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Technical Memorandum 1B- Evaluation of Recharge Potential for Phase 1 Conjunctive Use and Enhanced Aquifer Recharge Project:

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Technical Memorandum 1B

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From: Michael Maley and Matt Baillie, Kennedy/Jenks Consultants

Subject: **Evaluation of Recharge Potential**
Santa Cruz County Conjunctive Water Use and Enhanced Aquifer Recharge Study
K/J 0864005

1. Introduction

Kennedy/Jenks Consultants (Kennedy/Jenks) is pleased to provide the Santa Cruz County Health Services Agency (County) with Technical Memorandum 1B (TM1B) in support of the Conjunctive Use and Enhanced Aquifer Recharge Project (Conjunctive Use Project). The Conjunctive Use Project is one of fifteen projects funded by a Proposition 50 Water Bond grant from the California State Water Resources Control Board to the Community Foundation of Santa Cruz County. The Conjunctive Use Project is Project #3 of the grant and is being administered by the County.

1.1. Conjunctive Use Project Overview

The objective of the Conjunctive Use Project is to assess the most appropriate approaches for coordinating water projects and increasing groundwater storage to improve the reliability of drinking water supplies primarily for the Scotts Valley Water District (SVWD) and San Lorenzo Valley Water District (SLVWD), mitigating declines in groundwater levels in the Santa Margarita Groundwater Basin (SMGB), and increasing stream baseflow in the lower San Lorenzo River Watershed. The Conjunctive Use Project evaluates the opportunities to use water exchanges, winter streamflow diversion, enhanced stormwater capture and recharge, and/or reclaimed wastewater to replenish groundwater storage.

The two goals of the Conjunctive Use Project are to increase the volume of groundwater in aquifer storage, and to increase summertime baseflow in streams by increasing groundwater levels. An understanding of the factors controlling the ability to recharge water to the aquifer in the Scotts Valley area is important for the Conjunctive Use Project. This TM provides an evaluation of the recharge potential in the study area and provides an initial screening-level analysis appropriate for evaluating potential alternatives.

The study area is focused on the Scotts Valley area (Figure 1B-1). For the Conjunctive Use Project, the study area covers the portion of the Santa Margarita Groundwater Basin (SMGB) south of Bean Creek (Figure 1B-1).

1.2. Scope

TM1B summarizes the work performed as part of Task 1 – Evaluate Recharge Potential of the Conjunctive Use Project Scope of Work. This tech memo provides an evaluation of the following items:

- A general evaluation of the recharge potential of the project area. The objective of this task is to identify and prioritize the areas where active groundwater recharge would help mitigate groundwater supply issues in the project area.
- The recharge potential of the various surface soils and shallow geological units will be provided. This evaluation will be used to develop unit recharge potentials for recharge ponds and injection wells within the project area.

Based on this evaluation, a map was produced that defines the areas where active groundwater recharge by either surface ponds or injection wells would help mitigate groundwater supply issues in the project area.

This technical memorandum is intended for use in assessing feasibility, and is not appropriate for design, which would require additional site specific investigations and testing. The opinions presented in this technical memorandum have been formulated in accordance with generally accepted engineering practices that exist at this time. They are based on the investigation and evaluation methods described herein, and the assumptions implicit in those methods. The objectives of the recharge potential evaluation include:

- Identify the factors that influence recharge potential,
- Evaluate the range of sizes of an aquifer recharge facility to ensure adequate capacity to process a set range of discharge flow rates, and
- Identify additional data needs for future Conjunctive Use Project design.

1.3. General Approach

This evaluation was used to evaluate the recharge potential of various aquifer recharge methods. Based on this evaluation, a map was produced that defines the areas where active groundwater recharge by either surface ponds or injection wells would help mitigate groundwater supply issues in the project area. The potential options for active groundwater recharge considered in this tech memo include:

- **Percolation Ponds.** Large, shallow ponds situated above the groundwater level and enclosed by dikes or levees. Ponds are filled intermittently, followed by periods of drying and recharge water is delivered to the groundwater either directly to the saturated zone or through the unsaturated zone.

- **Infiltration Basins.** Deep recharge basins that are designed to continuously hold water and are typically excavated below the groundwater level.

- **Leach Fields.** A system of perforated pipes installed in a series of shallow trenches backfilled with highly permeable material to disperse the discharge flow. Discharge flow percolates through the unsaturated soils to reach groundwater.

- **Injection and Extraction Wells.** A series of wells drilled into a suitably transmissive zone in the underlying groundwater flow system. Recharge water is pumped under low pressures into these wells and allowed to flow directly into the aquifer, bypassing the unsaturated zone. Injection and extraction could be accomplished in a single well or in separate wells depending on site-conditions and future operational design.

