TECHNICAL MEMORANDUM

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

To:	Stratus Consulting, Inc.	Date:	May 15, 2015
Attention:	Robert S. Raucher, PhD	Project No:	14-0101
Copy to:	Kevin Crossly Heidi Luckenbach Jennifer Peers		
From:	Robert C. Marks, P.G., C.Hg		
Subject:	City of Santa Cruz WSAC; Reconnaissance-Level Evaluation of ASR and IPR		

EXECUTIVE SUMMARY

Presented in this Technical Memorandum (TM) are the results of a reconnaissance-level feasibility investigation of Aquifer Storage and Recovery (ASR) and Indirect Potable Reuse (IPR) for the City of Santa Cruz Water Department (SCWD). ASR and IPR involve utilizing injection wells for recharging aquifer systems with excess water supplies for temporary storage and later recovery when needed. ASR utilizes excess potable-quality water (water that meets drinking water standards) as the source water for injection, whereas IPR utilizes highly treated wastewater.

In order to feasibly implement ASR / IPR, the following four basic project components are required:

1. A supply of water for injection.
2. A system for the diversion, treatment and conveyance of water between the source and storage basin.
3. A suitable groundwater basin with available storage space.
4. Wells to inject and recover the stored water.

As applied to Santa Cruz, ASR would involve the diversion of “excess” winter and spring flows from the San Lorenzo River via the Tait Street Diversion facility, treated to potable standards at the Graham Hill Water Treatment Plant (GHWTP), then conveyed through the existing water distribution system(s) to ASR wells located in the Soquel-Aptos Groundwater Basin and/or the Santa Margarita Groundwater Basin in Scotts Valley. In this context, “excess” flows are those flows that exceed SCWD demands and in-stream flow requirements – in other words, water that would otherwise waste to the Pacific Ocean.

The scope of work for this reconnaissance-level feasibility study was limited to review and evaluation of readily available existing information related to the four key components of an ASR / IPR project for Santa Cruz. The study was also limited to a relatively short time-frame (3 months). Based on the currently available information, the study findings show that ASR appears to be technically feasible with no obvious fatal flaws at this stage. The main conclusions regarding what is known about the key components of a potential ASR project are summarized below:

Availability of Excess Water. Analysis of available excess San Lorenzo River flows, as constrained by existing water rights, in-stream flow requirements, and demands shows that approximately 558 million gallons per year (mgy) or more may be available.

Diversion / Treatment / Conveyance Capacities. The existing excess capacity of the Tait Street Diversion and GHWTP is limited to 2 mgd, which would be capable of diverting and treating approximately 145 mgy of the available excess flows, on average. With significant system modifications and upgrades to the existing Tait Street Diversion and GHWTP, available diversions up to 558 mgy could be achieved.

Available Aquifer Storage Space. Based on existing estimates of historical groundwater storage depletion, approximately 3,290 mg of potentially available aquifer storage space may be available in the Purisima Aquifer and approximately 2,355 mg may be available in the Scotts Valley Subarea (approximately 5,645 mg combined).

Per Well Injection Capacities. Based on the results of a screening level analysis of the theoretical injection capacities of existing wells, per-well injection capacities of 350 gpm (0.5 mgd) for new ASR wells in both the Purisima Aquifer and Scotts Valley Subarea appear feasible.

The study findings show that the primary existing constraint on the potential capacity of an ASR project is the excess capacity of the GHWTP, which is limited to 2 mgd / 145 mgy. This existing constraint leads to the development of a conceptually phased ASR project, where Phase 1 (2 mgd / 145mgy) would maximize the existing excess GHWTP treatment capacity and Phase 2 (6 mgd / 413 mgy) would involve infrastructural improvements to allow maximizing the available excess San Lorenzo River flows. At build-out, the conceptual project would have a capacity of approximately 8 mgd and an average annual project yield of approximately 500 mgy. Preliminary planning-level capital costs for the Phase 1 and Phase 2 ASR projects are estimated at approximately $40M and $200M, respectively.

With regards to IPR, the above findings regarding the available aquifer storage space and per-well injection capacities are generally applicable; however, because the source water for IPR is highly treated wastewater instead of potable-quality drinking water, under current regulations the same well cannot be utilized for both injection and recovery (which is allowed for ASR) and the injection wells need to be located at prescribed distances from the nearest drinking water supply wells in order to provide sufficient aquifer residence times.

The key existing unknowns regarding the feasibility of ASR / IPR include:

- The potential for adverse geochemical interactions between the source waters, native groundwater, and aquifer mineral matrices is not known; however, based on our experience with ASR in similar settings, we believe the potential for adverse geochemical reactions to present a fatal flaw to project implementation is low.

- The potential for, and quantification of, hydraulic losses to either the ocean or local creeks that would result from increased aquifer water levels / piezometric head that could limit overall project yields is not known. Numerical groundwater modeling of various ASR scenarios will likely be required to evaluate this issue further. Fortunately, a calibrated groundwater model of the Santa Margarita Groundwater Basin (including the Scotts Valley Subarea) already exists, and a calibrated groundwater model of the Soquel-Aptos Groundwater Basin is currently under development (scheduled for completion in June 2016).

It is noted that the above unknowns are based on the currently available information; however, it is believed these unknowns can be reasonably addressed through additional investigations and are not likely to present fatal flaws, particularly for small-scale ASR (i.e., Phase 1 of the Conceptual ASR Project). There is greater potential for unacceptable hydraulic losses associated with larger scale ASR and/or IPR projects; however, this issue can be assessed and reasonably quantified through groundwater modeling.

Should the SCWD decide to pursue further investigation of ASR, we recommend the following steps:

1. Perform site-specific theoretical injection capacity analysis of an existing well (or wells) that considers a variety of factors that were beyond the scope of this reconnaissance-level study.
2. Perform 3-component geochemical modeling of various mixes of the potential injection source water(s) and native groundwater in the presence of aquifer minerals
3. Based on the positive results of Steps 1 and 2 (no fatal flaws are identified), develop a pilot ASR demonstration test plan
4. Temporarily retrofit the selected well facility (or facilities) with a test pump, injection piping, metering, valving, etc.
5. Conduct initial well hydraulics, plugging rates, and sustainable injection rate testing (an approximate 2 to 4 week program).
6. Should Step 5 above be successful (no fatal flaws are identified), implement several Injection / Storage / Recovery (ISR) cycles of increasing volumes and durations to evaluate various water-quality related issues and long-term ASR operational parameters (an approximate 1 to 2 year program, depending on availability of recharge water during the testing period).

Based on the results of the above-described pilot ASR demonstration testing, permanent ASR project planning, permitting and implementation can then be reliably advanced.

INTRODUCTION

The City of Santa Cruz Water Department (SCWD or City) is considering Aquifer Storage and Recovery (ASR) and Indirect Potable Reuse (IPR) as potential methods for storage of excess water supplies for use during drought periods. ASR and IPR in this context are similar technologies in that injection wells are utilized for recharge; however, the source waters are different. Under current California regulations, the source water for ASR is required to be potable-quality water (water that meets drinking water standards) whereas for IPR the source water is advanced treated wastewater[1]. If feasible, ASR and/or IPR would provide the City the ability to take advantage of available excess water supplies when available for storage within the aquifer systems underlying the City (and/or adjacent areas) and later recovery for distribution to City customers during periods of high demand and/or deficiencies in the SCWD's other sources of supply.

The SCWD is considering the potential for ASR and/or IPR wells located within groundwater basins underlying the water distribution system service areas of the SCWD, Soquel Creek Water District (SqCWD) and Scotts Valley Water District (SVWD). The SCWD and SqCWD service areas overly the Soquel-Aptos Groundwater Basin (SAGB) and the SVWD service area overlies the Santa Margarita Groundwater Basin (SMGB). These areas are shown on **Figure 1**.

Presented in this Technical Memorandum (TM) is an evaluation of readily available existing information regarding the basic components of an ASR project, including discussions of the hydrogeologic setting(s) and a preliminary analysis of the potential ASR well capacities at both existing production wells and potential new ASR well sites. The results of these site-specific analyses are extrapolated to generally identify target aquifers and potentially more favorable areas for injection wells. Also presented is a preliminary evaluation of water-quality issues, regulatory and permitting settings, and typical O&M requirements associated with implementing a conceptual ASR program for the City.

ASR (and IPR) program development is an iterative process – continuing to be refined in response to input from the City (and other interested parties) and in response to more focused data analysis. The analysis described in this TM represents the initial step in that process and includes a high-level review of existing data and other published information with the application of Pueblo Water Resources, Inc.'s (PWR) professional judgement. Additional steps beyond this reconnaissance-level study will be required to further demonstrate the feasibility and effectiveness of these concepts.

BACKGROUND

ASR is a form of Managed Aquifer Recharge (MAR) that involves the conjunctive use of surface and groundwater resources. ASR involves the "banking" of water in an aquifer during times when excess water is available (typically wet periods), and subsequent recovery of the

[1] It is noted that there are other forms of IPR that utilize surface spreading / percolation basins as the recharge method; however, the subject of this study is limited to injection well methods.

water from the aquifer when needed (typically dry periods). ASR utilizes dual-purpose injection/recovery wells for the injection of water for storage and the subsequent recovery of the stored water by pumping. One advantage of ASR technology is that it allows recharge to be applied in those areas (or aquifers) with the most need, or where available groundwater storage space is the greatest. In addition, ASR well sites require minimal land use area, so they can be more easily located in urban settings than spreading basins or other types of recharge facilities.

The technology for MAR through the use of injection/recovery wells has been in existence around the world since the early 1950's. Typical applications for injection wells include the development of groundwater barriers to hold back seawater intrusion, groundwater basin replenishment, long-term or seasonal storage of water supplies, and water quality improvement. A significant benefit of ASR in basin recharge is that by direct injection into specific lower aquifer zones, the possibility of spreading shallow subsurface contaminants (such as leaking gasoline tanks, dry cleaning operations, etc., which are typically near-surface contaminants) is greatly diminished when compared to conventional spreading basins or percolation pond recharge methods. The recent development of ASR well technology is providing efficient and economical alternatives for water supply management. As a result, the use of this technology has been increasing dramatically in recent years. Currently, there are over 25 operating ASR facilities in the United States, and over 50 other projects in the development stages.

As the use of injection well / ASR technology continues to expand, so does the experience and knowledge on the subject. The overall conclusions about the technology in general that can be made at this time include:

- ASR and IPR can be effective and economical water supply management tools.
- Injection is most effective using treated potable-quality water (this is a regulatory requirement for ASR in California).
- In most cases, it is possible to recover almost the entire volume of injected water.
- Water-quality degradation is typically minimal and, if operated properly, overall water quality of groundwater could improve over time in basins where available source water quality exceeds the native basin groundwater quality.
- Well injection rates are typically 50 to 80 percent of well production rates.

A notable and relevant example of a nearby existing ASR project is the Monterey Peninsula ASR Project, which is being cooperatively implemented by the Monterey Peninsula Water Management District (MPWMD) and California American Water Company (CAW). The project is part of a portfolio of water supply projects intended to replace over-pumping in the Carmel River system and the Seaside Groundwater Basin (SGB). As applied to the Monterey Peninsula, ASR involves the diversion of excess winter and spring flows from the Carmel River system for conveyance to ASR wells located in the SGB. The excess water is captured by CAW facilities in the Carmel Valley during periods when flows in the Carmel River exceed fisheries bypass flow requirements, treated to potable drinking water standards, and then conveyed through CAW’s distribution system to ASR wells in the SGB. During periods of high demand, the same ASR wells and/or existing CAW production wells in the SGB are used to recover this "banked" water, which in turn allows for reduced extractions from the Carmel River system during dry periods. The project currently consists of two separate, dual-well ASR sites (2 ASR wells at each site, 4 ASR wells total) with a combined average annual yield of approximately 2,000 acre-feet per year ([afy], equivalent to approximately 650 million gallons per year [mgy]).

Indirect Potable Reuse (IPR) is similar to ASR in that injection wells are utilized to recharge aquifers; however, it differs significantly from ASR in that the source water for IPR is highly treated wastewater. Because the source water is non-potable, under current California regulations, single-purpose injection wells are used for recharge and water is recovered from separate recovery wells (or existing production wells) located at some distance from the point(s) of injection.

In order to feasibly implement ASR or IPR, the following four basic project components are required:

1. A supply of water for injection.
2. A system for the diversion, treatment and conveyance of water between the source and storage basin.
3. A suitable groundwater basin with available storage space.
4. Wells to inject and recover the stored water.

This TM documents the results of a reconnaissance-level study of readily available information regarding the basic components of a potential ASR (or IPR) project for SCWD. Should the SCWD decide to pursue ASR and/or IPR further based on the results of this reconnaissance-level study, next steps would include performing site-specific injection/recovery analyses, geochemical and numerical groundwater flow modeling, etc., to advance a project. The recommended next steps involved in advancing an ASR / IPR project further are discussed in greater detail below in the body of this TM.

PURPOSE AND SCOPE

The purpose of this study is to conduct a reconnaissance-level evaluation of the feasibility, potential yields, and costs of ASR and IPR for the SCWD. The scope was limited to reviewing and evaluating readily available existing information to develop an understanding of what is known on these two topics within an approximate 3-month timeframe, and develop what questions might be recommended that the SCWD investigate further to advance a project.

The scope of work was developed through discussions and correspondence between PWR and Robert S. Raucher, PhD, Principal, Stratus Consulting, Inc., and included the following:

1) Conduct a preliminary evaluation of existing information on basic components of ASR and IPR, including:

   a) Compilation and review of existing data and reports
   b) Identification of source water conditions
   c) Definition and description of hydrogeologic settings
   d) Estimation of aquifer storage capacities
   e) Description of hypothetical ASR and injection programs
2) Conduct a preliminary hydrogeologic evaluation, including:
   a) Identification of favorable and unfavorable areas for ASR
   b) Estimation of potential injection / recovery capacities of key existing wells
   c) Estimation of potential injection / recovery capacities of potential new wells
   d) Identification of potential water-quality related issues
3) Conduct a regulatory and planning evaluation, including:
   a) Description of regulatory and permitting settings for ASR and IPR
   b) Estimation of planning-level costs and timelines for program development
   c) Outlining of typical O&M requirements
   d) Identification of data gaps and provision of recommendations for further study
4) Preparation of this summary Technical Memorandum

FINDINGS

As applied to Santa Cruz, ASR would involve the diversion of “excess” winter and spring flows from the San Lorenzo River for conveyance to ASR wells located in the Soquel-Aptos Groundwater Basin and/or Santa Margarita Groundwater Basin. The evaluation of excess water was previously done by Fiske (2013) and Kennedy/Jenks (2013); these analyses included capture of the excess water at the Tait Street Diversion facility during periods when flows in the San Lorenzo River flows exceed fisheries bypass flow requirements, treated to potable drinking water standards at the Graham Hill Water Treatment Plant (GHWTP), and then conveyed through the existing (and/or improved) water distribution system(s) to the receiving groundwater basin(s). While these prior studies considered excess water transfer to other agencies for in lieu recharge based on their demands, this study considers aquifer recharge with the excess water.

Aquifer recharge would be accomplished via injection of these excess flows into specially-designed ASR wells located in the groundwater basin(s). The recharged water would be temporarily stored underground in the basin(s), utilizing the available storage space within the aquifer system(s). During periods of high demand, the same ASR wells and/or existing production wells in the basin(s) would be used to recover this “banked” water when needed (e.g., during drought periods).

AVAILABILITY OF EXCESS WATER

Source water for a potential Santa Cruz ASR Project would derive primarily from the San Lorenzo River. The San Lorenzo River has a drainage area of approximately 115 square miles (mi^2) and an average annual runoff volume of approximately 29,203 mgy (89,620 afy).[2]

The availability of "excess" water from this source has been previously investigated by Gary Fiske and Associates, Inc. (Fiske) as part of a study of potential water transfers from the SCWD to the Scotts Valley Water District (SVWD) and/or Soquel Creek Water District (SqCWD). The Fiske studies utilized the existing Confluence Model to examine the volumes of off-peak-season excess flows that could be transferred to SVWD and SqCWD if the capacity of the Tait Street Diversion was unlimited. In this context, "excess" flows are understood to be those flows in excess of existing SCWD demands and in-stream fisheries flows requirements (i.e., essentially water that would otherwise flow to the Pacific Ocean).

The results of the Fiske (2013) analyses showed that up to approximately 558 mgy of excess San Lorenzo River flows are potentially available for transfer; however, it is our understanding from recent discussions with SCWD staff that the above-described Fiske (2013) Confluence Model scenarios included a key constraining factor - the daily demands of the SVWD and SqCWD to receive transferred water - which likely limited the resulting volumes of "excess" available water. If the assumed ASR program demand was larger than the SVWD and SqCWD daily demands, then the overall amount of excess water available may increase; however, this would require additional supply modeling that is beyond the scope of this reconnaissance-level study.

DIVERSION / TREATMENT / CONVEYANCE CAPACITIES

The ability to divert and treat the available excess river flows, and convey them to ASR wells, is the next critical consideration. Under current California regulations, only potable water can be utilized for ASR. SCWD owns and operates the Tait Street Diversion, which delivers raw San Lorenzo River water directly to the Graham Hill Water Treatment Plant (GHWTP). The existing (and expanded) diversion and treatment infrastructural capacities were evaluated by Kennedy/Jenks Consultants (KJ) as a follow-up to the results of the above-described water transfer availability study by Fiske (2013).

Detailed descriptions of the Tait Street Diversion and GHWTP facilities and their operational parameters are presented in the subject KJ (2013) report, and will not be repeated here. In summary, the Tait Street Diversion includes a diversion structure in the river, a diversion inlet structure with fish screens, and a pump station that conveys water via a 24-inch pipeline from the diversion structure to the inlet of the GHWTP. The diversion has an existing capacity of approximately 8 million gallons per day (mgd). The GHWTP is a conventional surface water treatment plant with pre-oxidation, coagulation, flocculation, gravity sedimentation, media filtration and disinfection. The plant has a maximum capacity of

[2] Based on the USGS San Lorenzo River at Santa Cruz, CA gage and Water Years 1953 – 2013 period of record.

approximately 18 mgd; however, winter-time water-quality challenges (e.g., high turbidity following storm events) and maintenance requirements limit the capacity to approximately 10 mgd.

KJ evaluated a range of water transfer scenarios, from maximizing the existing diversion and treatment capacity to various levels of improvements needed to divert, treat and convey all of the available excess San Lorenzo River flows shown to be available by Fiske (2013). Each of the scenarios evaluated by KJ will not be repeated here, but the range is summarized here in order to bracket the possibilities.

Existing Facilities

The existing winter-time capacity of the GHWTP is approximately 10 mgd. City winter-time demands are approximately 8 mgd, resulting in an existing excess GHWTP capacity of approximately 2 mgd. The Tait Street Diversion capacity is limited to 8 mgd; however, the SCWD's North Coast stream sources (Liddell, Laguna, and Majors Creeks) of high-quality surface water that also feed the GHWTP have a capacity of approximately 4 mgd. Therefore, in the existing facilities scenario SCWD winter-time demand of 8 mgd is met first with 4 mgd from North Coast sources and 4 mgd from Tait Street Diversion. The remaining 4 mgd of Tait Street Diversion on the San Lorenzo River and 2 mgd of excess GHWTP capacity would be available for transfer (to ASR wells in this case). KJ estimated an average annual wet season (November to April) yield for this scenario of approximately 145 mgy. The distribution of the 145 mg over the 6 month period is not described; therefore, for the purposes of this TM, it is assumed to equate to 2 mgd for approximately 70 days per year on average (i.e., 145 mgy / 2 mgd = 73 days).

Expanded Facilities

KJ evaluated several scenarios that included various improvements to the Tait Street Diversion and GHWTP to increase their capacities. It was determined that increasing the capacity of the Tait Street Diversion would require a new separate diversion facility that would be constructed in parallel with the operating system, increasing the total diversion capacity from 8 to 14 mgd. The GHWTP would also need to be upgraded to handle the increased winter-time capacity. KJ identified a variety of feasible improvements to the GHWTP that could increase the winter-time capacity up to 16 mgd.

Under this scenario, when City winter-time demands are 8 mgd they are being met first with 4 mgd from North Coast sources and 4 mgd from Tait Diversion. An additional 8 mgd from Tait would be available for treatment at GHWTP and transfer (to ASR wells in this case). KJ estimated an average annual yield for this scenario of approximately 558 mgy (8 mgd for approximately 70 days per year on average).

The above-described KJ (2013) scenarios are summarized in **Table 1** below:

Table 1. Summary of San Lorenzo River Diversion and Treatment Capacities

Scenario Description	North Coast Capacity (mgd)	Tait Capacity (mgd)	GHWTP Capacity (mgd)	Average SCWD Demands (mgd)	Excess Capacity Available	
					mgd	mgy
Existing Facilities	4	8	10	8	2	145
Expanded Facilities	4	14	16	8	8	558

As shown, the existing excess GHWTP treatment capacity is limited to approximately 2 mgd, which results in an average annual yield of approximately 145 mgy; however, various technically feasible improvements could increase the excess capacity up to 8 mgd, which could result in an average annual yield of approximately 558 mgy.

With regards to the SCWD distribution system capacity to convey excess flows to ASR wells, it is unknown at this time whether there is sufficient capacity in the existing system to convey 2 to 8 mgd to ASR well sites. It is noted that conveying excess San Lorenzo River water to SqCWD and/or SVWD service areas would require distribution system intertie improvements. Hydraulic modeling of the distribution system(s) may be required to evaluate this issue once potential ASR well locations have been identified[3].

It is noted that there are other ongoing technical analyses being performed for the Water Supply Advisory Committee (WSAC) that address these points in more detail, and the preceding discussion is based on the currently available existing information.

