		
Group	**Well 6A: ASR Cycle 1**	**Well 6A: ASR Cycles 2 & 3**
F-1	2 x	1 / week
DBP		1 / week
G-1	2 x	1 x (@ end)
S-1	2 x	1 x (@ end)
S-2	2 x	1 x (@ end)
WELL BACKFLUSHING EPISODE		
Group	**Well 6A: ASR Cycle 1**	**Well 6A: ASR Cycles 2 & 3**
F-1	2x	2x / event
Bioassay		1x / 2 events

Table 4 Notes:

1 – “2 x” sample frequency should be taken during the first and last quartile of the period