- **Low Impact Development.** A series of distributed treatment/runoff measures that include constructed wetlands, infiltration basins, vegetated swales and buffer strips that allow percolation of stormwater runoff.

2. Key Recharge Potential Factors

This section provides an overview of the criteria considered when determining the sustainable rate at which recharge water can be discharged indirectly.

2.1. Soil Infiltration Rate

The U.S. Department of Agriculture (USDA) has compiled the soil survey for Santa Cruz County (USDA, 1980). In the soil survey report, the soils are classified throughout the country with respect to a variety of soil properties for a variety of hydrologic properties such as the permeability and available water capacity. Soil classifications have been grouped into four hydrologic groups according to the infiltration of water when the soils are thoroughly wet and receive precipitation from long-duration storms. These designations are useful for evaluating the recharge potential. The four hydrologic soil groups are:

- **Group A:** Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well-drained to excessively drained sands or gravelly sands. These soils have a high initial rate of infiltration, generally greater than 2.0 inches per hour.

- **Group B:** Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well- or well-drained soils that have moderately fine to moderately coarse texture. These soils have a moderate initial rate of infiltration, generally 0.6 to 2.0 inches per hour.

- **Group C:** Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine or fine texture. These soils have a slow initial rate of infiltration, generally 0.2 to 0.6 inches per hour.
- **Group D:** Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow and overlie impervious material. These soils have a very slow initial rate of infiltration, generally 0.06 to 0.2 inches per hour.

Figure 1B-2 shows a map of the four soil groups throughout the study area. Most soils in the area fall into groups A and B, indicating that soil permeability is at least 0.6 inches per hour though most of the basin.

Soils of Group A (the most permeable) occur throughout most of the western and southern parts of the basin. These soils mostly overlie, and are likely derived from, outcrops of the Santa Margarita Sandstone (Figure 1B-2).

Soils of Group B generally occur in areas underlain by alluvium along Bean and Carbonera Creeks, the Purisima, Monterey and Locatelli Formations (Figure 1B-2). These soils also occur across much of the central to eastern portions of the City of Scotts Valley.

Group C and D soils generally coincide with areas underlain by the Santa Cruz Mudstone in northern Scotts Valley. Isolated areas of Group C and D soils are also mapped in areas of alluvium along Bean and Carbonera Creeks, as well as other areas around the City of Scotts Valley.

2.2. Aquifers

The primary groundwater aquifers in the SMGB in the Scotts Valley area are the Santa Margarita Sandstone (Santa Margarita), the Lompico Sandstone (Lompico) and the Butano Formation (Butano). The Butano is exposed at the surface only in the northern parts of the basin and occurs at depths greater than 1,000 feet below Scotts Valley. Therefore, the Butano is not considered as a candidate for direct aquifer recharge. A summary of aquifer characteristics is provided below for the Santa Margarita and Lompico. Additional information on the hydrogeology is provided in TM1A (Kennedy/Jenks, 2011).

2.2.1. Santa Margarita

The Santa Margarita generally consists of massive, fine-to-medium-grained sandstone that forms a distinctive formation of white sand that can be observed in cliffs around the area (Clarke 1981). In the southern areas of Scotts Valley, the Santa Margarita occurs at the surface whereas it is overlain by the Santa Cruz Mudstone in the northern portions of Scotts Valley

(Figure 1B-3). Where the Santa Margarita is present at the surface, there is potential for using surface spreading; however, areas overlain by mudstone preclude the use of surface spreading. The areas where the Santa Margarita is exposed at the surface have the potential for surface spreading.

The upper Miocene age Santa Margarita can be up to 300 feet thick and generally consists of massive, fine-to-medium-grained sandstone. Laboratory analyses of this sandstone indicate that it is typically 85 to 90 percent sand, 7 to 8 percent silt, and 4 percent clay (USDA 1980). For the Santa Margarita, the hydraulic conductivity can range from 1 to 3,000 feet per day (ft/d) but more typically ranges between 2 to 50 feet per day (ft/d). The specific yield can range from 0.02 to 0.18 but typically ranges between 0.07 and 0.12 (Johnson, 2002, ETIC, 2006).

Thin, dense, lower permeability layers have been identified within the Santa Margarita. These layers have been known to form perching horizons, for example at the Watkins-Johnson site in Scotts Valley (Stollar and Associates, 1988). The perched aquifer formed above this horizon has been noted to have a significantly higher groundwater elevation compared to the regional Santa Margarita. However, these horizons are likely not continuous. Identification of these perching horizons is important because of their potential to impact aquifer recharge. If present, these layers could act as a barrier to aquifer recharge capacity and lead to groundwater mounding issues in the vicinity of surface aquifer recharge facilities.