HYDROGEOLOGIC SETTING

The success of an aquifer recharge project depends on the ability to physically place water into the aquifer and to effectively store and retrieve this previously stored water. The hydrogeology of the aquifer system is the primary factor controlling the rate at which water can be injected, the amount that can be stored, and the ability to recover the stored water. The hydrogeologic factors affecting the feasibility of an ASR program include groundwater basin structure and geometry, hydrostratigraphy, aquifer hydraulic parameters, and water-level conditions. For example, aquifer transmissivity (the product of hydraulic conductivity and saturated thickness) affects the ability to get water into and out of the aquifer. The lower the transmissivity, the more head (drawup or mounding) will be required at the injection well to achieve a given flow rate. Not all of these factors must be optimal for an ASR project to be successful, as less than optimum conditions for a particular hydrogeologic criterion can be offset

[3] Recent discussions with SCWD staff suggests that previous distribution system modeling performed by Akel Engineering Group (dated February 2013) as part of the SCWD2 desalination project may have sufficiently addressed this issue.

by another. For example, in a basin where depth to water is great, lower transmissivities may be acceptable as greater drawup is available to convey more water into the target aquifer(s).

The SCWD is considering the potential for ASR wells located within groundwater basins underlying the water distribution system service areas of the SCWD, SqCWD and SVWD. The SCWD and SqCWD service areas overly the Soquel-Aptos Groundwater Basin (SAGB) and the SVWD service area overlies the Santa Margarita Groundwater Basin (SMGB). These areas are shown on **Figure 1**.

Soquel-Aptos Groundwater Basin

Regional Setting. The Purisima Aquifer constitutes the western portion of the Soquel-Aptos Groundwater Basin (the eastern portion of the SAGB consists of the Aromas Aquifer, which is connected to the Pajaro Valley Groundwater Basin and is not currently under consideration). The boundary between the SCWD and SqCWD areas is a jurisdictional one that coincides with the service area boundaries, as opposed to a physical hydrogeologic barrier. As such, there is hydrogeologic connectivity within the Purisima Aquifer between the SCWD and SqCWD service areas, even though they are considered separate groundwater basins by the Department of Water Resources ([DWR] Bulletin 118, West Santa Cruz Terrace Groundwater Basin [Basin No. 3-26] and Soquel Valley Groundwater Basin [Basin No. 3-1], respectively).

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

As described, the Purisima Aquifer consists of several distinct zones within the geologic Purisima Formation (Tp). The Purisima Formation is a consolidated to semi-consolidated marine sandstone with siltstone and claystone interbeds and an uneroded thickness of approximately 2,000 feet. In the study area, the formation occurs within a tightly folded syncline north of Zayante Fault along the upper portions of the Soquel and Aptos Creek watersheds. The formation dips from west to east 2 to 5 degrees such that only remnants of its lower-most strata occur in the western portion of the basin (i.e., within the SCWD service area) and it becomes deeply buried beneath the Aromas Aquifer in the eastern portion of the basin. Exposures of Purisima Formation are also widespread immediately offshore along Opal Cliffs and Pleasure Point.

Underlying the Purisima Formation are older sedimentary formations, the presence of which varies depending on location. The Monterey Formation and Santa Cruz Mudstone are essentially non-water bearing; however, the Butano, Lompico and Santa Margarita Sandstones serve as productive aquifers in other areas (e.g., Scotts Valley and Seaside Groundwater Basin in Monterey) and could constitute a lower extension of the Purisima Aquifer in some areas.

Hydrostratigraphy. The Purisima Aquifer has been subdivided by previous investigators into hydrostratigraphic units for purposes of conceptualizing the distribution of hydrogeologic properties and pumping stresses. Brief descriptions of the characteristics of these hydrostratigraphic units are presented below (from youngest to oldest):

- Aquifer F (> 800 ft. thick). Aquifer F represents the undifferentiated upper portion of the Purisima Formation. It thickens and becomes less eroded to the east, becoming more than 800 feet thick where it underlies the Aromas Aquifer. The hydraulic conductivity is estimated to range between 2 and 6 ft/d.

- Aquifer DEF (330 ft. thick). This unit is penetrated by wells mainly west of Aptos Creek. It is a moderately coarse-grained unit with intermittent fine-grained intervals. The hydraulic conductivity is estimated to range between 2 and 6 ft/d.

- *Aquitard D (80 ft. thick).* Unit D is predominantly fine-grained with one or two minor coarse-grained intervals. The hydraulic conductivity is estimated to range between 0.005 and 1.0 ft/d.

- Aquifer BC (200 ft. thick). This is a moderately coarse-grained unit with a distinct 15 to 20 feet thick coarse-grained zone in the upper portion. Johnson (2004) combined the previously designated Unit C with the upper portion of Unit B to form Aquifer BC, which includes some thin aquitards. The hydraulic conductivity is estimated to range between 1 and 3 ft/d.

- *Aquitard B (150 ft. thick).* This aquitard unit is consistently fine-grained, with the lower 25 to 45 feet being the most highly correlated feature within the Purisima Formation in the area. The hydraulic conductivity is estimated to range between 0.005 and 1.0 ft/d.

- Aquifer A (250 ft. thick). Aquifer A is the thickest and most consistently coarse-grained unit with the Purisima. It typically consists of an upper and lower aquifer zone, with the lower zone tending to be thicker and coarser-grained than the upper zone. The hydraulic conductivity ranges between 7 and 65 ft/d.

- Aquifer AA (150 – 300 ft. thick). This unit consists of a sequence of interbedded, moderately coarse- to fine-grained underlying the relatively well defined Aquifer A. A fine-grained interval 20 to 70 feet thick separates the AA from the overlying A unit. Where present, a distinct coarse-grained zone commonly occurs towards the top of Aquifer AA with a thickness of 20 to 80 feet. The hydraulic conductivity is estimated to range between 1 and 10 ft/d.

- *Aquitard "Tp?" (0 – 200 ft. thick).* The Tp aquitard is a poorly defined fine-grained deposit at the base of Aquifer AA. It is unclear whether this unit is a lower portion of the Purisima Formation or an older fine-grained formation (e.g., the Santa Cruz Mudstone or Monterey Formation). The hydraulic conductivity of this unit ranges between 0.005 and 1.0 ft/d.

- Aquifer Tu (0 – 300 ft. thick). The Tu aquifer comprises the lower part of the undefined Tertiary-age deposits below the base of the Purisima Formation. This aquifer has been penetrated by relatively few wells in the area, and believed to be limited in areal extent. It is identified by a significantly high resistivity signature on geophysical logs of boreholes. It is believed the Tu aquifer consists of remnants of either Santa Margarita Sandstone (Tsm) or Lompico Sandstone (Tlo). The hydraulic conductivity of this unit ranges between 1 and 20 feet per day (ft/d).

Underlying these deposits are granitic or metamorphic rocks (i.e., bedrock) or fine-grained sedimentary rocks (e.g., Monterey Formation or Santa Cruz Mudstone) that are generally considered non-water bearing and constitute the base of the aquifer system in the area.

A geologic map of the surficial geology in the area is shown on **Figure 2** and two cross-sections through the study area showing the underlying hydrostratigraphic framework are shown on **Figures 3 and 4**.

As shown on **Figure 3**, Aquifers A and AA combined reach thicknesses of up to approximately 700 feet in much of the study area underlying the SCWD service area. Aquifer Tu (likely to be Tsm) has a thickness of approximately 100 feet. As shown on **Figure 4**, all of the above-described hydrostratigraphic units within the stratigraphic structure of Tertiary deposits underlying the area are shown dipping west to east from the SCWD service area through the western portion of the SqCWD service area.

Offshore Geology. Based on available offshore geologic mapping (Eittreim, S. I. et al., 2000), exposures of the Purisima Formation are widespread immediately offshore as shown on **Figure 5** and also along the walls of the Soquel Submarine Canyon (Essaid, H. I., 1992). The existence of exposures of the Purisima Formation offshore creates a potential for increased levels of subsurface discharge from the onshore aquifer system as a result of recharge and associated increases in inland water levels/piezometric head and seaward groundwater gradients. This issue is discussed further in later sections.

Aquifer Parameters. The key aquifer hydraulic parameters affecting groundwater flow and well performance are transmissivity (the product of hydraulic conductivity and saturated thickness) and storativity. These factors affect the ability to move water into and out of the aquifer. For example, the lower the transmissivity, the more head (water level drawup or mounding) will be required at the ASR well to achieve a given injection rate. During injection, excessive well pressures must be limited to avoid fracturing of confining layers or raising offsite water levels to an unacceptable level (e.g., raising ground water levels above ground surface at offsite wells).

Reliable aquifer parameter data are best developed from controlled pumping tests, and development of storativity values requires an observation well. Johnson (2004) presented detailed analyses of pumping test data for 9 wells in the Purisima Aquifer (3 SCWD wells and 6 SqCWD wells). Additional analyses are available from recent pumping tests performed on SCWD's Beltz 12 Well and SqCWD's O'Neill Ranch Well following their construction. The locations of these wells are shown on **Figure 6** and the derived aquifer parameters are summarized in **Table 2** below:

Table 2. Aquifer Parameter Data – Purisima Aquifer

Well Owner	Well Name	Hydro-Stratigraphic Unit	T (gpd/ft)	S (unitless)	K (ft/d)
SCWD	Beltz 7	A	935	NA	2.5
	Beltz 8	A	27,300	1.9×10^{-4}	37
	Beltz 9	A	32,460	1.4×10^{-2}	40
	Beltz 12	Tu/AA/A	18,480	NA	7.7
SqCWD	Main St.	Tu/AA	29,170	3.3×10^{-3}	9.8
	Garnet	A	33,510	NA	34
	Tannery	A	15,110	NA	10
	Estates	A/BC	17,950	NA	5.8
	Madeline	BC	1,795	NA	2.0
	O'Neill Ranch	Tu/AA	16,900	NA	6.5

Notes:
T - Transmissivity
S - Storativity
K - Hydraulic Conductivity
NA - Not Available

As shown in **Table 2** above, three of the four SCWD wells tested are completed in Aquifer A (Beltz 7 – 9). The transmissivity values for Beltz 8 and 9 are generally consistent, displaying moderate transmissivity values of approximately 30,000 gpd/ft. The test for Beltz 7 was very short duration (20 minutes) and the results from this test are not considered reliable or representative. Beltz 12 is screened in Aquifers A, AA and Tu, and displays a composite moderate transmissivity of approximately 18,500 gpd/ft.

Two SqCWD wells are screened solely in Aquifer A (Garnet and Tannery) and display transmissivity values ranging between approximately 15,000 and 33,500 gpd/ft, generally consistent with SCWD wells completed in Aquifer A. The O'Neill Ranch and Main St. wells are completed in Aquifers AA and Tu, and display moderate transmissivity values ranging between approximately 16,900 and 29,200 gpd/ft, respectively. It is noted that the O'Neill Ranch well is located in the vicinity of Beltz 12 (refer to **Figure 6**) and displays a comparable transmissivity value. The Madeline Well is screened only in Aquifer BC and displays a relatively low transmissivity value of approximately 1,800 gpd/ft.

Storage coefficient values are sparse (a proximate monitoring well is required during a pumping test to determine this parameter); however, the reported values for the Purisima Aquifer are in the range 1×10^{-2} to 10^{-4} (dimensionless), indicative of semi-confined aquifer conditions.

Water-Level Conditions. The feasibility of any ASR (or IPR) project depends on the potentially available "freeboard" in water levels in the receiving groundwater basin. During injection, the water level (head) in the injection well and aquifer will increase due to mounding in the aquifer. The available "freeboard" for water level drawup in the well casing for injection is determined based on the depth to water prior to injection (static water level) plus the amount of wellhead pressurization considered reasonable (if any). For conservative planning purposes, it is assumed that wellhead pressurization will not occur for this project; therefore, the available freeboard for drawup is limited in this study to the depth to water below ground surface.

Available long term records in the Purisima Aquifer indicate that prior to 1975, groundwater levels declined by several tens of feet in response to the initial stages of groundwater development. During the period 1975 - 2005, static levels have fluctuated in response to pumping cycles, but have not trended significantly up or down despite large increases in production (Johnson, 2004). This trend (or lack thereof) appears to have continued to the current period.

Published water-level contour maps for Spring and Fall 2012 are shown on **Figures 7 and 8**, respectively. As shown, water levels in the Purisima Aquifer are generally characterized by a broad and persistent pumping trough surrounding production wells. In particular, the contours for Fall 2012 show the pumping depression with water levels below sea level extending from SqCWD's Main St. well to the Estates well, including a long section of coastline. Although seawater intrusion has not been detected in most of the western Purisima Aquifer, these water level conditions mean that the productive hydrostratigraphic units AA and A remain at risk of seawater instruction (HMWRI, 2013).

Spring 2012 water levels are used to conservatively estimate the available "freeboard" at wells for water-level increases during injection, and available data for key wells are summarized in **Table 3** below. As shown in **Table 3**, depth to water levels at SCWD Beltz 8 – 10 wells are relatively shallow, ranging from approximately 35 to 50 ft bgs, depending on location. As such, there is somewhat limited freeboard for water-level increases during injection at these wells. Significantly greater freeboard exists at Beltz 12 of approximately 80 feet. Depths to water at SqCWD wells range between approximately 50 and 140 feet, depending on location. The effects of the available drawup on injection capacity at any given well site are evaluated further in a following section.

Santa Margarita Groundwater Basin

Regional Setting. The Scotts Valley Groundwater Basin (DWR Basin No. 3-27) is part of the larger Santa Margarita Groundwater Basin (SMBG). The SMGB covers over 30 square miles in the Santa Cruz Mountains forming a roughly triangular area that extends from Scotts Valley in the east, to Boulder Creek in the northwest, and to Felton in the southwest. The basin is bounded by two regional faults, the Ben Lomond Fault to the west and the Zayante Fault to the north. The southern and eastern boundaries are less well-defined; however, it is our understanding that these boundary conditions are currently being reevaluated by consultants to the SVWD.

Table 3. Water-Level Data – Purisima Aquifer (Spring 2012)

Well Owner	Well Name	Hydro-Stratigraphic Unit	GS Elevation (ft msl)	WL Elevation (ft msl)	DTW (ft)
SCWD	Beltz 8	A	47	10	37
	Beltz 9	A	43	0	43
	Beltz 10	A	58	5	53
	Beltz 11	Tu	57	20	37
	Beltz 12	Tu/AA	120	42	78
SqCWD	Main St.	Tu/AA	54	6	48
	Rosedale	AA/A	131	5	126
	Garnet	A	81	8	73
	Maplethorpe	A	135	12	123
	Tannery	A	124	11	113
	Monterey	A	113	7	106
	Estates	A/BC	144	2	142
	O'Neill Ranch	Tu/AA	117	45	72

Notes:
GS - Ground Surface
WL - Water Level
DTW - Depth to Water

The hydrogeology of the SMGB has been documented in detail in reports prepared by the United Stated Geological Survey (USGS), the California Department of Water Resources, (DWR), and various consulting firms. These documents describe the stratigraphy, structure, and hydraulic characteristics of the regional aquifer systems. The most recent comprehensive descriptions have been prepared by Kennedy/Jenks Consultants in annual Water Year reports for the SVWD pursuant to its Groundwater Management Program (2011, 2012, and 2013), which synthesize more than 45 years of previous investigations and form the primary basis for the description of the hydrogeologic setting presented herein.

As described, the SMGB consists of a sequence of sandstone, siltstone, and shale with a thickness of up to approximately 1,500 feet that is underlain by granite. The sequence of sedimentary rocks is divided into several geologic formations on the basis of the rock type and their relative geologic age. This sedimentary sequence has been folded into a down-warped area known as the Scotts Valley Syncline. Due to this geologic structure, a given geologic formation can be found near the ground surface to several hundred feet below ground surface, depending on location in the basin. This geologic complexity is also reflected by the variability of layers. The SMGB has been divided by previous investigators into two subareas:

- The Scotts Valley Groundwater Subarea including the portion of the SMGB served primarily by SVWD. This subarea is generally bounded by Bean Creek to the north, Hanson Quarry on the west, and the SMGB boundary to the south and east.

- The Pasatiempo Groundwater Subarea includes the portion of the SMGB served primarily by the San Lorenzo Valley Water District. This subarea is generally bounded on the east by the Scotts Valley Groundwater Subarea, by Bean Creek to the north, and by the SMGB boundary to the south and west.

Hydrostratigraphy. The Scotts Valley Groundwater Subarea underlies the SVWD service area and is the primary area of interest of the SMGB for this study. Geologic formations that contain significant sandstone layers are the primary aquifers in the area. Brief descriptions of the primary aquifers in the basin are presented below (from youngest to oldest):

- Santa Margarita Sandstone (Tsm). The Santa Margarita Sandstone (Santa Margarita) generally consists of a massive, fine- to medium-grained arkosic sandstone that forms distinctive white sand that can be observed in cliffs around Scotts Valley. The Santa Margarita thins from over 400 feet thick in the western part of the basin to being absent on the eastern edge. The Santa Margarita unconformably overlies the Monterey Shale, which has been completely eroded away in the southeast and southern portions of the basin. Where this occurs, the Santa Margarita and Lompico are in direct contact. The hydraulic conductivity of the Santa Margarita ranges between 2 to 50 ft/d (ETIC, 2006).

- Lompico Sandstone (Tlo). The Lompico Sandstone (Lompico) consists of a massive, fine- to medium-grained sandstone that is typically 200 to 350 feet thick in the area. Most groundwater pumping in the Scotts Valley area is from the Lompico. The hydraulic conductivity of the Lompico ranges between 0.6 to 3.5 ft/d (ETIC, 2006).

- Butano Formation (Tbu). The Butano Formation (Butano) is a thick sandstone unit with interbeds of lower permeability materials (mudstone, shale, siltstone) that divide the formation into three sandstone members (lower, middle, and upper). The Butano has an uneroded total thickness of approximately 5,000 feet; however, structural deformation and erosion limit its thickness in Scotts Valley to several hundred to a thousand feet. The hydraulic conductivity of the Butano ranges between 0.04 to 1.25 ft/d (ETIC, 2006)

Underlying these deposits are granitic (i.e., bedrock) or fine-grained sedimentary rocks (e.g., Locatelli Formation) that are generally considered non-water bearing and constitute the base of the aquifer system in the area.

A geologic map of the surficial geology in the area is shown on **Figure 9** and a regional cross-section through the study area showing the underlying hydrostratigraphic framework is shown on **Figure 10**.

As shown on **Figure 10**, in the southwest area underlying the SVWD service area, the Santa Margarita and Lompico aquifers combined reach thicknesses of up to approximately 500 feet and the Butano is absent. Towards the northeast, the Santa Margarita thins and becomes absent near the SVWD boundary. The maximum thickness of permeable deposits occurs within the Scotts Valley Syncline, where the combined thickness of the Santa Margarita, Lompico and Butano is as much as approximately 1,000 feet.

Aquifer Parameters. ETIC (2006) defined hydraulic conductivity values for the SMGB aquifers as part of developing a numerical groundwater flow model of the basin. As of this writing, the actual pumping test data and analyses have not been obtained; therefore, for purposes of this study the published horizontal hydraulic conductivity values utilized in the ETIC (2006) model are multiplied by average aquifer thicknesses to approximate transmissivity values and are presented in **Table 4** below. Published storativity values for the ETIC groundwater model are also presented in **Table 4** below:

Table 4. Aquifer Parameter Data – SMGB

Aquifer	Avg. Thickness (ft)	K (ft/d)	T (gpd/ft)	S (unitless)
Santa Margarita	200	7.5	11,220	1.0×10^{-2}
Lompico	200	3.0	4,488	1.0×10^{-4}
Butano	600	1.25	5,610	1.0×10^{-5}
Notes:				
T - Transmissivity				
S - Storativity				
K - Hydraulic Conductivity				

As shown in **Table 4** above, the Santa Margarita displays a moderate transmissivity value of approximately 11,000 gpd/ft. The Lompico and Butano are notably less permeable than the Santa Margarita, displaying transmissivity values of approximately 4,500 to 5,500 gpd/ft. Storage coefficient values for the Santa Margarita are on the order of 1×10^{-2}, indicative of semi-confined aquifer conditions. Values for the Lompico and Butano are in the range of 1×10^{-4} to 10^{-5} (dimensionless), respectively, indicative of confined aquifer conditions.

Water-Level Conditions. Available long term records from SVWD show that groundwater levels in many parts of the SMGB declined significantly (by over 200 feet in some areas) between the late 1960's and mid-1990's. Since the mid-1990's, groundwater levels in most wells in the basin have stabilized, or are declining at lower than historical rates (KJ, 2011). Brief descriptions of water level conditions in each of the principal SMGB aquifers are presented below:

<u>Santa Margarita Aquifer.</u> The Santa Margarita was historically an important aquifer in Scotts Valley; however, water level declines of up to approximately 200 feet occurred during the 1980's and early 1990's have diminished its current ability to supply water. A water-level

contour map for Fall 2012 is shown on **Figure 12**. As shown, water levels in the Santa Margarita Aquifer are higher in the uplands and lowest along Bean Creek (where groundwater discharges to the creek). As shown on **Figure 12** and as discussed previously, there are areas where the Monterey Shale is eroded and the Santa Margarita is in direct contact with the Lompico. Declining water levels in the Lompico have caused the Santa Margarita to become unsaturated or have depressed levels (KJ, 2013). As shown, a water level depression exists in the general vicinity of Mt. Hermon Rd. between Scotts Valley Dr. and Hanson Quarry.

Lompico Aquifer. The Lompico is the current primary source for groundwater pumping in the Scotts Valley area, and water levels have declined by 150 to 250 feet relative to pre-pumping levels (KJ, 2013). A water-level contour map for Fall 2012 is shown on **Figure 13**. As shown, a generally broad depression exists forming a trough along the southern margin of the basin, with isolated areas of concentrated depressions around actively pumping wells.

Butano Aquifer. The Butano is also an important source for groundwater pumping in the Scotts Valley area, and water levels have declined as much as 200 feet relative to pre-pumping levels (KJ, 2013). A water-level contour map for January 2013 is shown on **Figure 14**. As shown, a generally broad depression exists forming a trough along the southern margin of the basin, with isolated areas of concentrated depressions around actively pumping wells.

Spring 2012 static water levels obtained from SVWD for its wells are used to conservatively estimate the available "freeboard" at existing wells for water-level increases during injection, and are summarized in **Table 5** below:

Table 5. Water-Level Data – Scotts Valley Subarea (Spring 2012)

Well Owner	Well Name	Primary Aquifer	GS Elevation (ft msl)	WL Elevation (ft msl)	DTW (ft)
SVWD	#3B	Butano	673	258	415
	#7A	Butano	698	289	409
	#9	Santa Margarita	528	342	186
	#10A	Lompico	512	314	198
	#11A	Lompico	603	299	304
	#11B	Lompico	588	286	302

Notes:
GS - Ground Surface
WL - Water Level
DTW - Depth to Water

As shown in **Table 5**, depths to water levels in existing SVWD well range from approximately 190 to 415 ft bgs, depending on aquifer. The Santa Margarita aquifer has the least amount of available freeboard of approximately 190 feet. Depths to water in the Lompico range between approximately 200 to 300 ft bgs, depending on location. The greatest amount of available freeboard, approximately 400 feet, exists at wells in the Butano. The effects of the available drawup on injection capacity at any given well site are evaluated further in a following section.

AVAILABLE GROUNDWATER STORAGE CAPACITIES

The feasibility of any ASR project depends on the potentially available storage capacity of the receiving groundwater basin. Evaluations of the available information regarding the available storage capacities in each area of this study are presented below.

Purisima Aquifer

As discussed previously, available long term records in the Purisima Aquifer indicate that prior to 1975, groundwater levels declined by several tens of feet in response to the initial stages of groundwater development. Water levels in the Purisima Aquifer are generally characterized by a broad and persistent pumping trough surrounding production wells. In particular, the contours for Fall 2012 shows the pumping depression with water levels below sea level extending from SqCWD's Main St. well to the Estates well, including a long section of coastline. Although seawater intrusion has not been detected in most of the western Purisima Aquifer, these water level conditions mean that the productive hydrostratigraphic units AA and A remain at risk of for seawater instruction (HMWRI, 2013). These conditions also reflect potentially available aquifer storage space for ASR.

The available storage capacity of the Purisima Aquifer is not precisely known; however, for the current reconnaissance-level purposes of identifying potentially available groundwater storage space, a generally accepted first-approximation method is that it is approximately equal to the amount of cumulative historical storage depletion. The amount of historical storage depletion in the Purisima Aquifer (inclusive of both SCWD and SqCWD service areas) was most recently estimated by HMWRI (2012) utilizing a hydrologic budget approach (a mass-balance approach). Based on evaluation of the estimates of pumping in excess of sustainable yield in the Purisima Aquifer, the estimated cumulative pumping deficit since 1979 is approximately 3,290 mg (equivalent to approximately 10,100 acre-feet [af]).

Santa Margarita Groundwater Basin

The available storage capacity of the SMGB is not precisely known either; again however, for the current reconnaissance-level purposes of identifying potentially available groundwater storage space, the first-approximation method that it is approximately equal to the amount of cumulative historical storage depletion is used as well. The amount of historical storage depletion in the Santa Margarita Groundwater Basin was most recently estimated by KJ (2013). The Santa Margarita Groundwater Basin model was used to evaluate changes in groundwater in storage (a mass-balance approach). The modeled long-term changes in storage per aquifer in the Scotts Valley subarea of the SMGB are summarized in **Table 6** below:

Table 6. Model-Simulated Changes in Storage in Scotts Valley Subarea WY 1985 – WY 2012

Aquifer	Change in Storage (af)	Change in Storage (mg)
Santa Margarita	-3,760	-1,225
Lompico	-5,390	-1,756
Butano	-1,840	-600
Total	**-10,990**	**-3,581**

As shown, between WY1985 to WY 2012, the total estimated cumulative storage loss in the Scotts Valley subarea is approximately 3,580 mg. Of this amount, approximately 50 percent of the loss has occurred in the Lompico Aquifer, with lesser amounts in the Santa Margarita and Butano Aquifers.

Discussion

As discussed previously, the Purisima Aquifer is exposed on the seafloor just offshore of the basin and in the walls of Soquel Submarine Canyon (refer to **Figure 5**). Under pre-development conditions, groundwater discharged to the ocean where the aquifers crop out on the seafloor. Of concern for the success of the seasonal storage program is the efficiency with which the water that is injected into historically depleted storage space can be recovered following a prolonged injection cycle and/or hiatus between injection and recovery cycles. In a coastal basin that is in communication with the ocean, it is necessary to evaluate the possibility that the injection of substantial volumes of water into the aquifer system will substantially increase the seaward groundwater gradient, thereby increasing the amount of subsurface outflow from the aquifer system to the ocean. If the addition of water to the aquifer system substantially increases the volume of outflow, the overall efficiency of the managed recharge program may be reduced to the point where the project is of limited beneficial effect.

As also discussed previously, the target aquifers for this project are semi-confined to confined. The nature of confining aquifers deserves some further discussion in the context of an ASR recharge project. From a practical standpoint, obvious questions about ASR in confined systems are: how can a fully saturated confined aquifer under pressure release water from storage and still remain fully saturated, or, even more perplexing, how can a fully saturated confined aquifer take in additional water (i.e., during injection)? Extraction from, or injection into, an unconfined aquifer is easy to visualize, because water is simply drained from, or filled into, the pore spaces of the aquifer matrix as the water level falls (or rises) and the saturated thickness changes. In a confined aquifer, on the other hand, the saturated thickness of the aquifer does not change in response to pumping or injection.

A similar set of questions was investigated by Meinzer (1942), who observed that more water could be removed from a well in a confined aquifer than was calculated to be flowing laterally toward the well. Through a variety of investigative techniques, Meinzer (and others) have demonstrated that confined aquifers exhibit elastic storage characteristics, and do actually compress when fluid pressures are reduced (i.e., during pumping), and are expanded when the fluid pressure is increased (i.e., during recharge). Therefore, the two major sources of water to a pumping well completed in confined aquifers are; 1) water moving laterally through the aquifer toward the well, and, 2) water forced from the aquifer matrix by compression caused by the reduction in pore pressures and by the weight of the overlying rock. Lesser amounts of water are provided from the expansion of water and from water released from leaky aquitards (such as the Aquitard B unit of the Purisima Aquifer). During injection, therefore, water is introduced into the aquifer both by moving water laterally away from the well (e.g., displacement of the freshwater/seawater interface seaward), and by expansion of the aquifer matrix. Lesser amounts of storage are provided by compression of water and leakage into overlying aquitards. The increase in fluid pressures within the aquifer during injection and storage is manifested as increases in the piezometric head over very large areas.

Given these mechanics, increased outflow from the Purisima Aquifer to the ocean induced by managed recharge can potentially occur as both upward vertical leakage through the seafloor and lateral displacement through exposures in the walls of the submarine canyon. Additional losses to local creek beds as rising groundwater discharge (i.e., by increasing creek base flows) are also possible.

With regards to the potential for lateral displacement to cause hydraulic losses to the ocean, the landward movement of the freshwater / saltwater interface that has occurred during the period of over-pumping theoretically represents potential usable offshore storage space that would be available to recharge operations via lateral displacement. The amount of freshwater in storage offshore and the current location of seawater / freshwater interface is not precisely known; however, modeling work conducted by the USGS in the early 1990’s suggests it may have been as close as 1 to 2 miles offshore in the AA/A aquifers (Essaid 1992) with the outcrop on the wall of the Soquel Submarine Canyon being approximately 5 miles offshore. These conditions theoretically suggest that before significant hydraulic losses from aquifer storage due to lateral displacement can occur, the seawater / freshwater interface, which has presumably been advancing landward to some extent over the past 20 years or more, may need to be displaced and pushed back seaward (perhaps as far as the walls of the submarine canyon) before significant volumes of fresh water might begin to leak laterally from the aquifer through exposures in the walls of the submarine canyon.

It is also important to note that from a water supply / project yield perspective, there should be no expectation for “molecule-for-molecule” recovery of water that is recharged. For example, some of the molecules of water injected via a potential ASR well field in the vicinity of SCWD’s Beltz wells would be expected to drift downgradient towards the pumping depression(s) created by SqCWD’s wells (refer to **Figures 7 and 8**). The amount of drift would be dependent on a variety of factors, such as the duration of storage, amount of seasonal pumping by SCWD and SqCWD, etc.; however, regardless of the amount of drift, the recoverable yield of the project should be viewed from a mass-balance perspective. The amount of water recharged into the basin(s) essentially constitutes a commensurate increase in the basin sustainable yield (minus any induced hydraulic losses to the ocean or creeks). The water recharged by SCWD would represent “salvaged water” that would otherwise be wasted to the ocean and the rights to recover the same volume of water from the basin(s) should accrue to SCWD.

Numerical groundwater modeling to predict the aquifer response to potential injection operations would need to be performed to quantify estimates of increases in outflow from the basins(s) as a result of injection and storage, but is beyond the scope of this study. Such modeling work should include analyses of optimal injection and recovery strategies that would maximize the efficiency of recovery of the injected water and minimize the potential for hydraulic losses. This should include an analysis of optimal injection and recovery well site locations, as well as optimal temporal injection and recovery cycles, to minimize the potential for losses and maximize project yields. The groundwater model of the Soquel-Aptos Groundwater Basin currently under development (scheduled for completion in 2016) through the Basin Implementation Group (BIG) provides an excellent opportunity to evaluate these issues.

In the meantime, the only real reference for an estimate of the amount of increased subsurface outflow to the ocean associated with ASR in a similar coastal aquifer is the Monterey Peninsula ASR Project. Estimates there for the seasonal storage of approximately 325 mgy (1,000 afy) are on the order of approximately 6 percent of the amount recharged. It is important to note that these losses also would occur only after the large existing pumping depression in the basin had been filled, which has not occurred. For reconnaissance-level planning purposes, a 10 percent loss factor for this project is considered reasonable.

Summary

In summary, there has been approximately 3,290 mg and 3,580 mg of estimated historical storage depletion in the Purisima Aquifer and Scotts Valley Subarea, respectively. These findings suggest that there may be up to approximately 6,870 mg of potentially available storage space in local aquifers for managed aquifer recharge and recovery. For planning purposes at this stage (and in the absence of any other defensible factor), a 10 percent loss factor for hydraulic losses from recharge operations (i.e., as subsurface outflow to the ocean and/or losses to creeks) is considered reasonable.

WELL INJECTION CAPACITIES

Previous Investigations

The feasibility of injection into the Purisima Aquifer has been previously investigated as documented in the following reports:

- Luhdorff and Scalmanini Consulting Engineers (1999), *Feasibility of Injection into the Purisima Formation, Soquel-Aptos Area*, report prepared for Soquel Creek Water District.
- Luhdorff and Scalmanini Consulting Engineers (2001), *Pilot Injection Testing Summary Report*, letter-report prepared for Soquel Creek Water District.
- Williams, Derrik (2003), *Initial Analysis: Injection of Stream Diversion*, memorandum prepared for Nick Johnson.

These investigations were conducted for SqCWD as part of evaluating the feasibility of injecting treated excess winter stream flows from Soquel Creek into the Purisima Aquifer via existing production wells.

The 1999 Luhdorff and Scalmanini (LSCE) study generally consisted of an evaluation of the hydrogeologic setting, existing water level conditions, and estimated per well injection capacities. The methodology utilized to estimate well injection capacities consisted of two factors or assumptions for each well:

1. The specific injectivity (reciprocal of specific capacity) was assumed to be one-half of the pumping specific capacity, and,
2. The maximum water level rise in the well was equal to the distance between static water level and 10 feet below ground surface (i.e., no pressurized injection).

The results of this analysis indicated per well injection capacities of existing SqCWD production wells range between approximately 75 and 1220 gpm, depending on the well and static water level assumptions. The overall conclusion was that it was feasible for SqCWD to inject treated surface water into the Purisima with a combined total injection capacity of approximately 5,600 gpm (8 mgd).

The 2001 LSCE report documented injection testing performed at SqCWD's Garnet Well as a follow-up to the findings of the previous 1999 study. The Garnet Well was selected because it had one of the highest estimated injection capacities from the 1999 study, and because of other operational factors. The testing program essentially consisted of a four-day constant rate injection test at approximately 300 gpm (0.43 mgd) utilizing SqCWD system water injected via the existing column pipe and pump. Based on analysis of the testing results, it was estimated that full-scale injection could achieve a sustainable rate of approximately 600 gpm (0.86 mgd). The overall conclusion was that the results of the Garnet Well injection testing confirmed the general validity of the 1999 study results, which is an important consideration for planning purposes.

In 2003, Derrik Williams updated the 1999 LSCE per well injection capacity estimates based on an interpretation of the Garnet Well testing results, more conservative (spring time) static water levels, and a constraining factor whereby the pumping capacity of each well (i.e., the estimated injection capacity was not allowed to exceed the existing pumping capacity). Using this approach, the total SqCWD injection capacity was estimated at 3,370 gpm (4.85 mgd) with per well injection rates ranging between approximately 15 to 790 gpm. Based on these results, Williams recommended an average per-well injection rate of 350 gpm (0.50 mgd) for planning purposes.

As of this writing, no previous well injection capacity analyses for the SMGB have been found.

Existing Wells - Screening-Level Analysis

For purposes of providing estimates of injection capacities of existing wells in the three service areas of this study, a methodology analogous to that utilized by Williams (2003) is utilized here, but updated for current conditions (e.g., current well performance and water levels). We believe this approach is reasonable for a screening-level analysis and provides consistency between previous estimates for SqCWD wells and estimates for SCWD and SVWD wells for this study. Therefore, for this screening-level analysis, the per-well injection capacity is estimated based on the following factors:

1. Reported existing pumping capacity.
2. Specific injectivity is assumed to be one-half of existing specific capacity.
3. Available freeboard for water level drawup within well casings is based on the distance between Spring 2012 static water levels and ground surface (i.e., no pressurized injection).

The estimated injection capacity is the minimum of the three factors (i.e., injection capacity is not allowed to exceed pumping capacity). The resulting estimates are summarized in **Table 7** and discussed below:

SCWD Wells. The estimated injection capacities of SCWD's existing wells range between approximately 15 to 330 gpm, averaging approximately 160 gpm (0.23 mgd). Further review of **Table 7** reveals that Beltz 12 has the highest estimated injection capacity of approximately 330 gpm (0.48 mgd). This well is completed in Aquifers A, AA, and Tu, which are generally recognized as the most transmissive units within the Purisima Aquifer (refer to Aquifer Hydraulic Parameters section). The total combined estimated injection capacity of all 5 existing SCWD wells is approximately 820 gpm (1.2 mgd).

SqCWD Wells. The estimated injection capacities of SqCWD's wells range between approximately 350 to 920 gpm, averaging approximately 480 gpm (0.69 mgd). Further review of **Table 7** reveals that the Garnet and Estates Wells have the highest estimated injection capacities of approximately 600 and 920 gpm (0.86 and 1.32 mgd), respectively. These wells are completed in Aquifer A. The total combined estimated injection capacity of all 8 existing SqCWD wells in the western Purisima Aquifer is approximately 3,840 gpm (5.5 mgd).

SVWD Wells. The estimated injection capacities of SVWD's wells to range between approximately 100 to 320 gpm, averaging approximately 240 gpm (0.35 mgd). Wells #10A and #11B have the highest estimated injection capacities of approximately 320 gpm (0.46 mgd). Both of these wells are completed in the Lompico Aquifer, which is moderately transmissive and has also experienced the greatest amount of storage depletion in the Scotts Valley area. Further review of **Table 7** reveals that pumping capacity is the primary limiting factor for all of SVWD wells, as opposed to available drawup/freeboard for injection. The total combined estimated injection capacity of all 6 existing SVWD wells is approximately 1,450 gpm (2.1 mgd).

Table 7. Screening-Level Injection Capacity Estimates for Existing Wells

Well Owner	Well Name	Aquifer Unit	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Assumed Specific Injectivity (gpm/ft)	Avail. DUP[1] (ft)	Theoretical Injection Rate (gpm)	Estimated Injection Rate (gpm)
SCWD	Beltz 8	A	200	9.8	4.9	37	181	181
	Beltz 9	A	225	10.4	5.2	43	223	223
	Beltz 10	AA/A	150	2.7	1.3	53	70	70
	Beltz 11	Tu	150	0.8	0.4	37	14	14
	Beltz 12	Tu/AA/A	700	8.5	4.3	78	332	332
							Min	**14**
							Max	**332**
							Average	**164**
							Subtotal	**819**
SqCWD	Main St.	Tu/AA	1445	15.4	7.7	48	366	366
	Rosedale	AA/A	580	5.5	2.8	126	347	347
	Garnet	A	710	16.4	8.2	73	602	602
	Maplethorpe	A	350	12.3	6.2	123	757	350
	Tannery	A	530	7.2	3.6	113	405	405
	Monterey	A	430	14.3	7.2	106	755	430
	Estates	A/BC	1035	12.9	6.5	142	918	918
	O'Neill Ranch	Tu/AA	800	11.7	5.9	72	421	421
							Min	**347**
							Max	**918**
							Average	**480**
							Subtotal	**3839**
SVWD	Well #3B	Tbu	300	2.0	1.0	415	415	300
	Well #7A	Tbu	300	4.0	2.0	409	818	300
	Well #9	Tsm	110	2.0	1.0	186	186	110
	Well #10A	Tlo	320	6.4	3.2	198	634	320
	Well #11A	Tlo	100	1.8	0.9	304	274	100
	Well #11B	Tlo	315	2.7	1.3	302	403	315
							Min	**100**
							Max	**320**
							Average	**241**
							Subtotal	**1445**
							TOTAL	**6103**

Notes:
1 - Draw up (DUP) from **Tables 2 and 5**

In summary, both SCWD and SqCWD wells completed in aquifer units Tu/AA/A generally have the highest estimated injection capacities. In Scotts Valley, wells completed in the Lompico Aquifer have the highest estimated injection capacities. Combining both SCWD and SqCWD existing wells, the total estimated existing well injection capacity in the western Purisima Aquifer is approximately 4,660 gpm (6.7 mgd). Combining all three service area wells the total existing well estimated injection capacity is approximately 6,100 gpm (8.8 mgd).

Retrofitting existing production wells for ASR would generally consist of modifying wellhead piping, valving and metering to allow for reverse flow from the distribution system to the wells for injection. In addition, some method of injection downhole flow control (e.g., fixed orifice drop tubes or downhole flow control valves (FCVs) specially designed for injection wells) is required to maintain positive pressure in the piping system to prevent cascading of water in the well (cascading water conditions can lead to air entrainment and needs to be avoided to prevent air-binding of the well screens and gravel pack/aquifer matrices). The details of retrofitting each well would depend on a variety of site-specific factors (e.g., the existing wellhead piping, valving and metering configurations, the anticipated injection rates, existing pump characteristics, well casing diameters, etc.), analysis of which is beyond the scope of this reconnaissance-level study.

Potential New ASR Wells

The preceding analyses of existing well injection capacities is based on the current (or recent) specific capacities of those wells, and reflects potential injection capacities assuming the existing wells would be retrofitted for ASR operations. While it is our preliminary opinion that use of existing wells for injection does not represent a significant risk to the wells' service lives or production capacities, we acknowledge that a prudent operation may not want to put these facilities at risk, regardless of how insignificant. As an alternative to retrofitting existing wells, SCWD should consider the construction of dedicated ASR facilities.

Many of the existing wells presented in **Table 7** have experienced declines in specific capacity over their service lives as a result of gradual deteriorations in hydraulic performance. For example, when Beltz 8 was new (the well was constructed in 1998), it displayed a specific capacity of 22 gpm/ft with a pumping capacity of 800 gpm. As shown in **Table 7** above, this well currently displays a specific capacity of 9.8 gpm/ft and a pumping capacity of only 200 gpm. As such, the potential injection capacitites presented in **Table 7** are not considered representative of the potential capacity of properly designed, constructed, and maintained[4] new ASR wells.

For purposes of estimating the potential injection capacity of dedicated new ASR wells, a comparable analysis to that presented above for the existing wells is utilized, except that the specific capacities of the existing wells when they were new is utilized to represent the potential

[4] Typical recommend well maintenance includes the performance of routine, rigorous well rehabilitation (consisting of both mechanical and chemical methods) over a well's service-life to maintain capacity. Typical "triggers" for well rehabilitation are when the specific capacity declines by 25% or every 5 years, whichever comes first. Based on these criteria, most of SCWD's Beltz wells (except Beltz 12) appear to be candidates for well rehabilitation.

performance of new ASR wells. The limited number of existing wells for which reliable original specific capacity data are readily available (i.e., from well construction summary of operations reports) are summarized in **Table 8** below:

Table 8. Screening-Level Injection Capacity Estimates for Potential New Wells

Well Owner	Well Name	Aquifer Unit	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Assumed Specific Injectivity (gpm/ft)	Avail. DUP[1] (ft)	Theoretical Injection Rate (gpm)	Estimated Injection Rate (gpm)
SCWD	Beltz 8	A	800	22.0	11.0	37	407	407
	Beltz 9	A	700	21.0	10.5	43	452	452
	Beltz 10	AA/A	350	11.1	5.6	53	294	294
	Beltz 12	Tu/AA/A	700	8.5	4.3	78	332	332
SqCWD	O'Neill Ranch	Tu/AA	800	11.7	5.9	72	421	421
							Min	**294**
							Max	**452**
							Average	**381**
SVWD	Well #10A	Tlo	400	5.3	2.7	198	525	400
							Min	**400**
							Max	**400**
							Average	**400**

Notes:
1 - Draw up (DUP) from **Tables 2 and 5**

As shown in **Table 8**, per well injection capacities for potential new ASR wells completed in the Tu/AA/A aquifers units of the Purisima Aquifer range between approximately 300 to 450 gpm, averaging approximately 380 gpm. In Scotts Valley, the only well construction report readily available was for Well #10A. As shown in **Table 8**, this well when new had a potential injection capacity of 400 gpm. Based on these results, for planning purposes we recommend a conservative per-well injection rate of 350 gpm (0.5 mgd) for new ASR wells in each of the three service areas.