Historically, groundwater levels have been significantly higher in the Scotts Valley area than they are today; however, these recent declines are mostly localized. Some areas have experienced over 200 feet of groundwater level declines, whereas nearby areas have experienced relatively little change in groundwater levels during the same period. The volume of groundwater in the Santa Margarita has declined by as much as 5,000 acre-feet from 1985 through 2007 (Johnson 2002, ETIC 2005, 2006, Kennedy/Jenks 2008, 2009, 2010). The areas with large historical declines in groundwater levels provide the potential capacity for a Conjunctive Use Project.

Groundwater in the Santa Margarita in the Scotts Valley area primarily flows from south to north. Discharge is primarily to springs along outcrops of the Santa Margarita where Bean Creek has eroded through to the underlying Monterey Formation (Monterey). The groundwater gradient is generally on the order of 0.02 to 0.03 feet per foot (ft/ft). These gradients can steepen in the vicinity of large production wells. Pumping rates for production wells in the Santa Margarita typically range between 100 and 200 gallons per minute (gpm) where sufficient saturated thickness exists. Higher pumping rates may have been achievable historically when groundwater levels were higher.

2.2.2. Lompico

The Lompico is found in the subsurface throughout much of the basin; however, the few outcrops found in the Scotts Valley area are limited to the basin margins (Figure 1B-3). The

Lompico is typically 200 to 350 feet thick (Clark, 1981, Brabb 1997). The lower third of the unit consists of thick beds of light-gray, medium-grained sandstone whereas the upper two-thirds of the unit are composed of massive yellowish-gray, fine-grained sandstone beds (Clark 1981). Geophysical logs from local wells show thin shale interbeds within the Lompico that may affect vertical flow within the unit. For the Lompico, the horizontal hydraulic conductivity ranges from 0.6 to 7 ft/d (Johnson, 2002, ETIC, 2006). The specific yield ranges from 0.04 to 0.07 and the storativity ranges from 0.0001 to 0.01 (Johnson, 2002, ETIC, 2006).

Groundwater level declines in the Lompico have been more widespread than in the Santa Margarita. Groundwater levels have declined by 100 to 250 feet over broad areas underlying Scotts Valley. The volume of groundwater in the Lompico has declined by up to 10,000 acre-feet from 1985 through 2007 (Johnson 2002, ETIC 2005, 2006, Kennedy/Jenks 2008, 2009, 2010). The areas with large historical declines in groundwater levels provide the potential capacity for a groundwater recharge project.

Groundwater flow in the Lompico is primarily from north to south. The groundwater gradient is also generally on the order of 0.02 to 0.03 ft/ft. Discharge is primarily to the large groundwater pumping wells operated by Scotts Valley Water District (SVWD) and San Lorenzo Valley Water District (SLVWD). These gradients can steepen in the vicinity of large production wells. Pumping rates for large production wells in the Lompico typically range between 200 and 400 gpm.

The lack of surface exposure of the Lompico in the Scotts Valley area means that any recharge applied to this unit must first pass through another, overlying unit. The Lompico is typically overlain by the low-permeability Monterey Formation. The thickness of the Monterey varies widely across the study area as a result of geologic deformation and erosion prior to deposition of overlying layers. Where present, the Monterey forms a significant aquitard that limits groundwater movement between the Santa Margarita and the Lompico; in these areas, there is little potential for surface spreading as a mechanism for recharge to this unit.

In parts of the Scotts Valley area, especially within a strip along the southern and eastern portions of the basin (i.e. the eastern rim of the SMGB), the Monterey was eroded away prior to deposition of the Santa Margarita, so that the Santa Margarita lies directly upon the Lompico. In these areas, there is no known barrier to percolation of groundwater from the Santa Margarita to the Lompico, so surface recharge would have the potential to reach the Lompico. The distribution of this contact forms a strip along the southern and eastern portions of the basin (Figure 1B-4).

2.2.3. Butano

The Butano has been mapped in surface outcrop along the northern SMGB margin (Figure 1B-3) by Clark (1966, 1981), Brabb (1997), and McLaughlin and others (2001). The Butano Sandstone consists largely of sandstone and interbeds of mudstone, shale, and siltstone.

Specifically, the Butano consists of three members that include the lower sandstone member, the middle siltstone member, and the upper sandstone member (Clark, 1981).

The Butano is a thick sandstone unit that forms a wedge along the northern portion of the SMGB (Clark 1981). The Butano has a total stratigraphic thickness of up to 5,000 feet; however, due to structural deformation and erosional history the thicknesses found in the Scotts Valley area is several hundred to a thousand feet thick (Clark, 1981, Brabb 1997). For the Butano, the horizontal hydraulic conductivity was estimated at 1.25 ft/d, the specific yield at 0.06 and the storativity at 0.0001 (ETIC, 2006).

Groundwater recharge is most likely from infiltration of precipitation and from the streams that flow over the Butano Formation in these exposure areas north of Scotts Valley. Correspondingly, the Butano Formation appears to have few natural discharge points.