Regardless of the location, any new ASR well should have common design features that maximize the injection capacity, limit potential plugging rates, and extended well service lives. General design considerations for any new ASR well include the following:

1. Fully penetrate the target aquifer(s) to maximize specific capacity and available drawdown for backflushing.
2. For injection rates up to 350 gpm, well casing diameter of at least 12-inches in order to limit downhole velocities and maximize injection capacity.
3. Constructed entirely of stainless steel casing and wire-wrapped screen to limit plugging and extend well service lives.

Target Aquifers / Favorable Areas for ASR Wells

The results of the preceding evaluation of hydrogeologic settings, aquifer storage depletion / available storage, and screening-level injection capacity analyses allow for general identification of target aquifers and favorable areas for ASR/IPR wells.

For the Purisima Aquifer, aquifer units Tu/AA/A should be targeted as the most transmissive zones and for having the greatest theoretical per-well injection capacities. The overlying Aquifers BC through F appear to be less transmissive and, therefore, considered less favorable for ASR wells. All other considerations being equal, areas farther from the coastline would be considered more favorable due to concerns regarding the potential for losses to increased subsurface outflow. The areas roughly north of Hwy 1 and south of the base of the coastal terrace (e.g., in the general vicinity of Beltz 12, O'Neill Ranch, Main St. and Tannery Wells) would be considered generally more favorable than areas south of Hwy 1.

For the SMGB / Scotts Valley Subarea, the Lompico Sandstone would be the most favorable target aquifer for ASR wells, with the Butano Formation secondarily favorable, based both on well performance characteristics and the estimated amount of storage depletion / available storage. The general area along the axis of the Scotts Valley Syncline would be generally more favorable than other areas due to the overall greater saturated thickness and corresponding well capacities.

The Santa Margarita Sandstone is the least favorable for ASR wells due to the lack of saturated sediments for well backflushing. As such, the amount of estimated historical storage depletion in this aquifer (1,225 mg) should be deducted from the total amount of potentially available aquifer storage space for ASR. As such, the revised total estimated potentially available aquifer storage in the Scotts Valley Subarea is 2,355 mg (refer to **Table 6**). It is noted, however, that the Santa Margarita may be a good candidate for recharge via surface spreading (e.g., via existing quarries); however, evaluation of that method of managed aquifer recharge is not part of this study.

INDIRECT POTABLE REUSE (IPR)

Indirect Potable Reuse (IPR) via injection wells is similar to ASR in that excess water supplies are injected into an aquifer for storage and later recovery. As such, much of the preceding evaluation of ASR is directly applicable to IPR as well (i.e. per well injection capacities and available aquifer storage space); however, IPR differs significantly from ASR in that the source water is highly treated recycled waste water, which is currently considered non-potable by the SWRCB. Under current regulations, the well utilized for injection cannot be utilized for recovery due to aquifer residence time and associated setback requirements from any potable-supply wells.

The SWRCB Division of Drinking Water ([DDW] formerly California Department of Public Health [DPH]) has adopted regulations for groundwater replenishment using recycled water that became effective in June 2014 (DPH-14-003E, Groundwater Replenishment Using Recycled Water). The regulations cover aquifer recharge via both surface spreading and direct injection methods. With regards to direct injection methods (surface spreading is outside the scope of this study), the following important requirements apply:

1. Advanced wastewater treatment of injection source water: The treatment train must consist of at least three treatment processes that achieve 10- to 12-log reductions in specific pathogens (enteric virus, Giardia cyst, and Cryptosporidium oocyst).
2. Required setback distances from potable wells: These are site-specific based on providing a certain amount aquifer residence time between points of injection and the nearest potable-supply well, depending on the level of treatment.

With regards to setback distances and residence / retention times, there are two primary considerations:

1. Pathogenic Microorganism Control (Section 60320.208): For purposes of planning an IPR project, each month of aquifer residence time is credited for additional virus log reductions beyond that achieved by the treatments system depending on the method used to estimate the retention time as summarized in **Table 9** below:

Table 9. Retention Time Estimation Method vs. Virus Log Reduction Credit

Method Used to Estimate Retention Time	Virus Log Reduction Credit Per Month
Tracer study utlizing an added tracer	1.00
Tracer study utlizing an intrinsic tracer	0.67
Numerical modeling with a calibrated three-dimensional groundwater flow model	0.50
Analytic methods using academically accepted groundwater flow equations (e.g., Darcy Equation)	0.25

2. Response Retention Time (Section 60320.224): The injected wastewater must be retained underground for a period of time sufficient to allow adequate response time to identify treatment failures as necessary to protect public health. The minimum required response time is two months. For planning purposes, demonstration of the required minimum retention is credited depending on the method used to estimate residence time as summarized in **Table 10** below:

Table 10. Retention Time Estimation Method vs. Response Time Credit

Method Used to Estimate Retention Time	Response Time Credit Per Month
Tracer study utlizing an added tracer	1.00
Tracer study utlizing an intrinsic tracer	0.67
Numerical modeling with a calibrated three-dimensional groundwater flow model	0.50
Analytic methods using academically accepted groundwater flow equations (e.g., Darcy Equation)	0.25

The above retention time requirements affect well siting and the number of potentially available well sites. As noted, these requirements are very site-specific and identifying and evaluating specific site for IPR wells is beyond the scope of this reconnaissance-level study. However, KJ (2014) recently prepared a technical memorandum evaluating groundwater replenishment via IPR for SqCWD. Two groundwater replenishment projects were evaluated:

1. Mid-County GWR Project: This project would develop facilities within the SqCWD service area with a capacity of approximately 1.3 mgd (490 mgy / 1,500 afy).

2. Santa Cruz Regional GWR Project: This project would develop a larger regional project in the Soquel-Aptos Groundwater Basin with a total capacity of approximately 3.6 mgd (1,300 mgy / 4,000 afy). SqCWD's proportional share of this project would be 1.3 mgd (490 mgy / 1,500 afy).

For purposes of IPR injection well siting, KJ assumed that the advanced wastewater treatment plant would achieve the required virus log-reductions and the minimum separation distance was based on an assumed minimum response time criterion. Based on the SqCWD's Drinking Water Source Assessment Study, the estimated two-year groundwater travel time for the Main St. and Estates wells was approximately 1,100 feet. Based on this travel distance time, a minimum separation distance of 500 feet was estimated to provide between six months to one year of residence time.

Based on these criteria, KJ identified three potential injection well locations based on the previously referenced Williams (2003) injection capacity TM for the SqCWD:

1. Anna Jean Cummings Park: This site is generally located in the vicinity of the Main St. Well (greater than 500 feet). Based on the estimated injection capacity of the Main St. Well, an injection rate for an IPR well at this site was estimated to range between 250 to 300 gpm (0.35 to 0.43 mgd);

2. Cabrillo College: This site is generally located in the vicinity of the Estates Well (greater than 500 feet). Based on the estimated injection capacity of the Estates

Well, an injection rate for an IPR well at this site was estimated to range between 700 to 800 gpm (1.0 to 1.15 mgd);

3. Monterey St.: This site is generally located in the vicinity of the Monterey Well (greater than 500 feet). Based on the estimated injection capacity of the Monterey Well, an injection rate for an IPR well at this site was estimated at 400 gpm (0.58 mgd). KJ also noted that IPR at the Monterey St. location could provide for both replenishment and act as a seawater intrusion barrier well.

We find KJ's analysis to be reasonable given the available information and generally agree with their conclusions and recommendations. With regards to potential IPR well sites within the SCWD service area, it is our preliminary opinion that the options are likely relatively limited compared to those available in the SqCWD service area for three primary reasons:

1. The area of productive hydrostratigraphic units within the Purisima Aquifer underlying the SCWD service area is relatively small compared to that available in SqCWD.

2. The existing Beltz well field wells are already concentrated in the best areas. IPR well sites would need to have the minimum required separation distances, which further limits potential sites.

3. If the SCWD implemented small-scale ASR in its Beltz well field (as recommended later in the TM), the available sites for IPR and ASR wells would likely be in conflict.

It is noted that use of recycled water injection to form seawater barriers is historically the most common form of IPR in California. This technology has been used very successfully in Orange and Los Angeles Counties for over 50 years. The injection barriers are generally operated in a manner that maintain water levels at the coast to the necessary protective levels to prevent seawater intrusion (which vary depending on location and the underlying hydrogeology), allowing the inland portions of the groundwater basins to be dynamically managed in response to variations in supply and demand, including other forms of MAR (i.e., spreading basins and injection wells that recharge excess surface water when available) and municipal production wells. This alternative utilization of IPR, possibly in conjunction with San Lorenzo River-sourced ASR at inland locations, should also be considered for the Soquel-Aptos basin.

WATER QUALITY ISSUES

General Overview

Although the primary goal of most ASR programs is to maximize water supply reliability by storing seasonally available water in the aquifer until needed, an equally important goal is the preservation or enhancement of water quality through the ASR process. The capture, treatment, conveyance, and later recovery of this water (in addition to the cost of water purchase and/or water rights) results in the recharge water being a highly valued commodity; and as such, maintaining the quality of this water during storage is of high importance.

During the process of ASR, water is injected directly into the target aquifer(s) through the perforated (screened) intervals of the well. As the water enters the target aquifer it displaces native groundwater within the geologic matrix pore spaces. The displacement is also accompanied by a certain amount of intermixing, which is a characteristic function of the pore spaces and orientation of the geologic matrix of the aquifer. In addition to displacement/dispersion/intermixing mechanisms, ASR operations result in various chemical (and even biological) reactions. These reactions must be evaluated to ensure that adverse reactions do not compromise an otherwise successful program.

ASR and IPR projects typically involve the conjunctive utilization of waters that have different origins, and in most cases the quality of the recharge and receiving (i.e., native aquifer) waters are measurably different. Native groundwaters are typically more mineralized than surface water, low in dissolved oxygen and redox potential, and near mineral saturation equilibrium as a result of their (generally) long residence time within the aquifer and lack of contact with atmospheric oxygen. Seasonally available recharge waters, on the other hand, are generally low in mineral content and saturation, but are in equilibrium with the atmosphere. Additionally, the treated potable recharge water is highly oxidized, having a chlorine residual as a result of the potable water treatment process, in addition to being saturated with oxygen from atmospheric exposure. Because of these differences, chemical reactions may occur when recharge waters intermix with native groundwaters during aquifer storage.

In order to accurately characterize water quality for ASR suitability, a variety of physical and chemical parameters must be quantified to assess both the individual stability and character of each water on an individual basis, and to model the potential interaction of the waters when mixed in various proportions within the aquifer's mineral matrix, as would occur during ASR operations. Collecting the needed water-quality data and performing such geochemical modeling are beyond the scope of this reconnaissance-level feasibility study. However, a general overview of typical ASR water-quality reactions is presented below for reference.

In a broad context, water-quality changes during aquifer storage can occur from simple dilution/mixing, chemical interaction between injected and native groundwaters (as discussed above) or from reactions between the newly introduced recharge water and the aquifer minerals. Biological processes – both bioactivity and biomediated chemical reactions – can also occur (or be exacerbated) as a result of ASR operations. These changes can be beneficial or detrimental depending on the variety of environmental factors involved.

Beneficial changes in aquifer water quality from ASR operations can include:

- Reductions in mineralization/salinity
- Stabilization of corrosive waters
- Elimination of taste and/or odor causing compounds
- Oxidation of iron / manganese / sulfide / arsenic species
- Reduction / elimination of anaerobic bacteria

The potential for adverse chemical reaction also exists, and can occur under certain circumstances. Examples of undesirable changes in water quality include:

- Creation of dissolved gasses in the well/aquifer interface and/or in the recovered water
- Taste and/or odor issues
- Leaching of undesirable metals or radionuclides from aquifer minerals
- Creation of precipitation scales, which plug aquifer pores
- Ion exchange reactions, which can swell formation clays and reduce aquifer permeability

Well Plugging

Deterioration of well performance is a universal occurrence, in both ASR wells and conventional production wells. In the case of ASR wells, the issue of well plugging is much more significant, both in the rate of performance decline and in the variety of mechanisms by which well plugging occurs.

Unlike conventional production wells, plugging of ASR wells occurs primarily from the injection of water and the reversal of flow from the well casing outwards through the well screen, gravel annulus, and borehole wall into the aquifer. In this case, water is traveling both radially outward, and thus at an exponentially slower velocity as it moves out into the aquifer, and at the same time is generally traversing through finer and finer pore spaces (screen slot vs. gravel pack vs. formation porosity). Both of these elements - velocity reduction and pore space reduction - exacerbate plugging phenomena and can make unplugging a well a difficult task. Once plugged, the well will operate at reduced efficiency in both the injection and extraction modes.

ASR well plugging can be caused by a variety of factors, including poor well design, poor recharge water quality, and poor operating practices. Specific water-quality related plugging mechanisms include the following:

- Particulate fouling: Fine particles present in the recharge water physically plug the aquifer pores.
- Biofouling: Microorganisms and/or non-pathogenic bacteria present in the recharge water attach to the well bore and proliferate as a result of nutrient-rich injected waters passing over the biomass. The biogrowth will continue, often at an exponential rate, until either injection operations stop, or the population outstrips the availability of food sources. This is particularly important issue for IPR wells due the typically high nutrient-species content (e.g., nitrogen and phosphorus) of the source water (recycled waste water).

- Gas Binding: Air or gasses entrained in the recharge water (or evolved from geochemical reactions) become lodged in aquifer pore spaces which result in reduced hydraulic conductivity.
- Chemical Precipitation: Chemical reactions between the recharge water and native groundwater or minerals create precipitate scales that clog well pores.

These different well plugging mechanisms result in characteristically different declines in well performance, and a different treatment mechanism is needed of each condition. Prevention of fouling must specifically address the mechanism(s) involved; however, the best practice is to assess and maintain a high-quality recharge water (i.e., with low particulate and nutrient-species concentrations), and cease recharge operations when water quality is impaired.

Regardless of the treatment processes, 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 perforated section is, therefore, a critically important consideration when designing and operating ASR well facilities.

Should SCWD decide to further investigate the technical feasibility of ASR, a specialized suite of water-quality analyses for the GHWTP produced water would need be obtained in conjunction with similar water-quality analyses for candidate pilot demonstration wells when specific wells / sites are identified (e.g., Beltz 12); the recharge water-quality data will then need to be geochemically modeled with the specific native groundwater and mineral conditions present in the target aquifer(s) to complete a 3-component geochemical interaction analysis.

This modeling effort would assess the potential for native and recharge water intermixing as well as reactions with the rocks in the aquifer formations during aquifer storage. In addition to identifying the potential for adverse geochemical reactions (which may be able to be avoided via pilot program design and/or operations), the results of the modeling effort may be required by the Central Coast RWQCB as part of the approval process for permitting a permanent ASR program to demonstrate that no significant or permanent impairment of the aquifer will result from injection.

REGULATORY FRAMEWORK

The implementation of both pilot scale and permanent, full-scale ASR programs requires authorization and/or conformance to a variety of regulations and regulatory agencies. For the most part, compliance is relatively simple for ASR projects that involve the injection and recovery of potable waters in underground aquifers. For the subject project, applicable regulations include the following:

Federal Regulations

Underground injection of water supplies is regulated by U.S. EPA's Underground Injection Control (UIC) program as part of the Safe Drinking Water Act. The UIC program regulations prohibit any underground injection except as authorized by rule or permit. Injection wells are currently authorized by rule until further regulations become applicable. This rule exempts potable water injection wells from permitting procedures, although the U.S. EPA may require a permit on a case-by-case basis. However, all owners of injection wells authorized by rule must submit inventory information to the U.S. EPA. Compliance with the UIC program is essentially procedural and can be quickly completed.

State of California Regulations

Several state agencies and policies can affect injection programs. The State Water Resources Control Board (SWRCB) has broad authority over discharges to waters of the State. California has adopted a "nondegradation policy" (Statement of Policy with Respect to Maintaining High Quality of Waters in California; Resolution No. 68-16; October 1968) for State waters, whereby actions that tend to degrade the quality of groundwaters is prohibited. Oversight of this policy is done through the Regional Water Quality Control Boards (RWQCB).

As water supplies become more limited and the prospect of climate change negatively affecting conventional water storage in California (i.e., surface reservoirs and Sierra snowpack) becomes more apparent, the utility and benefits of ASR technology are being increasingly supported by governmental agencies throughout the state, including the SWRCB and Department of Water Resources (DWR). The SWRCB has thus recognized that it is in the best interest of the state to develop a comprehensive regulatory approach for ASR projects, and has recently (September 2012) adopted general waste discharge requirements for ASR projects that inject drinking water into groundwater (Order No. 2012-0010-DWQ or General Order). The General Order provides a consistent statewide regulatory framework for authorizing both pilot ASR testing and permanent ASR projects. It is important to note that under these current regulations, only potable water can be utilized for ASR. Oversight of these regulations is done through the RWQCBs.

The SWRCB Division of Drinking Water (DDW) regulates drinking water quality, use of recycled water, and may advise individual RWQCBs on discharge requirements. In addition, DDW also enforces the California Water Well Standards for municipal production wells, which provide specific requirements for well location (setbacks from sanitary hazards) and construction (adequate surface sanitary seal and well head protection). To date, DDW has approved ASR projects that utilize potable-quality water for injection. Operating projects in California have only chlorinated the recovered water prior to introduction into the distribution system. For permanent ASR wells, DDW requires submission of an amendment to the agency's Water Supply Permit.

CONCEPTUAL ASR PROJECT

Based on the results of this initial reconnaissance-level review of existing information relevant to a Santa Cruz ASR project, the necessary basic components for an ASR project appear to exist (or can be reasonably constructed) with recharge volumes ranging between approximately 145 mgy and 558 mgy. The initial findings related to basic components of an ASR project are summarized in **Table 11** below:

Table 11. Summary of Existing Information Related to Key ASR Components

ASR Component	Description	Excess Capacity Available for ASR		Source
		mgd	mgy	
San Lorenzo River Flows	Excess flows above SCWD demands and in-stream flow requirements	8	558	Fiske (2013)
Diversion	Tait Street (existing)	4	--	KJ (2013)
	Tait Street (expanded)	10	--	
Treatment	GHWTP (existing)	**2**	**145**	KJ (2013)
	GHWTP (expanded)	8	558	
Conveyance	SCWD Distribution System	Unknown		--
Aquifer Storage Space	Purisima Aquifer	3,290 mg		HMWRI (2012)
	Santa Margarita Groundwater Basin	2,355 mg		KJ (2013)/PWR (2015)
Per Well Injection Capacity (new ASR wells)	Purisima Aquifer	0.50	--	PWR (2015)
	Santa Margarita Groundwater Basin	0.50	--	PWR (2015)

As shown, the existing primary limiting constraint on ASR capacity is the GHWTP capacity to treat excess San Lorenzo River flows; however, improvements to both the Tait Street Diversion and GHWTP facilities appear to be technically feasible (KJ, 2013) that would allow for maximized use of the available excess San Lorenzo River flows. Preliminarily, these factors provide for a logically phased ASR project that begins with maximizing the existing diversion / treatment infrastructural capacity, with subsequent phase(s) increasing the diversion / treatment capacity and adding ASR wells as needed (perhaps incrementally).

Based on the above, a preliminary conceptual ASR project for Santa Cruz can be advanced, and is summarized in **Table 12** below:

Table 12. Summary of Conceptual ASR Project for Santa Cruz

Phase	General Description	Infrastructural Improvements			Storage Aquifer(s)	Service Areas	# of ASR Wells	Injection Capacity (mgd)	Average Annual Recharge (mgy)	Hydraulic Losses (10%) (mgy)	Average Annual Yield (mgy)
		Diversion	Treatment	Conveyance							
1	Maximize Existing Diversion / Treatment Facilities	None	Minimal	Undetermined (minimal anticipated)	Purisima	SCWD	4	2	145	15	130
2	Maximize Available San Lorenzo Excess Flows	+6 mgd	+6 mgd	Interties to SqCWD and/or SVWD (minimum)	Purisima and/or Lompico	SqCWD and/or SVWD	12	6	413	41	372
						Combined	16	8	558	56	502

As shown in **Table 12**, Phase 1 of the conceptual ASR project would essentially involve maximizing the existing diversion and treatment facilities capacity with the addition of 4 ASR wells within the SCWD service area (e.g., in the general vicinity of Beltz 12 and O'Neill Ranch wells). For conservative planning purposes at this stage, it is assumed that new dedicated ASR wells would be constructed, as opposed to retrofitting existing wells. This project would have an average annual yield of approximately 130 mg. Based on a projected worst-case drought year (1977) shortage of 650 mg, the Phase 1 project would require approximately 5 years (on average) to store/bank this volume.

If additional capacity is required, Phase 2 would involve expanding the existing diversion and treatment capacities to allow capture and treatment of remaining available excess San Lorenzo River flows. It is anticipated that this phase would require expanding the ASR well field into the SqCWD and/or SVWD service areas in order to accommodate up to an additional 12 ASR well sites. For planning purposes at this stage, it is assumed the additional ASR capacity would be equally split between SqCWD and SVWD service areas (i.e., 6 new 0.5 mgd ASR wells totaling 3 mgd of injection capacity in each service area) This project would also require distribution system interties to allow excess flows to be conveyed from SCWD to these areas. At build-out, the combined Phase 1 and Phase 2 project yield would be approximately 500 mgy. Based on a projected worst-case drought year (1977) shortage of 650 mg, the project would require approximately 1.3 years (on average) to store/bank the needed volume.