Groundwater level declines in the Butano are not as well understood as those in the Lompico and the Santa Margarita due to a lack of monitoring wells completed entirely within the Butano. Static groundwater levels fluctuate about 100 feet seasonally due to pumping, but overall groundwater levels have maintained a relatively stable trend. This suggests that the Butano is actively recharged, allowing groundwater levels to recover each year in spite of the high volume of groundwater produced by these wells. Annual groundwater production from the Butano is estimated to range from 500 to 1,000 acre-feet per year.

The Butano is over 1,000 feet deep underneath most of Scotts Valley, and few wells have been drilled deep enough to encounter the Butano. The lack of surface exposure and overlying fine-grained layers precludes any surface recharge methods for the Butano. The Butano is absent over much of the Study Area, and is only present at depths over 1,000 feet in the northern portions of Scotts Valley causing increased injection well installation costs. Because of these limitations, the Butano is not considered to be a viable candidate for groundwater recharge by the Conjunctive Use Project.

3. Other Factors Influencing Recharge Potential

Several factors can influence the overall recharge potential. A brief overview of these factors is provided.

3.1. Aquifer Characteristics

Transmissivity (T) is a parameter that defines the ability of the aquifer to transmit water. The higher the transmissivity, the higher the flow of water the aquifer is capable of accepting (Morris and Quinn, 1999). An effective infiltration system requires an unconfined aquifer with high transmissivity to allow lateral flow away from infiltration system and minimize mounding (Bouwer, 2002). The soils overlying the aquifer must have high hydraulic conductivity (K) with sufficient thickness to convey the required quantity of water. Clay soils tend to have the lowest hydraulic conductivity and coarse sands tend to have the highest hydraulic conductivity.

3.2. Groundwater Mounding

Groundwater mounding typically occurs immediately below indirect discharge facilities. Because groundwater moves relatively slowly, a localized increase in groundwater elevation, or mound, develops. If the mound rises to near the recharge facility, this can significantly limit the amount of water that can be recharged. The presence of shallow clay or hardpan layers can increase mounding due to their low hydraulic conductivity. The height of the mound is controlled by the permeability of the sediments, the application rate of water at the surface, and the depth to groundwater. A greater the depth to groundwater allows for a larger vertical separation between the facility and the groundwater, leaving more space for mound development. Under similar soil permeability conditions, the greater depth to groundwater would allow for a greater potential for recharge.

3.3. Clogging and Plugging

Several mechanisms can lead to soil/aquifer plugging during aquifer recharge. Clogging rates increase with increasing infiltration rates, increasing injection pressures in injection wells and increasing the water depth in infiltration basins (Bouwer, 2002). A summary of these mechanisms is provided below.

3.3.1. Clay Expansion and Dispersion

Expansion and dispersion of clay particles which are naturally present in aquifers can occur by ion-exchange reactions and can significantly reduce hydraulic conductivity. Ion exchange involves the replacement of ions absorbed on the surface of clay particles in aquifers by ions (primarily sodium, calcium, and magnesium) in solutions. This process is known as base or cation exchange (Todd, 1980).

From the Santa Cruz County Soil Survey (USDA, 1980), the Group A and B soil hydrology groups typically have low clay content. The Group C soil hydrology group may have fine-grained sediments that could experience clogging. The Group D soil hydrology group would have a high likelihood of containing shallow clay layers that could potentially lead to significantly more clogging.

3.3.2. Mineral Precipitation

Chemical reactions can occur between groundwater and recharged water introduced to the aquifer, causing precipitation of insoluble compounds (e.g. calcium carbonate, iron, and manganese oxides). The chemical reactions generally depend on chemical and physical-chemical conditions, including pH, temperature, and availability of a surface area for precipitate deposition (ASCE, 2001). Mineral precipitation would be most problematic for injection wells and leachfields where buildup of mineral precipitates within well screens would have the potential to significantly reduce the total open area of the screen, resulting in a loss in efficiency. If mineral precipitates develop on the well screens, additional maintenance costs would be incurred to mitigate the buildup through physical and chemical rehabilitation treatments.

Plugging by mineral precipitation generally has not been a serious problem in percolation ponds and infiltration basins because: (1) the total volume of precipitation is too small to significantly affect the hydraulic conductivity; (2) precipitation typically occurs in isolated pore spaces (interstices) with little effect on the hydraulic conductivity; and (3) the slow kinetics of the reactions cause precipitation to occur over a large area of the aquifer rather than at the recharge water-aquifer interface (Wood, 1980).

3.3.3. Physical Plugging

Physical plugging is caused mainly by the accumulation in pore spaces of suspended solids contained in recharge water. The solids can consist of fine inorganic particles like silt, fine sand, clay, and flocs, and/or organic solids such as algal cells or decaying organic matter (ASCE, 2001). For surface spreading system, physical clogging occurs on the bottom and sides of the basin. In an injection well, this can occur on the well screen, in the sand or gravel pack, or in the surrounding aquifer.

As discussed by Bouwer (1997), clogging due to accumulation of suspended solids is a major consideration for aquifer recharge because solids either settle or are strained out, mainly on the soil surface. Clogging layers can range from 1 millimeter to several tens of millimeters thick and with time the hydraulic impedance of a clogging layer can increase and become the limiting factor of the infiltration process.

Previous experiments have shown that recharge water used for percolation applications should have suspended solids (SS) levels below 2 milligrams per liter (mg/l) to reduce physical plugging problems. Other research conducted in the same aquifer system showed no problem when recharge water with SS levels in excess of 25 mg/l was used (Rinck-Pfeiffer et al, 1999).

3.3.4. Biological Plugging

Plugging of well screens and aquifers is also caused by biological growth primarily of bacteria. The actual plugging results from both physical plugging caused by the growth of cells and accumulation of waste products and chemical plugging resulting from chemical reactions induced by biological activity (Wood, 1980). Similar to mineral precipitation, bacteria or other biological buildup can develop on well screens and reduce their efficiency. If biological buildup does develop on the well screens, additional maintenance costs would be incurred to mitigate the buildup through physical and chemical rehabilitation treatments.

A potential drawback of shallow recharge basins is weed growth. Biological growth requires energy and a nutrient source, and rates of biological growth are enhanced by warm temperatures, sunlight, and greater concentrations of nutrients in the form of dissolved and suspended solids. Pretreatment of the water to remove nutrients (phosphorus and nitrogen) may reduce clogging. Biological plugging also can be reduced by disinfection (e.g. chlorination and UV).

3.4. Hydraulic Loading

Long-term average infiltration rates should be developed when determining the hydraulic capacity of percolation ponds. Initial infiltration rates will decrease over time due to clogging and the ponds must be dried periodically for cleaning. According to Bouwer (2002), hydraulic loading rates for percolation ponds in warm, relatively dry climates with good-quality water range from 30 m/year in fine textured soils to 500 m/year for coarse, clean sands. Evaporative losses are small compared to percolation rates so they are not included in sizing calculations.

The water depth of the percolation basins should be carefully selected. As discussed by Bouwer (1997, 2002), while high hydraulic heads (corresponding to large water depths) produce higher infiltration rates, they also tend to compress clogging layers, thereby increasing the hydraulic resistance of the clogging layer. Thus, contrary to intuitive expectations, deep basins can produce lower average infiltration rates than shallow basins in similar settings.

3.5. Temperature and Viscosity

As discussed by Bouwer (2002), infiltration rates vary inversely with viscosity. Viscosity can cause winter infiltration rates to be as low as half the summer infiltration rate in areas with high seasonal temperature fluctuations. Therefore, temperature can have large effects on infiltration rates if recharge water temperature fluctuates widely. Indirect discharge facility capacities should be designed using the coldest regional temperatures when infiltration rates are lowest.

4. Sustainable Rate Assessment of Percolation Ponds

Utilizing both the unsaturated (vadose) zone and the saturated zone, percolation ponds are large, shallow ponds that are filled intermittently and are enclosed by dikes or levees. The pond bottom is situated above the water table (the upper boundary of the saturation zone in a groundwater system). The recharge water percolates through the unsaturated soils to reach groundwater. Thus, the ponds have no direct connection to underlying groundwater.

The primary benefit of percolation ponds is the improvement of water quality realized due to the fact that the water passes through the unsaturated zone. Soil aquifer treatment is provided by filtration, sorption, chemical precipitation and reaction, and biological transformation of constituents in the percolating water. Another benefit is that percolation ponds are a well-known technology with a well-established, reliable work history. Percolation ponds have been used reliably for decades in the study area and elsewhere. Yet another benefit of percolation ponds is their relatively lower construction, maintenance and energy costs as compared to other indirect discharge options. Percolation ponds are the least susceptible to long-term flood impact because fines can be removed manually after the flood events.