Recovery of 650 mg of banked ASR water within the projected 9-month (approximately 270 days) period of projected supply deficit would require approximately 2.5 mgd of recovery capacity (equivalent to approximately 1,700 gpm). ASR wells are typically designed with pumping capacities that are two times the injection capacity; therefore, for the Phase 1 project with 4 ASR wells having 2 mgd combined injection capacity would have a "built-in" recovery capacity of 4 mgd, which exceeds the required 2.5 mgd of recovery capacity (and does not include the existing Beltz well field pumping capacity).

Planning-Level Capital Cost Estimates

Preliminary planning-level capital costs have been estimated based on our experience with similar ASR projects, costs presented by KJ (2013) for Tait Diversion and GHWTP system improvements, and costs associated with the SCWD's most recent municipal well project (Beltz 12). The conceptual ASR project presented in **Table 12** above has been developed to a planning level, with conceptual design criteria, site locations and a basic understanding of project elements; therefore, the estimates presented should be considered accurate plus or minus 30 to 50 percent.

Injection Well Facility Costs. An itemized Opinion of Probable Costs spreadsheet for a typical project ASR well is included in **Appendix A**. As shown, we estimate total per-well construction costs should be on the order of approximately $1.2M (2015 dollars). Depending on market conditions at the time of bidding (e.g., the cost of stainless steel and demand for competent drillers), the actual bid costs could vary by as much as 25 percent from this estimate.

In addition to the ASR well itself, the following criteria were identified for ASR well site facilities:

- Potable water supply line capable of delivering 350 gpm to the well at a minimum pressure of 30 psi.
- Electrical utilities capable of serving 75 HP (nominal) for each well (for water recovery and well flushing at 700 gpm at ~300 ft TDH).
- Open backflush percolation pit, minimum 40,000 gallon size (approximately 60 minutes at 700 gpm).
- Adequate site area for construction and servicing of the well.
- Miscellaneous piping, valving and metering.
- Wellhead treatment system for iron and manganese removal of recovered water.

The estimate includes capital expenses for development of the well and well site improvements, including wells and well pumps, piping, electrical and instrumentation, and site work. Also included are costs (based on cost factor contingencies) for project design (10 percent), construction inspection/administration (10 percent), permitting (5 percent), and legal fees (5 percent). A 40 percent project contingency was added to the overall project totals. Details of these costs are provided in **Table 13** below:

Table 13. Estimated Capital Cost Details for Single ASR Well Site

Item	Cost
ASR Well (700 ft deep)	$ 1,160,000
Pump/Motor Assembly (75 HP)	$ 150,000
Electrical Service	$ 30,000
Instrumentation/SCADA	$ 50,000
Piping/Valving/Metering	$ 80,000
Backflush Pit	$ 50,000
Wellhead Treatment System	$ 2,500,000
Land Acquisition (1/4 acre minimum)	$ 1,000,000
Subtotal	$ 5,020,000
Design / Engineering (~10%)	$ 500,000
Construction Management (~10%)	$ 500,000
Permitting (~5%)	$ 250,000
Legal (~5%)	$ 250,000
Subtotal	$ 1,500,000
Project Contingency (~40%)	$ 2,610,000
Total	**$ 9,130,000**

As shown, per-well ASR facility costs are estimated at approximately $9.1M (2015 dollars), inclusive of a 40 percent contingency ($2.6M). The estimated costs for infrastructural improvements to the existing diversion and treatment facilities have been estimated by KJ (2013). The details of the KJ estimates will not be repeated here, but are summarized in **Table 14** below for the above-described conceptual ASR project:

Table 14. Estimated Capital Cost Details for Infrastructure Improvements

Item	Phase 1 (Existing Infrastructure)	Phase 2 (Expanded Infrastructure)
Tait Street Diversion Improvements		
Improvements to Existing 8 mgd System	$ 2,770,000	$ 3,840,000
Expansion to 14 mgd System	$ -	$ 5,950,000
GHWTP Improvements		
Pre-Treatment	$ -	$ 24,800,000
Oxidation and Disinfection	$ -	$ 20,240,000
Solids Handling	$ -	$ 12,670,000
Distribution System Improvements		
Intertie to SqCWD	$ -	$ 18,410,000
Intertie to SVWD	$ -	$ 5,770,000
Total	**$ 2,770,000**	**$ 91,680,000**

Based on the above, estimated capital costs for the conceptual ASR project are presented in **Table 15** below:

Table 15. Estimated Capital Costs for Conceptual ASR Project

Project Component	Phase 1	Phase 2	Phases 1 and 2
Tait Street Diversion Improvements			
Improvements to Existing 8 mgd System	$ 2,770,000	$ 3,840,000	$ 6,610,000
Expansion to 14 mgd System	$ -	$ 5,950,000	$ 5,950,000
GHWTP Improvements			
Pre-Treatment	$ -	$ 24,800,000	$ 24,800,000
Oxidation and Disinfection	$ -	$ 20,240,000	$ 20,240,000
Solids Handling	$ -	$ 12,670,000	$ 12,670,000
Distribution System Improvements			
Intertie to SqCWD	$ -	$ 18,410,000	$ 18,410,000
Intertie to SVWD	$ -	$ 5,770,000	$ 5,770,000
ASR Well Facilities			
4 ASR Wells in SCWD (2 mgd)	$ 36,520,000	$ -	$ 36,520,000
6 ASR Wells in SqCWD (3 mgd)	$ -	$ 54,780,000	$ 54,780,000
6 ASR Wells in SVWD (3 mgd)		$ 54,780,000	$ 54,780,000
Total	**$ 39,290,000**	**$ 201,240,000**	**$ 240,530,000**

As shown, estimated capital costs for Phase 1 are on the order of approximately $39.3M. Expansion to Phase 2 would require significant (about an order of magnitude) additional capital expenditures estimated at approximately $201M. These additional costs are associated with improving the existing diversion and treatment capacities, as well as the assumed need to construct interties with the SqCWD and/or SVWD service areas in order to access additional aquifer storage space, and additional ASR well sites to support the larger volumes associated with Phase 2.

Typical ASR Operations and Maintenance

In general, ASR operations involve several sequential steps or phases during a typical year, as outlined below:

<u>Wet Periods – Recharge Phase</u>

1. Diversion of available excess San Lorenzo flows at Tait Diversion Facility during winter/spring periods.
2. Treatment of the diverted flows to potable quality at GHWTP.
3. Conveyance of the treated flows through the existing (or expanded) potable distribution system(s) to ASR wells sites in Purisima Aquifer and/or Scotts Valley.
4. Injection of treated flows into the target aquifer(s) via dedicated new ASR wells.
   - Each ASR well injecting approximately 350 gpm (0.5 mgd)
   - Periodic (weekly) backflush pumping of the ASR wells during the injection season to minimize well plugging and maintain well injection capacities.

<u>Dry Periods - Recovery Phase</u>

1. Following a period of storage, recovery of water during dry periods when needed
   a. Utilizing the ASR wells and/or,
   b. Utilizing existing municipal production wells.

A more detailed discussion of each phase is presented below:

Diversion/Treatment/Conveyance. Injection operations would occur during periods of excess flow in the San Lorenzo, typically November through April, depending on hydrologic conditions. Excess flow would be diverted using the existing (or expanded) Tait Diversion Facility. The diverted flows would be treated to potable quality at the existing or improved Graham Hill Water Treatment Plant, and then conveyed through the distribution system (existing or improved) to ASR well sites in the Purisima Aquifer and/or Scotts Valley Subarea for injection.

Injection. Typical injection operations would consist of injection of the diverted and treated San Lorenzo water at each ASR site. There could be 4 to 19 individual ASR well sites, depending on size of project and where ASR wells are located. Wells would simultaneously inject at a rate of approximately 350 gpm each ([0.5 mgd] higher rates may be possible) while excess San Lorenzo water is available.

Backflushing. During the injection season, each of the ASR wells would need to be periodically backflushed (pumped). This is a routine maintenance measure that would be required whenever injection occurs. By pumping the well to waste at high rates (typically two times the injection rate), residual plugging materials are cleared from the well, thereby maintaining high well performance and produced water quality. Backflushing operations would generally consist of:

1. Temporary suspension of injection operations at one well (the other wells would continue to inject).
2. Backflush pumping and surging the well for a period of 15 to 60 minutes, until the well is flushed clear.
3. Resumption of injection operations.
4. Repeat the procedure for each well at the site.

It is anticipated that backflushing of each ASR well would be required at one- to two-week intervals, depending on the quality of the source water and plugging characteristics of individual wells. By individually backflushing one at a time, no significant interruptions in the overall ASR well array operations would occur.

Recovery. At the end of the injection season (i.e., when excess San Lorenzo flow is not available), the injected water would be stored temporarily until needed. The stored water would be recovered (pumped) from the aquifer utilizing the ASR wells and/or existing municipal wells in the target aquifer(s) to meet consumptive demands. Because each of the ASR wells would be equipped with pumps capable of producing 700 gpm (1 mgd) or more for backflushing purposes, the production capacity of the system would likely exceed demands by a factor of 2. The recovery wells could be alternated during the recovery season or between recovery seasons, depending on operational and economic factors.

By the end of the recovery period the water injected and stored during the previous injection season will have largely been extracted, thereby restoring the aquifer's available storage. Once San Lorenzo flows resume the following winter or wet period, the entire injection/storage/recovery cycle would begin again.

IMPLEMENTATION OF A PILOT ASR DEMONSTRATION TESTING PROGRAM

If the SCWD should choose to further evaluate the potential feasibility and benefits of ASR technology for enhancing its conjunctive use of its surface water and groundwater resources, a pilot ASR demonstration program would be the logical next step in the investigative process. In implementing such a program, specific areas of investigation would address the following:

- What is the actual sustainable injection rate before some head limitation is reached?

- What is the plugging rate and how often does the well need to be backflushed to maintain injection capacity.
- What is the potential for increased water levels due to injection to affect existing subsurface contamination plumes?
- Does the mixing of native groundwater and recharge water result in the formation of precipitate scales, gasses, or other compounds that would reduce aquifer permeability and potential injection capacities?
- Will the introduced recharge water leach heavy metals or other undesirable constituents from the aquifer minerals?
- What happens to DBP’s present in the recharge water during aquifer storage?
- What are the environmental benefits (or impacts) that result from ASR operations?
- Are there any DDW or consumer acceptance issues with the recovery and conveyance of stored water to the public?

Specific goals of an ASR demonstration test program would typically include the following:

- Determine hydraulic response of well and aquifers to ASR operations.
- Assess the occurrence and rate of well plugging from ASR operations.
- Determine optimum backflushing parameters to maintain well performance.
- Evaluate the influence, migration, and drift of injected water in the aquifer zone.
- Observe water quality stability and/or changes during aquifer storage.
- Establish design and operating parameters for an expanded and/or long-term ASR program.

Based on the result of this reconnaissance-level ASR feasibility study and our knowledge of the SCWD Beltz well field, we believe that Beltz 12 is a good candidate for pilot ASR testing, based on the following considerations:

- It is owned and operated by the SCWD. As such, should it desire to do so, the SCWD can proceed with ASR implementation at this well without negotiated agreements with the other two districts, which would likely be required in order to implement ASR testing at the other district’s wells.
- It has the highest screening-level estimated injection capacity of the existing SCWD wells.
- The well is relatively new (drilled in 2012) and is designed and constructed in a manner that is more ASR-compatible (e.g., constructed of entirely stainless steel, wire-wrapped screen, select gravel pack, etc.) than the other Beltz wells.
- The existing 35,000 gallon backwash tanks at the site could be utilized for backflushing the well.

- It is located at a more favorable inland location relative to the other SCWD Beltz wells (i.e., in an area that minimizes the potential for hydraulic losses to the ocean).
- It is completed in the Tu, AA and A aquifers, allowing recharge of all three principal aquifers in the western Purisima Aquifer.
- Based on downhole velocity surveys ("spinner surveys") performed during pumping tests following construction, approximately 60 percent of production from Beltz 12 derives from the Tu/Tsm. Assuming a similar relationship exists for injection (this is a reasonable, but not certain, assumption), injecting more water into the Tu/Tsm would also limit the potential for hydraulic losses to the ocean because the Tsm is buried below the Purisima Aquifer and no outcrops of the Tsm have been mapped offshore.
- PWR possess drill cuttings samples from the target aquifer zones that can be submitted to a specialty laboratory for mineralogy analysis, which is necessary for geochemical interaction modeling.

All of these factors suggest that Beltz 12 may be the most favorable candidate for a pilot injection testing program. Whether Beltz 12 is selected or not, the recommended steps in implementation of a pilot ASR demonstration program generally include the following:

1. Perform a site-specific theoretical injection capacity analysis that considers the following factors for the selected well:
    a. Well response to injection operations (both pressurized and non-pressurized injection)
    b. Backflushing capacity
    c. Downhole velocity constraints
    d. Hydrofracturing limits
    e. Offsite impacts limits
2. Perform 3-component geochemical modeling of various mixes of the injection source water and native groundwater in the presence of aquifer minerals
3. Based on the positive results of Steps 1 and 2 (no fatal flaws are identified), develop a pilot ASR demonstration test plan:
    a. Anticipated injection rates and durations
    b. Water-level and –quality monitoring programs
    c. Defined Injection / Storage / Recovery (ISR) cycles
4. Temporarily retrofit the well facility with a test pump, injection piping, metering, valving, etc.
5. Conduct initial well hydraulics, plugging rates, and sustainable injection rate testing (an approximate 2 to 4 week program).

6. Should Step 5 above be successful (no fatal flaws are identified), implement several Injection / Storage / Recovery (ISR) cycles of increasing volumes and durations to evaluate various water-quality related issues and long-term ASR operational parameters (an approximate 1 to 2 year program, depending on availability of recharge water during the testing period).

Based on the results of the pilot ASR demonstration testing, permanent ASR project planning, permitting and implementation can then be reliably advanced.

CONCLUSIONS

Based on the findings of this reconnaissance-level ASR feasibility study, it is our opinion that a seasonal storage project utilizing surface water transferred from the San Lorenzo River for storage in, and subsequent recovery from, the Purisima Aquifer and/or Scotts Valley Subarea appears technically feasible with no obvious fatal flaws. The main conclusions regarding what is known about a potential ASR project are summarized below:

Availability of Excess Water. Analysis of available excess San Lorenzo River flows, as constrained by existing water rights, in-stream flow requirements, and demands shows that approximately 558 mgy (or more) may be available. This number would need to be confirmed as described previously based on new modeling conditions.

Diversion / Treatment / Conveyance Capacities. The existing excess capacity of the Tait Street Diversion and GHWTP is limited to 2 mgd, which would be capable of diverting and treating approximately 145 mgy of the available excess flows, on average. With significant system modifications and upgrades to the existing Tait Street Diversion and GHWTP, available diversions up to 558 mgy could be achieved, on average. This number would need to be confirmed as described previously based on new modeling conditions.

Available Aquifer Storage Space. Based on existing estimates of historical groundwater storage depletion, approximately 3,290 mg of potentially available aquifer storage space may be available in the Purisima Aquifer and approximately 2,355 mg may be available in the Scotts Valley Subarea (approximately 5,645 mg combined).

Per Well Injection Capacities. Based on the results of a screening level analysis of the theoretical injection capacities of existing wells, a general per-well injection capacity of 350 gpm (0.5 mgd) for new ASR wells in both the Purisima Aquifer and Scotts Valley Subarea appear feasible.

Additional conclusions include:

- Retrofitting of all of SCWD existing extraction facilities in the Beltz well field would provide for approximately 820 gpm (1.2 mgd) of capacity; therefore, additional ASR well capacity may be required to maximize the use of existing San Lorenzo diversion and treatment capacities.

- Full utilization of available excess flows would require the development of injection facilities capable of injecting approximately 5,600 gpm (8 mgd). Retrofitting of all of SCWD, SqCWD and SVWD existing extraction facilities would provide for approximately 6,100 gpm (8.8 mgd) of capacity, which would be sufficient if fully implemented.

- While it is our preliminary opinion that use of existing wells for injection does not represent a significant risk to the wells' service lives or production capacities, we acknowledge that a prudent operation may not want to put these facilities at risk, regardless of how insignificant. As an alternative to retrofitting existing wells, SCWD should consider the construction of dedicated ASR facilities. The planning-level per-well injection capacity of new ASR wells is estimated at 350 gpm (0.5 mgd).

- ASR well sites located in the Purisima Aquifer should target the Tu/AA/A aquifer units. In order to limit the potential for hydraulic losses from the aquifer to the ocean via increased subsurface outflow, ASR wells located the general area of the Purisima Aquifer bounded on the south by Hwy 1 and on the north by the edge of the coastal terrace would be considered more favorable than locations closer to the coast.

- ASR well sites located in the Scotts Valley Subarea should primarily target the Lompico Sandstone and then the Butano Formation. Due to the lack of saturated aquifer thickness for backflushing, the Santa Margarita Sandstone is considered the least favorable aquifer for ASR in Scotts Valley; however, the Santa Margarita Sandstone may be a good candidate for managed aquifer recharge via surface spreading (e.g., in the Hanson Quarry).

- The findings regarding available aquifer storage space, target aquifers, and per-well injection capacities are applicable to IPR as well. The principal difference between ASR and IPR is that the source water for IPR is non-potable recycled wastewater. Under current regulations, the practical effect of this difference is that the same well cannot be utilized for both injection and recovery. Recovery wells (either existing or new wells) must be located at some distance from the point(s) of injection in order to provide prescribed amounts of aquifer residence time before recovery.

- Phase 1 of the conceptual ASR project (maximize existing diversion and treatment capacities) is estimated to have a project yield of approximately 130 mgy (assuming 10 percent hydraulic losses). Total Phase 1 project capital costs are estimated at approximately $40M.

- Phase 2 of the conceptual ASR project (maximize available excess San Lorenzo River flows) is estimated to have an incremental project yield of approximately 370 mgy (assuming 10 percent hydraulic losses). Total Phase 2 project capital costs are estimated at approximately $200M.

- If completely built-out, the combined Phase 1 and 2 project yield would be approximately 500 mgy (assuming 10 percent hydraulic losses) with a total estimated capital cost of approximately $240M.

- Based on this preliminary analysis and our knowledge of the SCWD Beltz wellfield, we believe Beltz 12 represents a good opportunity for pilot scale ASR demonstration testing.

The main conclusions regarding what is not known about a potential ASR project are summarized below:

- **Existing Conveyance System Capacity:** The hydraulic capacity of the existing distribution system(s) to convey 2 to 8 mgd of diverted San Lorenzo River flows from GHWTP to potential ASR wells sites in the various distribution systems under consideration is not known. Hydraulic modeling of the distribution system(s) may be required to establish current capacities and identify any hydraulic constraints.

Additional key unknowns include:

- The potential for adverse geochemical interactions between the source waters, native groundwater, and aquifer mineral matrices is not known; however, based on our experience with ASR in similar settings, we believe the potential for adverse geochemical reactions to present a fatal flaw to project implementation is low.

- The potential for, and quantification of, hydraulic losses to either the ocean or local creeks that would result from increased aquifer water levels / piezometric head that would limit overall project yields is not known. Numerical groundwater modeling of various ASR scenarios will likely be required to evaluate this issue further. Fortunately, a calibrated groundwater model of the Santa Margarita Groundwater Basin (including the Scotts Valley Subarea) already exists, and a calibrated groundwater model of the Soquel-Aptos Groundwater Basin is currently under development (scheduled for completion in 2016).

It is noted that the above unknowns are based on the currently available information; however, it is believed these unknowns can be reasonably addressed through additional investigations and are not likely to present fatal flaws, particularly for small-scale ASR (i.e., Phase 1 of the Conceptual ASR Project). There is greater potential for unacceptable hydraulic losses associated with larger scale ASR and/or IPR projects; however, this issue can be assessed and reasonably quantified through groundwater modeling.

RECOMMENDATIONS

Based on the findings and conclusions of this reconnaissance-level ASR feasibility study and our experience with similar ASR projects, we offer the following recommendations:

- If the assumed ASR program demand was larger than 558 mgy (i.e., the amount of excess San Lorenzo River flows estimated to be available based on the SVWD and SqCWD daily demands), we recommend that the SCWD undertake further analysis of the availability of excess San Lorenzo River flows independent of existing diversion, treatment, water rights and system demands limitations in order to establish the actual timing and total availability of excess water that may be available for an ASR project.

- Hydraulic modeling of the existing potable distribution system(s) should be performed to determine if there are any infrastructural constraints on the conveyance of a) potential ASR flows from GHWTP to potential ASR well sites when excess flows are available, and, b) the recovery of the stored water from the ASR well sites back into the distribution system for conveyance to customers when needed

- More focused site-specific analyses of ASR feasibility at the more favorable existing well locations should be performed. This should include identifying candidate well sites for ASR demonstration testing and evaluating each candidate well sites for whether the existing well, or a new well specifically designed for ASR, should be used for ASR demonstration testing.

- Water-quality samples from the GHWTP product water and candidate pilot demonstration wells (e.g., Beltz 12) should be collected and analyzed for the full suite of water-quality parameters. Samples of drill cuttings from the target aquifers should be analyzed for mineralogy identification. The recharge water-quality data should then be geochemically matched and modeled with the specific native groundwater and mineral conditions present at a given site to complete a 3-component geochemical interaction analysis.

- Potential ASR and/or IPR operational impacts for various project scenarios should be simulated with calibrated three-dimensional groundwater models of the target groundwater systems. This would be particularly important for evaluating large-scale ASR and/or IPR operations in the Purisima Aquifer in order to assess the potential for hydraulic losses to the ocean.

- Based on our current knowledge of the SCWD's Beltz Wells, we recommend that pilot scale ASR demonstration testing at Beltz 12 be pursued in order to advance the project and refine the per-well injection capacity estimates. Such testing will provide for confirming injection capacities, evaluating well plugging rates and backflushing requirements, and evaluating geochemical interactions.

CLOSURE

This memorandum has been prepared exclusively for Stratus Consulting, Inc. for the specific application to the City of Santa Cruz Reconnaissance-Level ASR Feasibility Evaluation. The findings and conclusions presented herein were prepared in accordance with generally accepted hydrogeologic practices. No other warranty, express or implied, is made.

REFERENCES

American Society of Civil Engineers (2001), *Standard Guidelines for Artificial Recharge of Ground Water*.

Brabb, E.E. (1997), *Geologic Map of Santa Cruz County, California: A digital database*, USGS Open-File Report 97-489.

California Department of Water Resources (2003), *Bulletin 118: California's Groundwater.*

Driscoll, F.G. (1986), *Groundwater and Wells, Second Edition*, published by Johnson Screens.

Eittreim, S.I. et al. (2000), *Seafloor Rocks and Sediments of the Continental Shelf from Monterey Bay to Point Sur, California*, USGS Miscellaneous Field Studies MF-2345.

Essaid, H.I. (1992), *Simulation of Freshwater and Saltwater Flow in the Coastal Aquifer System of the Purisima Formation in the Soquel-Aptos Basin, Santa Cruz County, California,* USGS Water-Resources Investigations Report 91-4148.

ETIC Engineering, Inc. (2007), *Scotts Valley Water Management District Groundwater Management Program, Annual Report 2006 Water Year,* prepared for Scotts Valley Water District.

- (2006), *Groundwater Modeling Study of the Santa Margarita Groundwater Basin,* prepared for Scotts Valley Water District.

Feeney, M.B. (2007), *Summary of Operations – SVWD Well No. 10A*, letter-report prepared for Scotts Valley Water District.

Fugro West, Inc. (1997), *Reconnaissance-Level Feasibility Study for Seaside Basin Injection/Recovery Project,* prepared for Monterey Peninsula Water Management District.

– (1998), *Summary of Operations Report, Beltz Wells A and B Construction Project, Santa Cruz County*, California, prepared for City of Santa Cruz Water Department.

Gary Fiske and Associates, Inc. (2013), *Phase 2 Water Transfer Project Draft Task 3 Technical Memorandum: Potential Transfers with Unlimited Tait Street Capacity*, prepared for Linette Almond and John Ricker.

– (2013), *Supplemental Analysis of Water Transfer Volumes*, memorandum prepared for Kevin Crossly and Todd Reynolds.

Hopkins Groundwater Consultants, Inc. (2010), *Supplemental Hydrogeological Study, Purisima Aquifer Delineation Live Oak – Capitola Area of Soquel-Aptos Groundwater Basin, Santa Cruz, California,* prepared for City of Santa Cruz.

– (2004), *Summary of Operations Report, City of Santa Cruz Live Oak Monitoring Well and Test Well Project, Live Oak, California*, prepared for Carollo Engineers.

Huisman, L., and Olsthoorn, T.N. (1983), *Artificial Groundwater Recharge*, Delft University of Technology, Pitman Advanced Publishing Program.

HydroMetrics WRI (2011), *Soquel-Aptos Area Groundwater Management Annual Review and Report, Water Year 2010,* prepared for Soquel Creek Water District.

- (2012), *Soquel-Aptos Area Groundwater Management Annual Review and Report, Water Year 2011,* prepared for Soquel Creek Water District.

- (2013), *Soquel-Aptos Area Groundwater Management Annual Review and Report, Water Year 2012,* prepared for Soquel Creek Water District.

- (2013), *O'Neil Ranch Well Construction, Development and Testing Report,* prepared for Soquel Creek Water District.

- (2014), *Soquel-Aptos Area Groundwater Management Annual Review and Report, Water Year 2013,* prepared for Soquel Creek Water District.

- (2012), *Revised Protective Groundwater Elevations and Outflows for the Aromas Area and Updated Water Balance for Soquel-Aptos Groundwater Basin*, prepared for Soquel Creek Water District.

Johnson, N.M., et al. (2004), *Groundwater Assessment of Alternative Conjunctive Use Scenarios, Technical Memorandum 2: Hydrogeologic Conceptual Model*, prepared for Soquel Creek Water District.

Kennedy/Jenks Consultants (2013), *Water Transfer Infrastructure Summary Report*, prepared for Santa Cruz Water Department and County of Santa Cruz Environmental Health Services and Regional Water Management Foundation.

- (2011), *Annual Report 2010 Water Year, Scotts Valley Water District Groundwater Management Program*, prepared for Scotts Valley Water District.

- (2012), *Annual Report 2011 Water Year, Scotts Valley Water District Groundwater Management Program*, prepared for Scotts Valley Water District.

- (2013), *Annual Report 2012 Water Year, Scotts Valley Water District Groundwater Management Program*, prepared for Scotts Valley Water District.

- (2014), *Draft Technical Memorandum No. 2, Groundwater Replenishment with Recycled Water Alternatives*, prepared for Soquel Creek Water District.

Luhdorff and Scalmanini Consulting Engineers (1999), *Feasibility of Injection into the Purisima Formation, Soquel-Aptos Area*, report prepared for Soquel Creek Water District.

- (2001), *Pilot Injection Testing Summary Report*, letter-report prepared for Soquel Creek Water District.

Meinzer, O.E., Editor (1942), *Hydrology*, McGraw Hill Book Company, New York, NY.

Pueblo Water Resources, Inc. (2013), *Summary of Operations, Well Construction and Testing, City of Santa Cruz Beltz Well No. 12*, prepared for City of Santa Cruz Water Department.

Pyne, R.D. (1994), *Ground Water Recharge and Wells*, Boca Raton, Florida, CRC Press.

State Water Resources Control Board, Division of Drinking Water (2014), *Groundwater Replenishment Using Recycled Water*, DPH-14-003E.

State Water Resources Control Board (1968), *Statement of Policy with Respect to Maintaining High Quality of Waters in California*, Resolution No. 68-16.

- (2012), *General Waste Discharge Requirements for Aquifer Storage and Recovery Projects that Inject Drinking Water into Groundwater,* Water-Quality Order 2012-0010.

Theis, C.V. (1935), *Relationship Between Lowering of Piezometer Surface on the Fate and Duration of Discharge of a Well Using Ground Water Storage*, Transactions of the Geophysical Union, vol. 16, pp. 519-524.

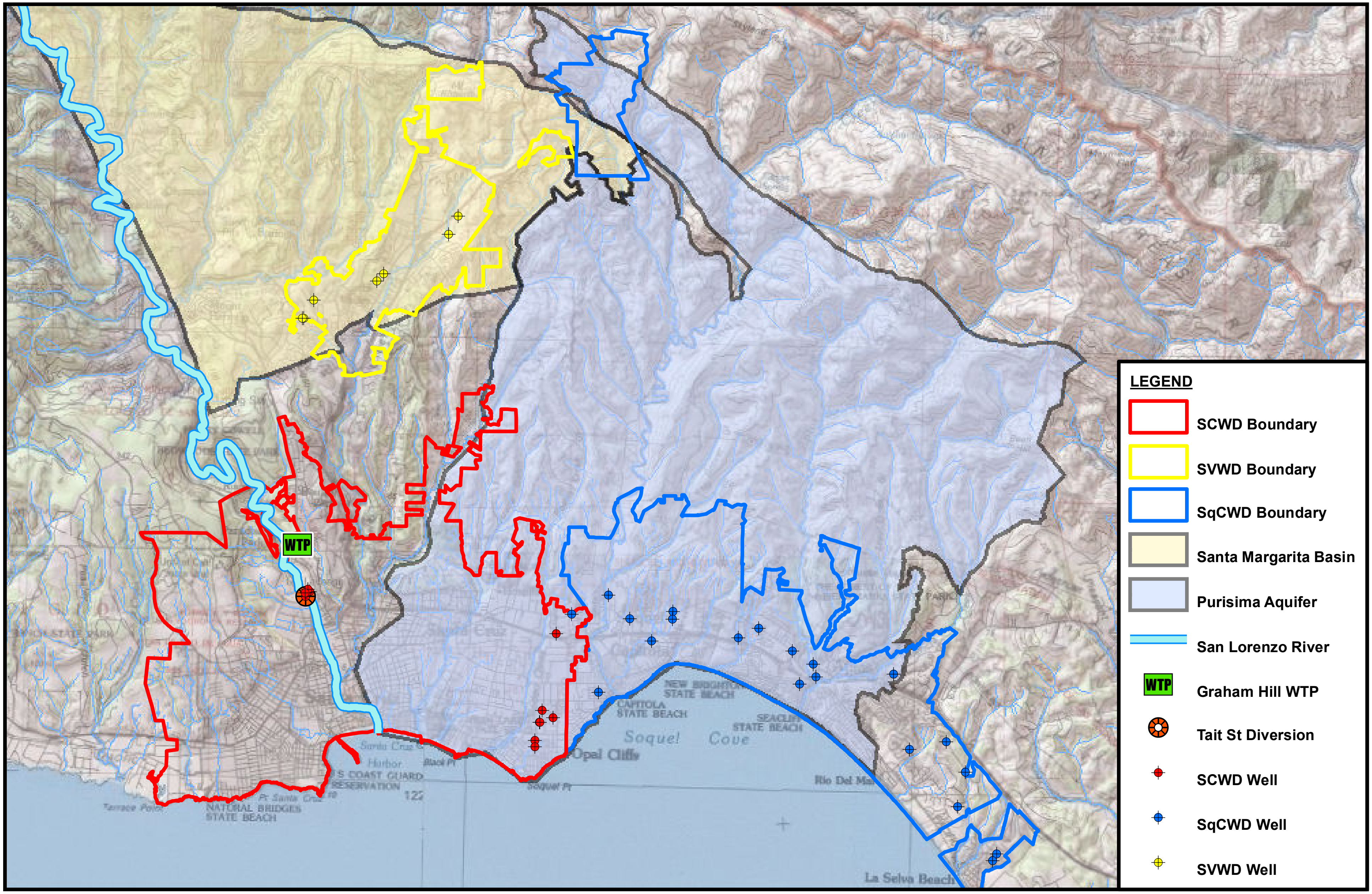
Todd Groundwater (2014), *Peer Review of Technical Water Resources Studies Prepared for Soquel Creek Water District - Final*, Memorandum prepared for Soquel Creek Water District

Walton, W.C. (1991), *Principles of Groundwater Engineering*, Lewis Publishers.

Williams, Derrik (2003), *Initial Analysis: Injection of Stream Diversion*, memorandum prepared for Nick Johnson.

FIGURES

May 2015
Project No. 14-0101



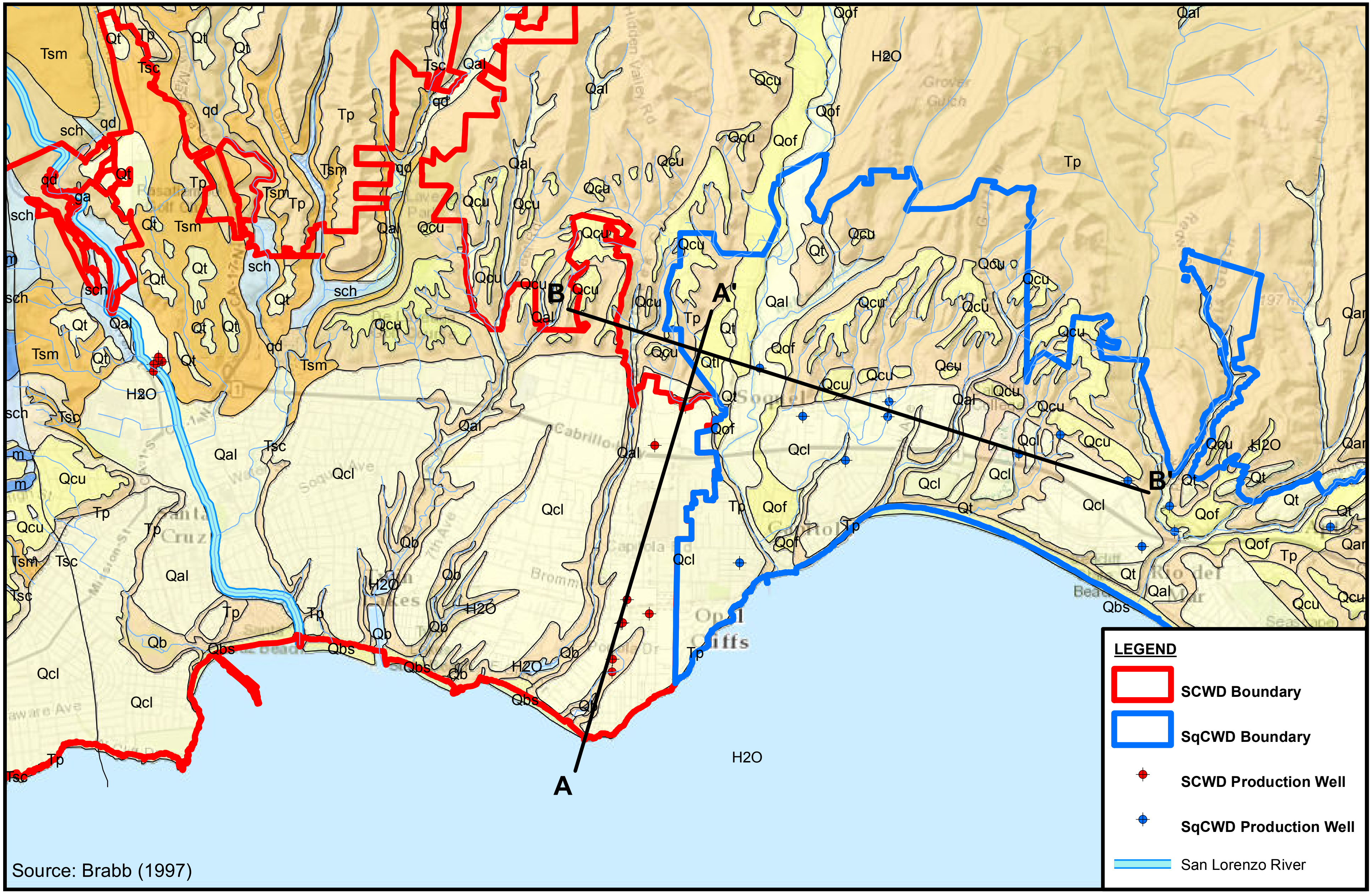
PUEBLO water resources

N
W E
S

1 inch = 10,000 feet

0 5,000 10,000 20,000 Feet

FIGURE 1. STUDY AREA LOCATION MAP
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz WSAC



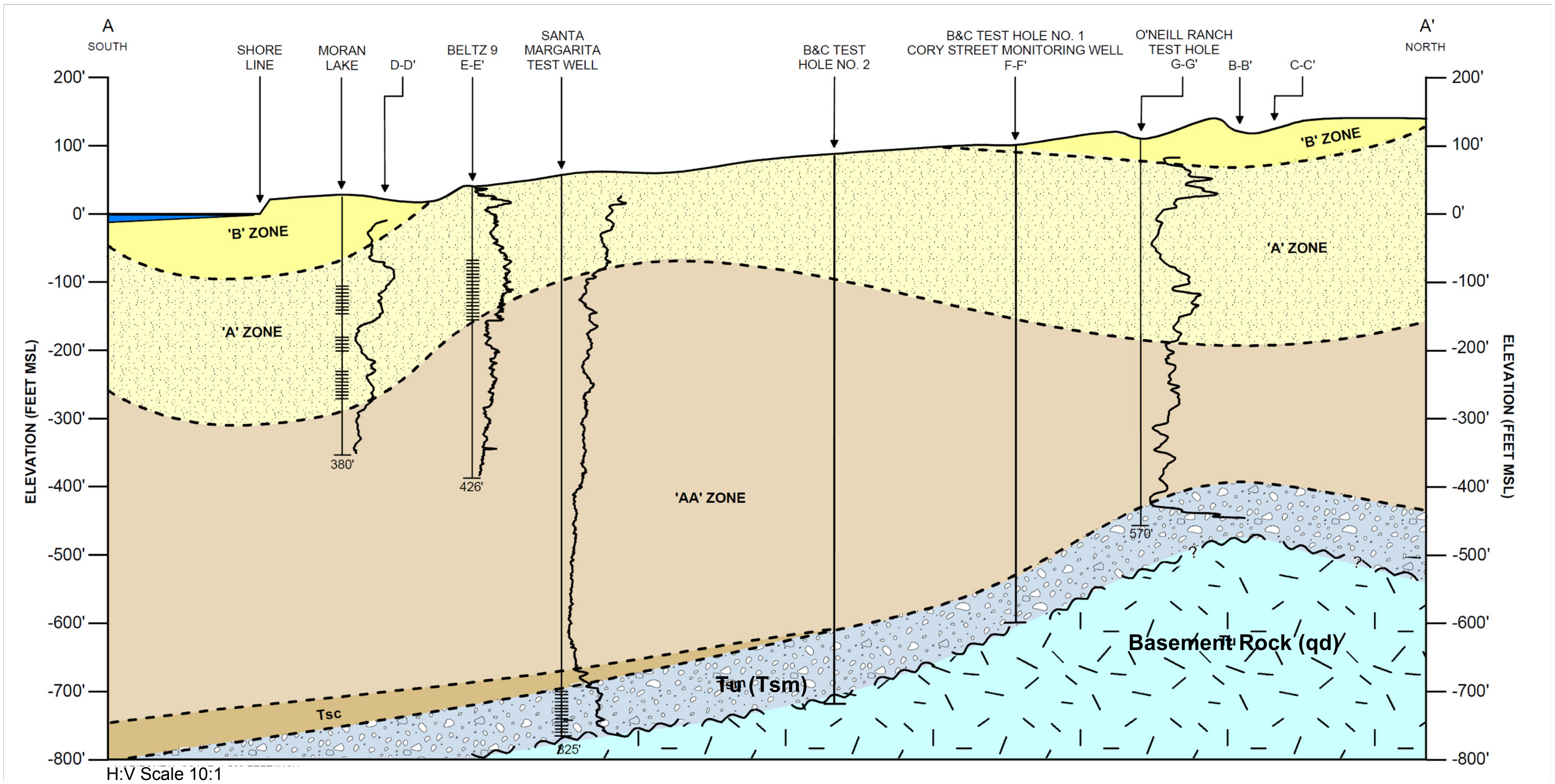
PUEBLO water resources

N
W E
S

1 inch = 5,000 feet

0 2,500 5,000 10,000 Feet

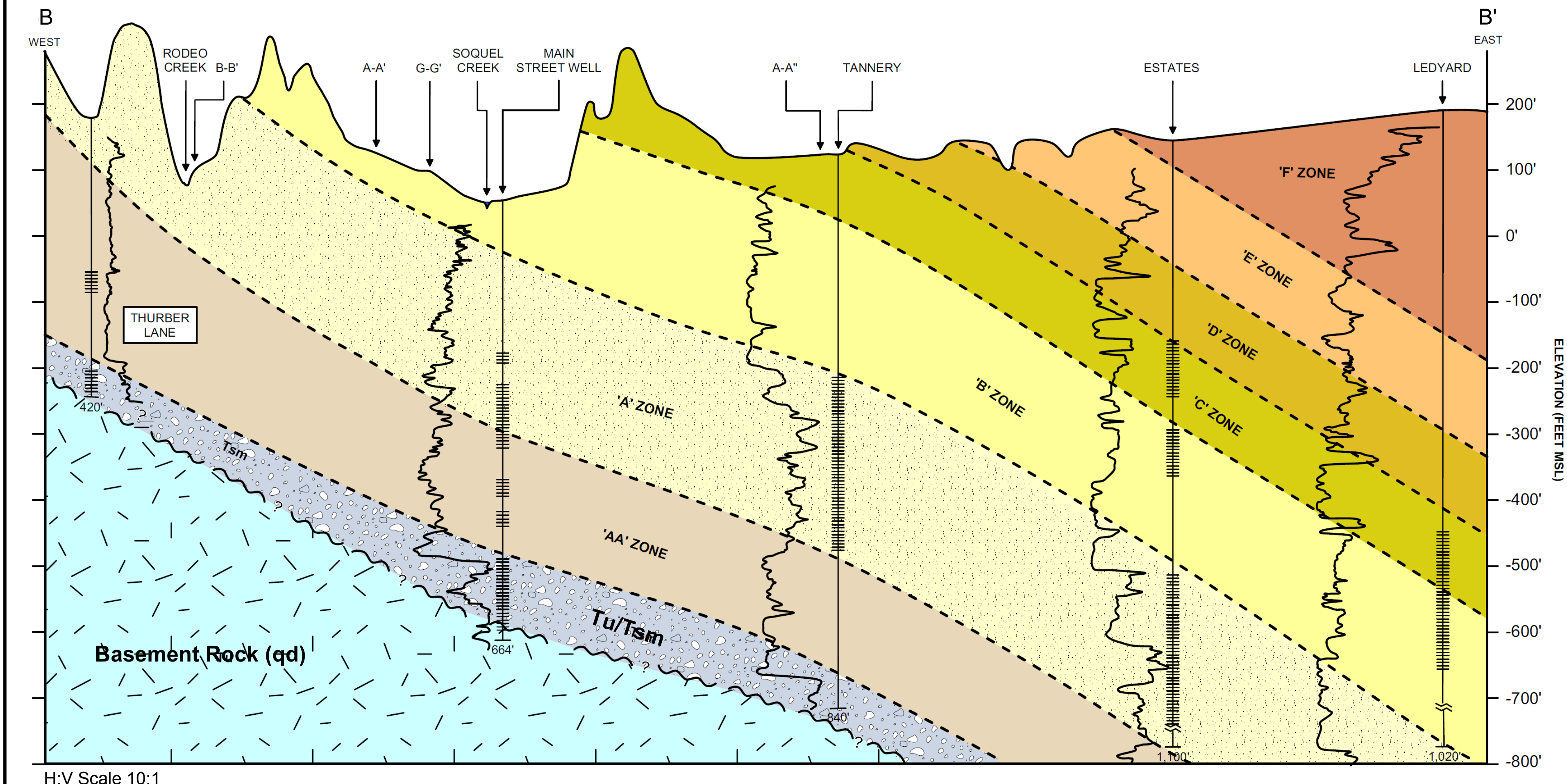
FIGURE 2. GEOLOGIC MAP - WESTERN PURISIMA AREA
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz WSAC