4.1. Percolation Pond Sizing

The sizing of percolation ponds is controlled by a range of site specific factors including soil conditions, geological factors, and operational issues. These will need to be addressed during future studies of potential sites and as the operational considerations are better developed. For the purposes of this evaluation, the following technical specifications are used as conservative assumptions for making a preliminary estimate of the size of the percolation ponds. The specifications have been used for some percolation ponds, but variations to the specific design for use in the Scotts Valley area may be appropriate. The assumed technical specifications used for this analysis include the following:

- Discharge season is 180 days/year.
- Ponds operate 6 months/year.
- Initial soil percolation rates are (USDA, 1980):
    - 2 in/hr for Type A Soil
    - 0.75 in/hr for Type B Soil
    - 0.25 in/hr for Type C Soil
- De-rate factor is 6 to account for reductions in the percolation rate as the pore space below the facility is filled (Bouwer et al., 1974, Bouwer, 2002). For example, the sustainable percolation rate in Type A soil is 2 in/hr; however, the long-term infiltration rate is considered to be 0.33 in/hr or 0.67 feet per day. Without site-specific testing, using a de-rate factor of 6 is a conservative assumption that provides a factor of safety that the percolation ponds are of adequate size to handle the anticipated discharge rates.
- Each pond is flooded 10 days/month.
- Drying time for each pond is 18 to 21 days/month.
- Facility consists of multiple ponds so that some ponds are active while other ponds are drying at any given time.
- Initial pond loading depth is 3 feet.

The designed loading depth marks the operational range of water levels in the ponds at any one time. An additional 0.75 feet would be provided to accommodate a large, single-day rain event of 9 inches. Two-feet of freeboard would be provided for all berms. Percolation ponds facility sizes are determined using the following additional criteria:

- Berms are constructed between ponds to provide separation and access for maintenance vehicles. Berm design assumptions include:
    - Height of 5.75 feet
    - Base width of 35 feet
    - Top width of 12 feet
    - Side slope of 2:1
- Additional land would be included for an operations facility and a 150-foot wide buffer zone surrounding the ponds to accommodate groundwater mounding.

A percolation facility to accommodating 1 million gallons per day (mgd) of aquifer recharge on Type A soil would require approximately 13 acres of active pond area (including berms) and approximately 15 acres for the entire facility site, including the buffer and operations facilities. Table 2 provides pond sizes and total facility sizes (based on Bouwer, 1997, 2002) needed to accommodate various discharge rates and soil percolation rates.

Table 1: Percolation Pond Sizing for Varying Discharge Rates and Soil Type

		0.5 mgd		1.0 mgd		2.0 mgd		4.0 mgd	
Soil Type	**Initial Percolation Rate**	**Total Pond Area (acres)**	**Total Facility Size (acres)**	**Total Pond Area (acres)**	**Total Facility Size (acres)**	**Total Pond Area (acres)**	**Total Facility Size (acres)**	**Total Pond Area (acres)**	**Total Facility Size (acres)**
A	**2 in/hr**	8	9	13	15	22	25	40	47
B	**0.75 in/hr**	28	32	53	61	78	89	102	118
C	**0.25 in/hr**	78	89	152	175	226	260	300	345

Note: Actual pond capacity would depend upon site-specific soil and aquifer characteristics.

4.2. Operations and Maintenance

Maintenance of percolation ponds should be an integral part of percolation performance optimization. The primary maintenance consists of periodically scraping off the top later of accumulated sediment and organic material from the pond bottom (Bouwer, 1985, 1997, 2002). According to Bouwer (1997), if the clogging layer is primarily organic, drying to partly decompose, crack, and curl up the organic material can be an effective method of restoring percolation rates until the clogging process repeats itself. The preferred mechanism to treat the organic material is manual raking and removal of the material. The organic layer can be shaved off or removed with a loader or similar equipment. However, the process disperses the organic material into the soil and compacts the soil, reducing future percolation rates. The organic layer can also be treated by discing of the soil, which disturbs the organic layer and can temporarily increase percolation rates. However, the discing process distributes the organic material in a thicker zone which can then act to impede long-term percolation rates; therefore, discing should be avoided if possible. If the clogging layer is inorganic (silt or clay), the layer should be mechanically removed. Much of the pond maintenance would be done during the dry summer months.

Ridges located in the bottom of a recharge basin and furrows adjacent to the ridges facilitate cost effective maintenance of the basin using the naturally occurring forces of gravity, water currents, and wave action. The ridges are normally formed from material taken from the furrows into shapes that facilitate sediment migration from the ridges into the furrows. While submerged, sediment settles on the ridges and furrows. The sediment on the submerged ridges tends to migrate toward and into the furrows. The basins are routinely dewatered allowing wind-driven or induced wave action against the sides of the ridges to wash the sediments from the ridges into the furrows, thereby maintaining the permeability of the ridges (Peyton, 2002).

Regular operation of the ponds would involve two ponds actively percolating while the remaining four are resting. The assumed operational rotation has two ponds to receiving discharge for 10 days, followed by a 20-day resting period. During the resting period, the ponds are allowed to drain completely to allow for partial subsidence of groundwater mounding and drying and settling of accumulated sediments and organics. Drying the ponds also helps to minimize bacterial growth on the bottom of the pond that may impede long-term percolation. Rotating the ponds with regular resting periods is good practice to maintain long-term sustainable percolation rates (Bouwer, 1985, 1997, 2002).

4.3. Assessment

The size of an aquifer recharge facility using percolation ponds would be based on the site-specific conditions. The smaller the size of the facility the lower the overall capital and O&M costs to maintain the facility. Placing the facility in areas of high permeability soils would improve performance and maximize infiltration potential. Locating the facility over areas with significant unsaturated aquifer material would limit mounding problems and maximize the potential percolation rates.

The primary limitation of percolation ponds is the requirement for significant land area. Land acquisition is a significant capital cost. Another limitation is the aesthetic impacts due to the visibility of percolation ponds from the surface and overhead. To minimize the size of the aquifer recharge facility, percolation ponds would best be located in areas with

- Hydrologic Soil Group A soils,
- Santa Margarita near the surface,
- Absence of the Santa Cruz Mudstone,
- Sufficient available groundwater storage, and
- Absence of the Monterey where the Santa Margarita and Lompico are in direct contact is preferable.

Figure 1B-5 provides a map of the study area showing the distribution of areas that are likely to have these characteristics, and are therefore suitable for large-scale surface recharge using percolation ponds. Those areas that coincide with the area where the Santa Margarita and Lompico are in direct contact would have the highest potential because aquifer recharge from the surface could reach the Lompico. This includes the southern portion of the Hanson Quarry. In the areas north of the direct contact area, surface recharge from percolation ponds would be restricted to only the Santa Margarita.

4.4. Additional Data Needs

Based on the relative benefits and limitations, percolation ponds are considered a viable mode of aquifer recharge for further evaluation. Testing should be performed to provide the following data that are needed prior to developing a percolation pond facility:

- Site specific soil conditions,
- Field test of percolation rates,
- Site specific groundwater levels and characteristics,
- Field test of clogging rate, and
- Site specific geotechnical analysis.

5. Infiltration Basins

Infiltration basins are similar to percolation ponds except that they are much deeper and the basins remain filled with water throughout the year. Typically, infiltration basins discharge directly to the saturated zone. Water discharged into an infiltration basin escapes the basin through the basin side or bottom via installation.

5.1. Infiltration Basin Sizing

The size required for an infiltration basin is comparable to that of percolation ponds for the same recharge water flows because groundwater mounding during seasonally high groundwater, is the primary factor controlling the size of both types of facilities. The basins may be excavated as much as 10 to 50 feet deep. If the basin is completed through the unsaturated zone, the recharge water is allowed to infiltrate directly into the groundwater aquifer.

The specifications for infiltration basins will require additional evaluation to develop a design appropriate for the Scotts Valley area. The sizing of infiltration basin is controlled by a range of site specific factors including soil conditions, geological factors, and operational issues. These will need to be addressed during future studies of potential sites and as the operational considerations are better developed.

5.2. Operations and Maintenance

Operation of the facility consists of discharging water into the infiltration basin through a single discharge pipe. Piping at the site consists of a single discharge pipe from the main conveyance to the site and two discharge structures.

Although high hydraulic heads in infiltration basins can result in higher infiltration rates, they also tend to compress clogging layers, which increases hydraulic resistance of the clogging layer. Therefore, it is assumed that after a period of time, the hydraulic capacity of an infiltration basin would be limited by the permeability of the clogging layer and would be equivalent to that of a percolation pond.

Because groundwater mounding is a primary concern, a monitoring well system should be planned to aide in monitoring the local groundwater mounding from facility operations. The facility would include 10 monitoring wells to monitor water levels. The monitoring wells would typically be installed within 100 feet of the basin margins. One set of wells with well screens completed to different vertical depths is assumed to be completed downgradient of the basin to evaluate vertical flow characteristics.

Clogging due to fines and organics may reduce the permeability at the interface with the soil and form a limiting condition that reduces inflow. Because the basin would be saturated year round, it is more difficult, time-consuming and expensive to clean the basin or control biological growth after it has been constructed. Removal of the built-up material would require expensive dredging operations. Without dredging, the performance of the infiltration basin would decline over time (Bouwer, 1999, 2002; Oaksford, 1985). Flood events would cause long-term degradation to sustainable flow rate because of the additional fines introduced into the basin without a means to dry the basin and remove the top layer of soil, as in a percolation pond.

A limitation of infiltration basin is the long-term maintenance of the basins to ensure a sustainable discharge rate. Control of algal growth on the basin surface and of biological growth on the embankments is an important part of maintenance. If left unchecked for extended periods of time, could compromise infiltration rates and water quality. Periodic algaecide application may be necessary to ensure continued performance of the infiltration basins if conditions become problematic.

5.3. Assessment

The primary benefit of an infiltration basin would be if the site area was covered by low permeability sediments, but a high-permeability aquifer was present at a lower depth. The infiltration basin allows for higher discharges in this situation by circumventing the low-permeability sediments.

Infiltration basins can be used opportunistically where an existing excavation is already present, such as from a sand mining operation, as making use of existing features can significantly reduce construction costs.