Source: Hopkins (2010), modified by PWR

FIGURE 3. CROSS-SECTION A - A'
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz

May 2015
Project No. 14-0101

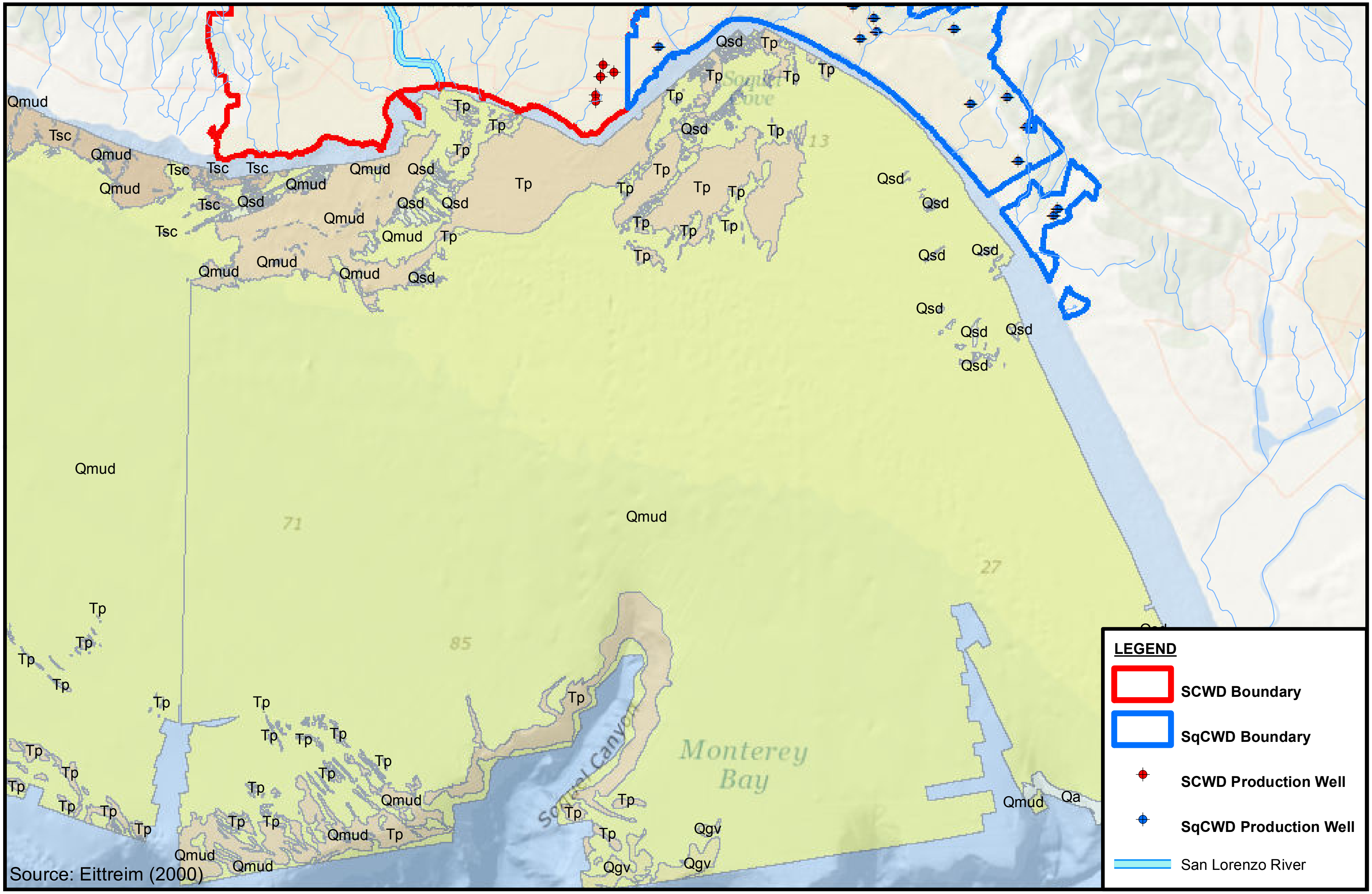


Source: Hopkins (2010), modified by PWR

PUEBLO water resources

FIGURE 4. CROSS-SECTION B - B'
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz

May 2015
Project No. 14-0101



PUEBLO water resources

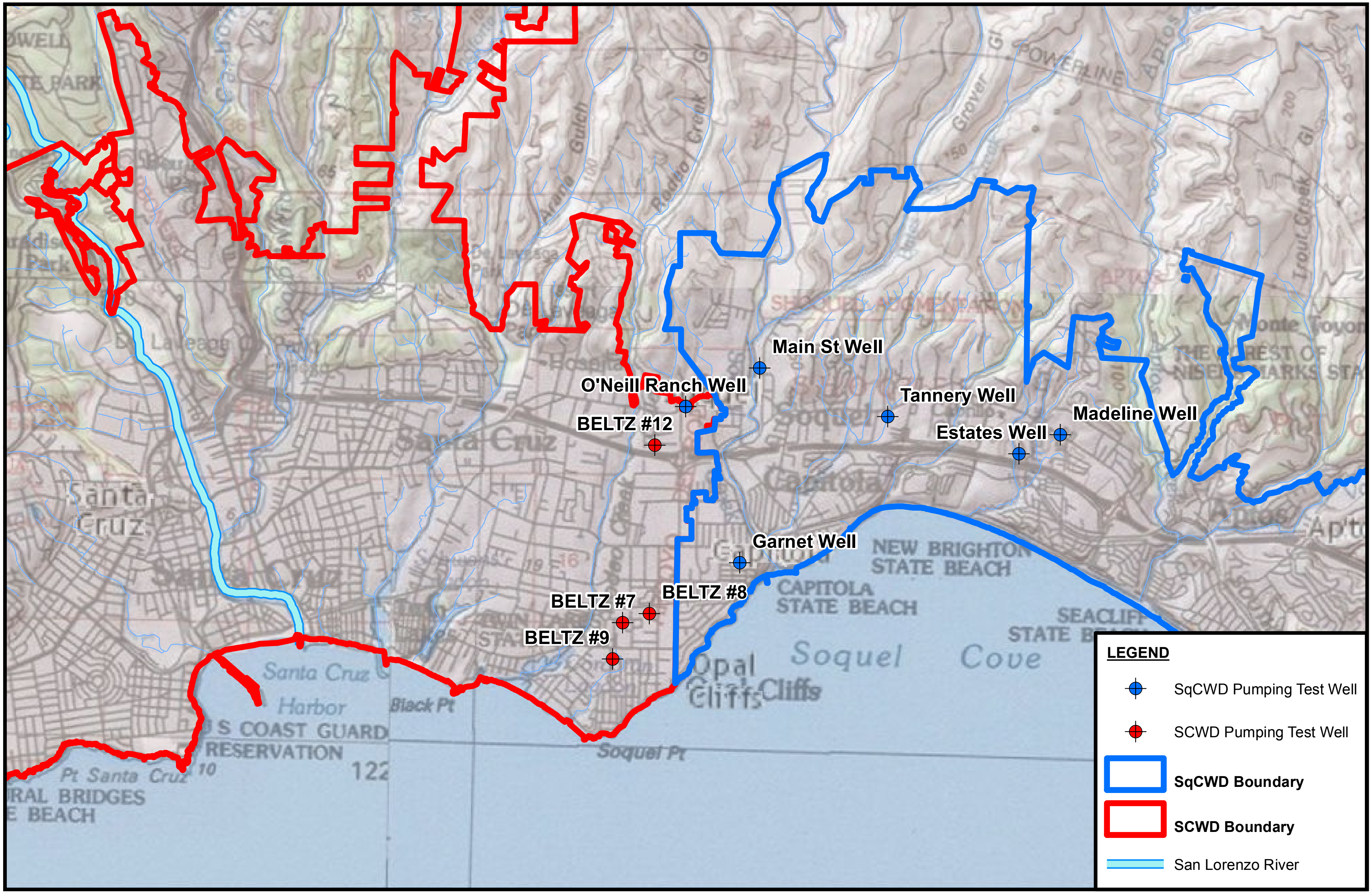
N W E S

1 inch = 10,000 feet

0 5,000 10,000 20,000 Feet

FIGURE 5. OFFSHORE GEOLOGIC MAP - WESTERN PURISIMA AREA
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz WSAC

May 2015
Project No. 14-0101

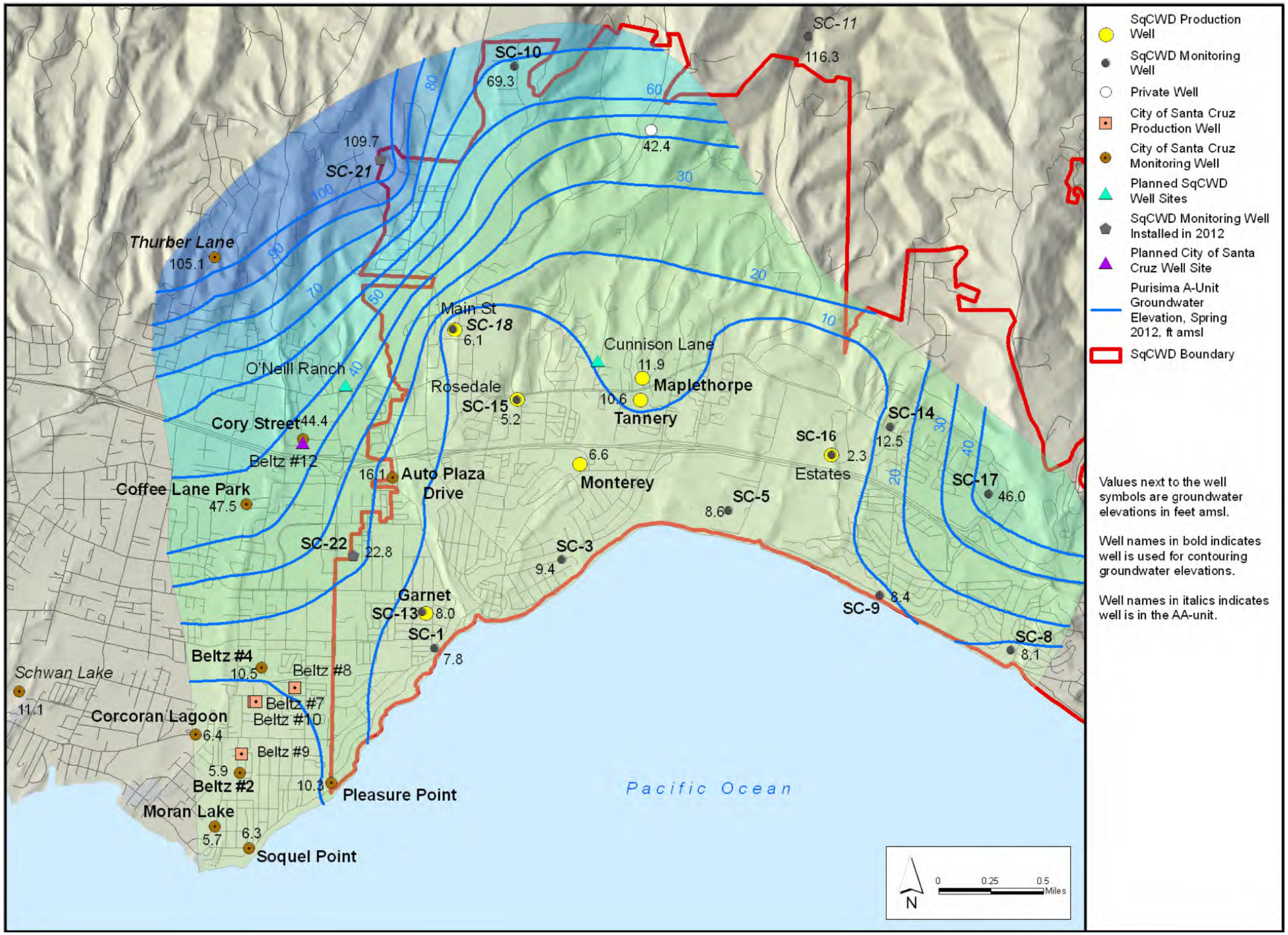


PUEBLO water resources

N
W E
S

1 inch = 5,000 feet
0 2,500 5,000 10,000 Feet

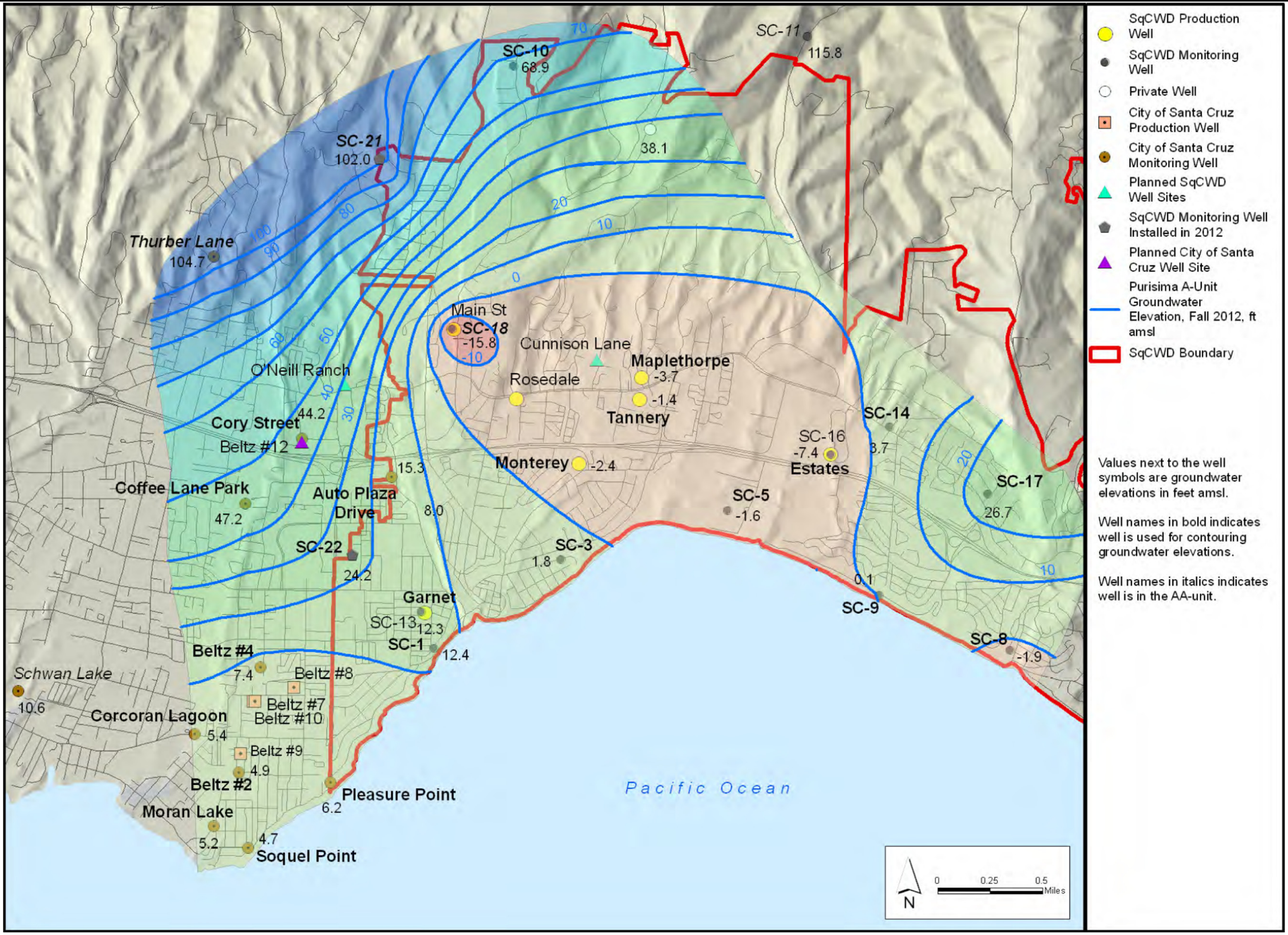
FIGURE 6. WELL LOCATION MAP - WESTERN PURISIMA AREA
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz WSAC



Source: HMWRI (2013)

PUEBLO water resources

FIGURE 7. PURISIMA A-UNIT GROUNDWATER ELEVATION CONTOURS - SPRING 2012
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz

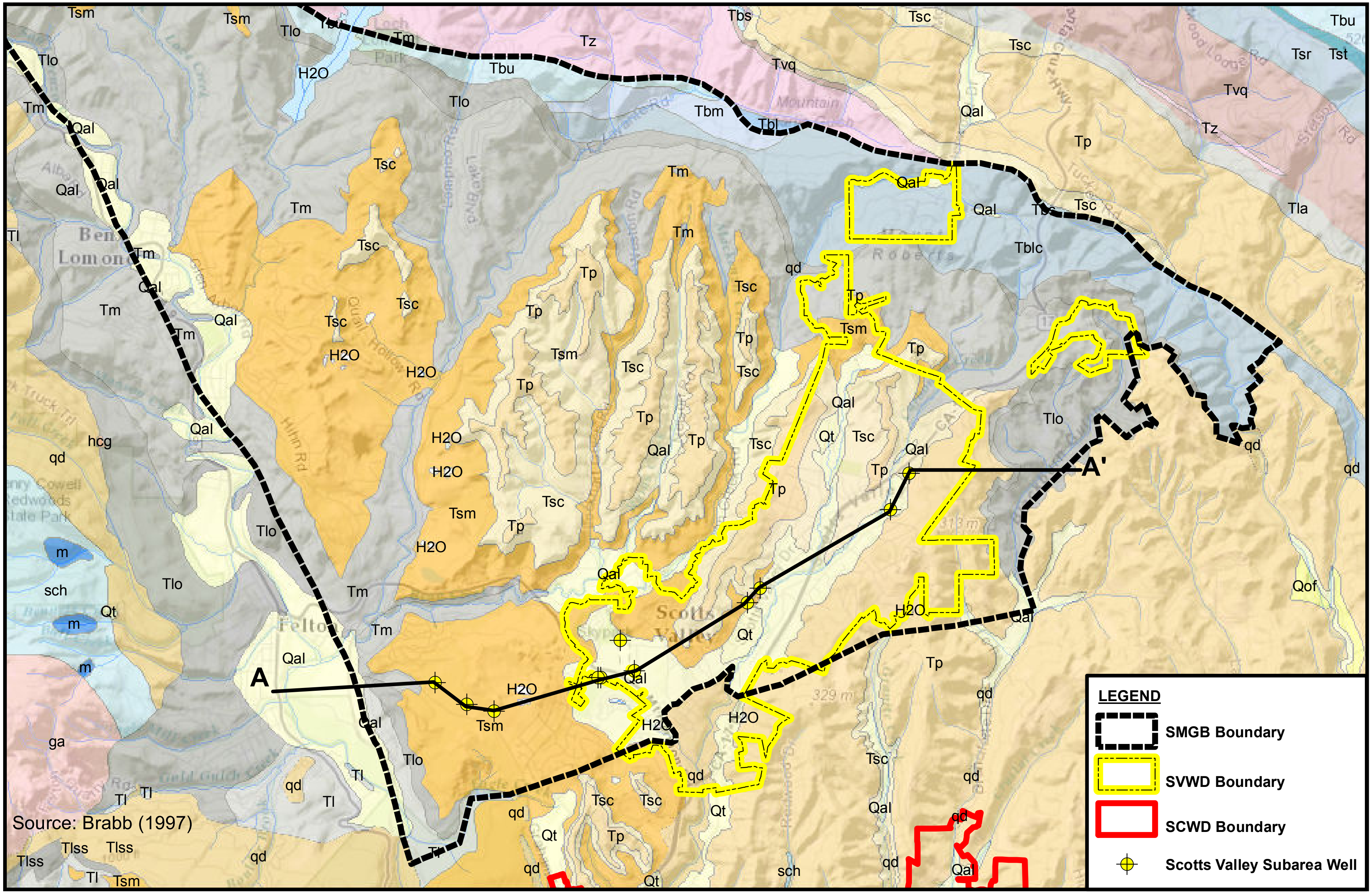


Source: HMWRI (2013)

PUEBLO water resources

FIGURE 8. PURISIMA A-UNIT GROUNDWATER ELEVATION CONTOURS - FALL 2012
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz

May 2015
Project No. 14-0101

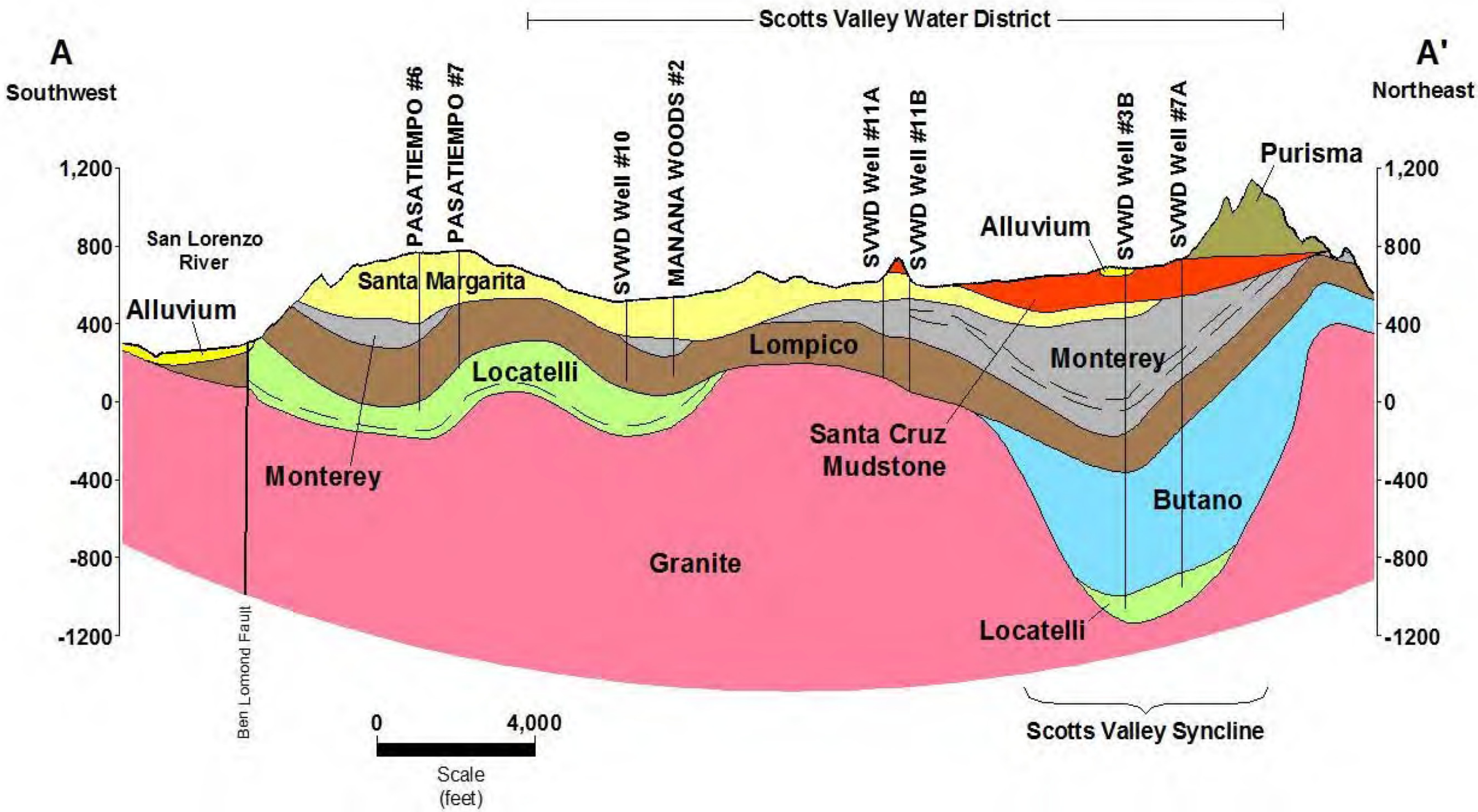


PUEBLO water resources

1 inch = 5,000 feet

0 2,500 5,000 10,000 Feet

FIGURE 9. GEOLOGIC MAP - SANTA MARGARITA GROUNDWATER BASIN
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz WSAC

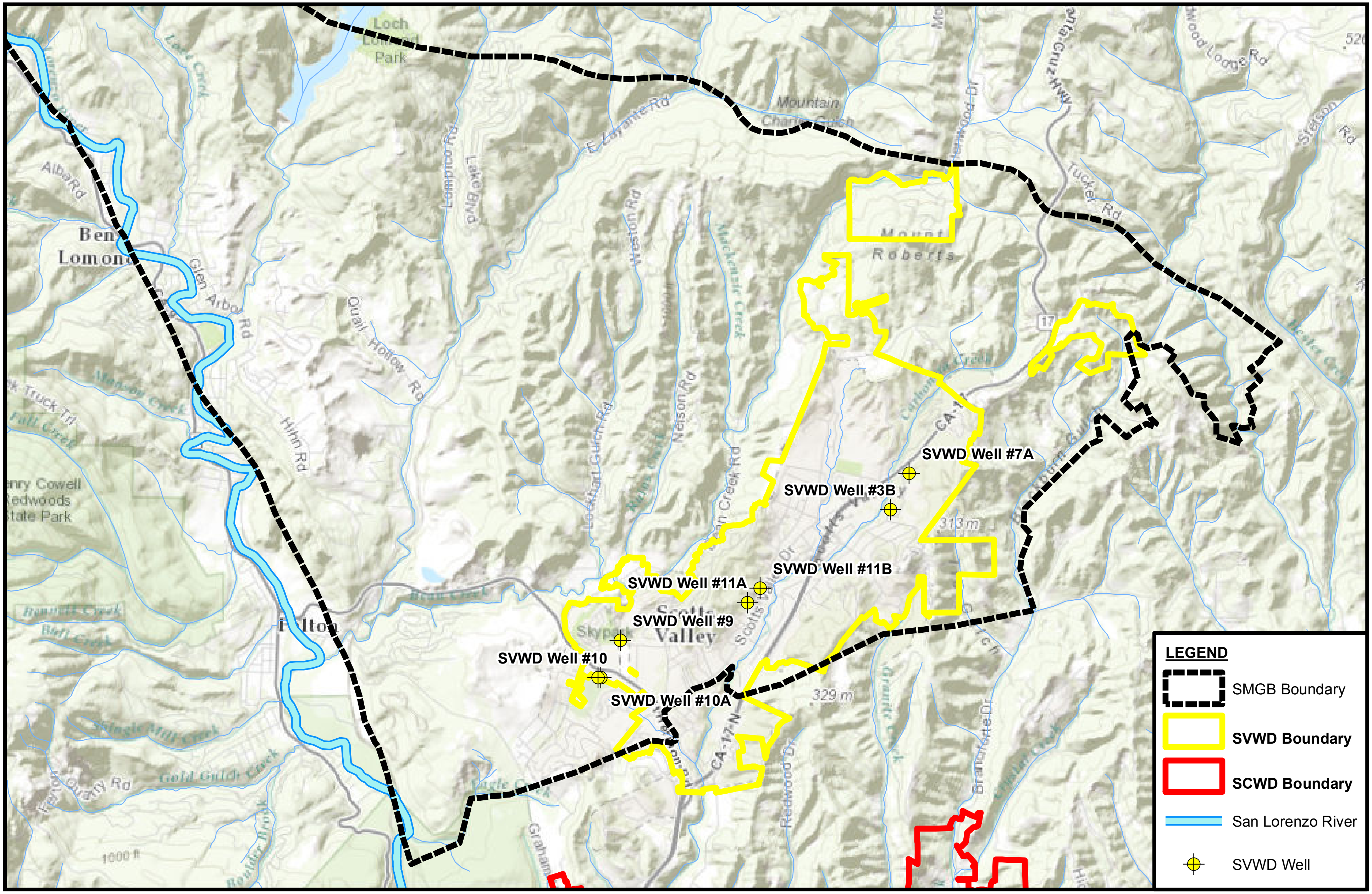


Source: Kennedy/Jenks Consultants (2011)

PUEBLO water resources

FIGURE 10. SANTA MARGARITA GROUNDWATER BASIN CROSS-SECTION A - A'
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz

May 2015
Project No. 14-0101

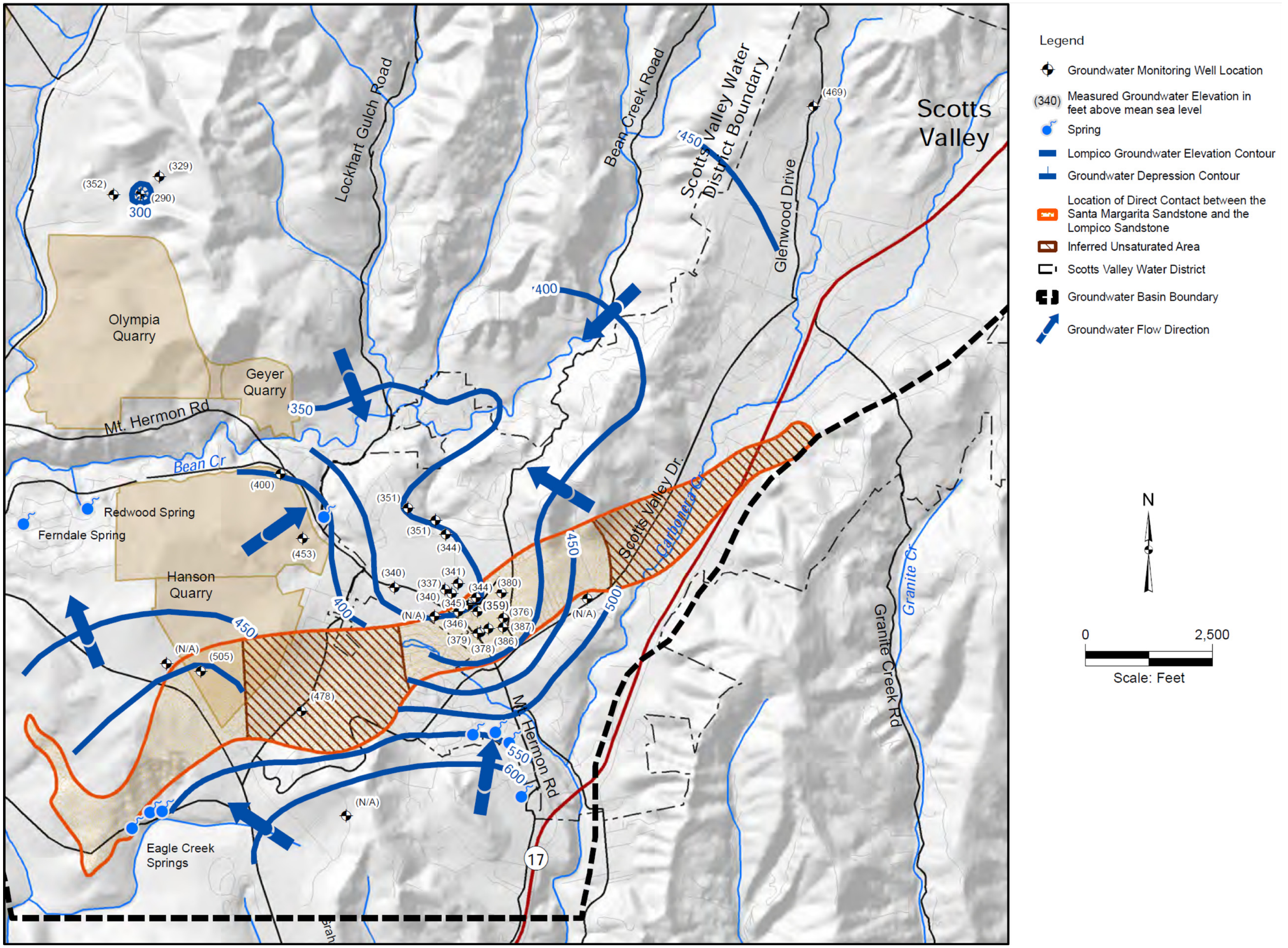


PUEBLO water resources

1 inch = 5,000 feet

0 2,500 5,000 10,000 Feet

FIGURE 11. WELL LOCATION MAP - SCOTTS VALLEY SUBAREA
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz WSAC

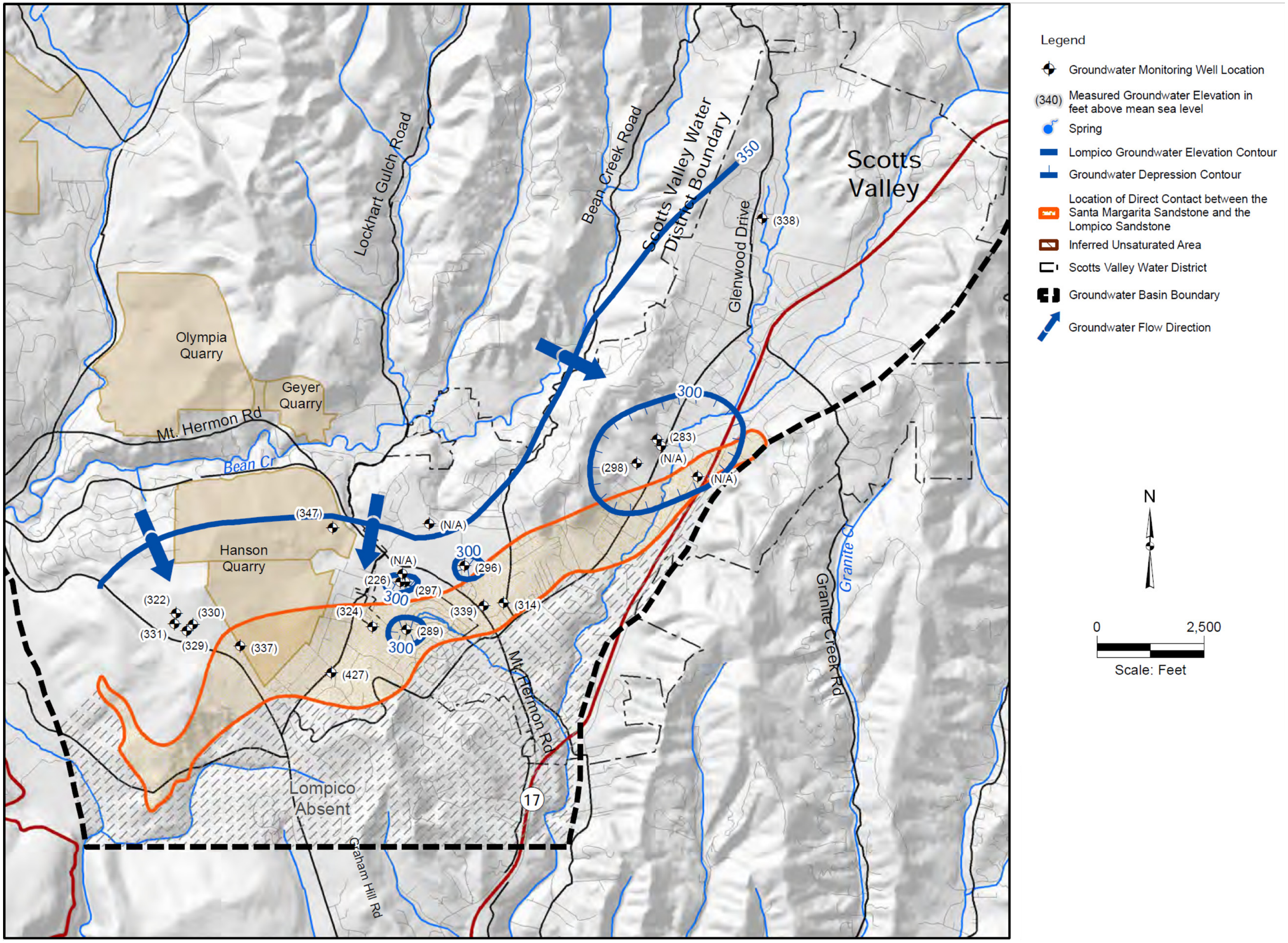


Source: Kennedy/Jenks Consultants (2013)

PUEBLO water resources

FIGURE 12. SANTA MARGARITA AQUIFER GROUNDWATER ELEVATION CONTOURS - FALL 2012
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz WSAC

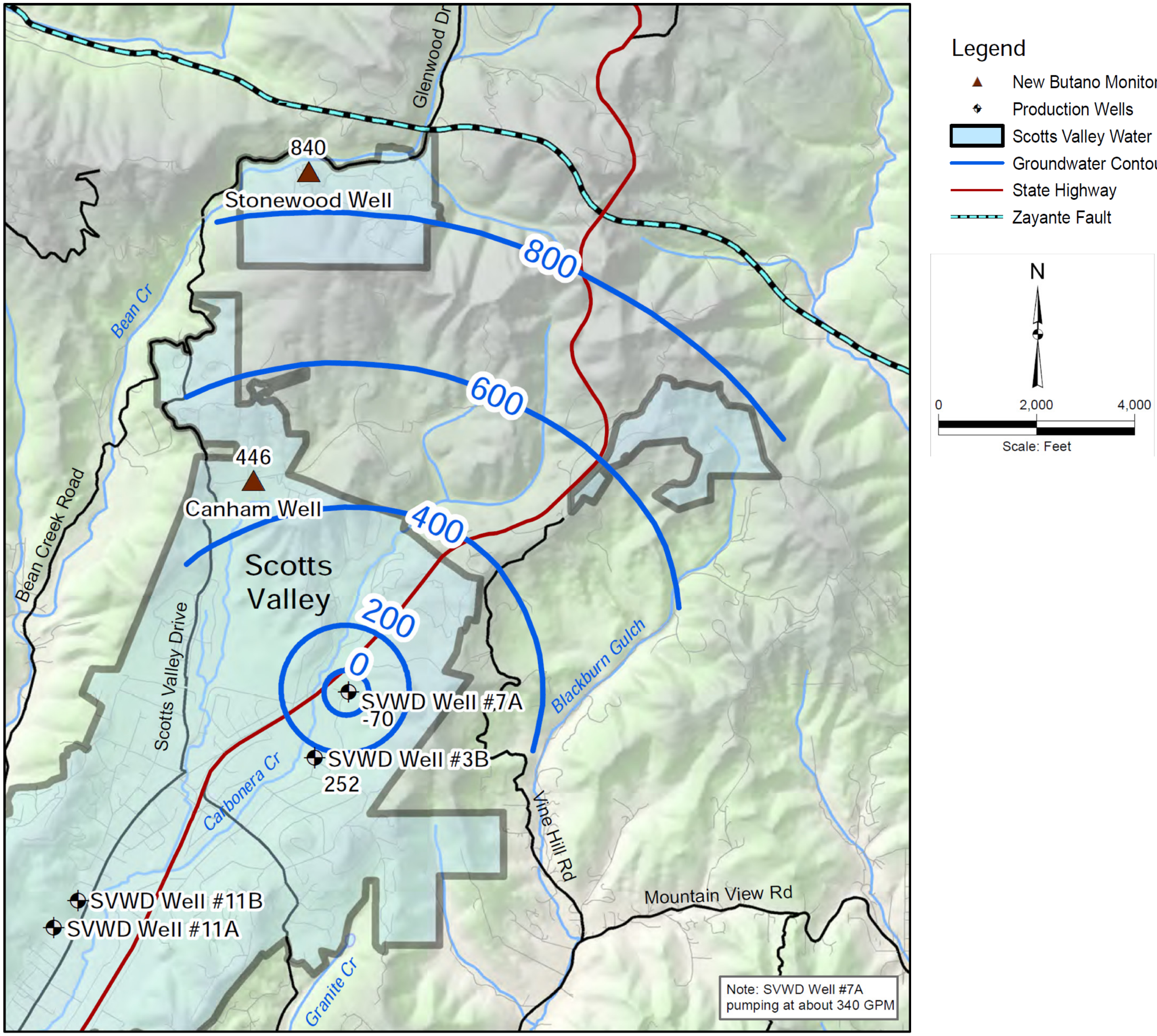
May 2015
Project No. 14-0101



Source: Kennedy/Jenks Consultants (2013)

PUEBLO water resources

FIGURE 13. LOMPICO AQUIFER GROUNDWATER ELEVATION CONTOURS - FALL 2012
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz WSAC



Source: Kennedy/Jenks Consultants (2013)

PUEBLO water resources

FIGURE 14. BUTANO AQUIFER GROUNDWATER ELEVATION CONTOURS - JANUARY 2013
Reconaissance-Level ASR Study
Stratus Consulting / City of Santa Cruz WSAC

APPENDIX A
OPINION OF PROBABLE COST - TYPICAL ASR WELL

OPINION OF PROBABLE COST
CLIENT: City of Santa Cruz Water Department
PROJECT NAME: Reconaissance-Level ASR Feasibility Study

BID ITEM NO.	ITEM DESCRIPTION	UNITS	QUANTITY	OPINION OF PROBABLE COST	
				UNIT COST	ITEM COST
1	MOBILIZATION AND DEMOBLIZATION (~10% OF TOTAL)	LS	1	$100,000	$100,000
2	SOUND BARRIER	LF	500	$200	$100,000
3	26" O.D. CONDUCTOR CASING	LF	55	$1,000	$55,000
4	PILOT BORE DRILLING	LF	645	$250	$161,250
5	GEOPHYSICAL LOGGING	LS	1	$5,000	$5,000
6	REAMING PILOT HOLE (24" DIA.)	LF	645	$250	$161,250
7	CALIPER SURVEY	LS	1	$4,000	$4,000
8.1	14" 1/4 STAINLESS STEEL BLANK CASING	LF	380	$300	$114,000
8.2	14" NOMINAL STAINLESS STEEL WIRE-WRAPPED SCREEN	LF	300	$250	$75,000
8.3	14" STAINLESS STEEL CELLAR CASING AND END CAP	LF	20	$300	$6,000
8.4	3" STAINLESS STEEL GRAVEL FEED LINE	LF	250	$75	$18,750
8.5	3" STAINLESS STEEL SOUNDING PIPE	LF	250	$75	$18,750
8.6	3" STAINLESS STEEL CASING VENT PIPE	LS	1	$500	$500
9	GRAVEL PACK 8 x 16	LF	450	$125	$56,250
10	CEMENT GROUT SEAL	LF	250	$125	$31,250
11.1	MECHANICAL WELL DEVELOPMENT	HR	50	$500	$25,000
11.2	PUMPING WELL DEVELOPMENT	HR	50	$500	$25,000
12	PRODUCTION TESTING	HR	36	$500	$18,000
13	DOWNHOLE VELOCITY SURVEY	LS	1	$7,500	$7,500
14	PLUMBNESS AND ALIGNMENT SURVEYS	LS	1	$5,000	$5,000
15	ACCEPTANCE VIDEO SURVEY	LS	1	$2,500	$2,500
16	DISINFECTION	LS	1	$5,000	$5,000
17	WELLHEAD AND PUMP FOUNDATION	LS	1	$10,000	$10,000
18	SITE CLEAN-UP	LS	1	$50,000	$50,000
19	FLUIDS AND CUTTINGS CONTAINMENT / DISPOSAL	LS	1	$100,000	$100,000
				TOTAL	**$1,155,000**