The primary limitations of infiltration basins are the cost and time required for their construction of a large basin. The cost of excavation would depend on the size and depth of the basin. Construction of infiltration basins would require heavy equipment and significant slope stabilization depending on the excavation depth. During construction, this facility would look like a sand mining operation. After heavy earthwork construction activities, the infiltration basin site development would be similar to that of a percolation pond site. The excavated material would need to be trucked offsite for disposal if a buyer cannot be found.

5.4. Additional Data Needs

Based on the relative benefits and limitations, infiltration basins are considered a viable mode of aquifer recharge for further evaluation. Testing should be performed to provide the following data that are needed prior to developing a percolation pond facility:

- Site specific soil conditions,
- Field test of percolation rates,
- Site specific groundwater levels and characteristics,
- Field test of clogging rate, and
- Site specific geotechnical analysis.

6. Sustainable Rate Assessment of Leach Fields

A leach field utilizes a system of perforated pipes installed in a series of shallow trenches backfilled with highly permeable material to disperse the discharge flow. The pipes and trenches are situated above the water table. A leach field uses the same principle as a percolation pond, namely percolation of discharge water to the water table through the unsaturated zone. Thus, the trenches have no direct connection to underlying groundwater.

6.1. Leach Field Sizing

A leach field is assumed to be of a comparable size to a percolation pond facility; therefore, to accommodating 1 mgd of aquifer recharge on Type A soil would require approximately 15 acres.

The primary advantage of a leach field is that it may be less visually intrusive compared to percolation ponds. As with an injection well field, a leach system may be landscaped to produce an aesthetically pleasing indirect discharge site. Similar to the percolation ponds, the leach field has the water quality benefit of having the discharge water pass through the unsaturated zone. Another advantage of the leach field is the potential flexibility of design.

6.2. Operations and Maintenance

Flow through the system would be controlled by a series of valves. Flow in each distribution line would be controlled such that the leach field can be operated in a manner similar to the percolation ponds with part of the system operational and part of the system resting at any given time. Each lateral would have a valve to control flow and ensure even distribution of flow among the laterals. Additional pumping facilities may be necessary to provide enough pressure for rapid percolation of the discharge flow.

The primary disadvantage of the leach field concerns long-term maintenance. Since the perforated piping is completed above the water table, the system cannot be backflushed by pumping groundwater to remove sediments and organics that may clog the perforations (Bouwer, 2002). The perforated piping can be accessed and mechanically swabbed. For this purpose, each lateral would be equipped with a cleanout. However, without the inflowing water, this method may further smear the clogging material causing the situation to deteriorate further. If clogging becomes too severe, the perforated pipes may require re-excavation and replacement. This would significantly impact the long-term maintenance costs. Based on this, leach fields are a less desirable option for indirect discharge compared to percolation ponds, infiltration basin and injection wells.

6.3. Assessment

The conditions suitable for leachfields are considered to be similar to those for percolation ponds. Figure 1B-5 provides a map of the study area showing the distribution of areas that are likely to have these characteristics suitable for percolation ponds and leachfields. Similar to the percolation ponds, the highest potential areas are those that overlie the area where the Santa Margarita and Lompico are in direct contact because recharge from leachfield near the surface could reach the Lompico.

6.4. Additional Data Needs

Testing should be performed to provide the following data that are needed prior to developing a leach field facility:

- Site specific soil conditions,
- Field test of percolation rates,
- Site specific groundwater levels and characteristics,
- Field test of clogging rate, and
- Site specific geotechnical analysis.

7. Sustainable Rate Assessment of Low Impact Development

An alternative to dedicated multi-use aquifer recharge facilities is smaller, more distributed sites using Low Impact Development (LID) techniques. These consist primarily of small-scale infiltration structures that collect stormwater and allow it to percolate into the shallow soil and ultimately to the aquifer. The primary advantage of LID is that it can be more readily incorporated into developed areas due to its smaller size. It can have advantages for aquifer recharge due to its distributed nature so that aquifer recharge is not focused into a single area. A disadvantage is that the distribution is controlled by development and land use patterns that may not be optimal for aquifer recharge. It should be noted that there are potential cumulative benefit of these structures in helping to meet other stormwater management issues. Scotts Valley currently has an ordinance requiring use of LID structures where geologic conditions are appropriate. The retrofitting existing developments would also have a potentially significant benefit.

7.1. Operations and Maintenance

LID is primarily designed to be operated passively. Small infiltration facilities are constructed that capture a portion of the stormwater runoff, and it is allowed to percolate into the ground. This type of facility tends to have significantly lower operational costs than other types of aquifer recharge facilities discussed above. The infiltration facilities require maintenance to remove the buildup of fine-grained sediments or organics. The type of maintenance would vary depending on the type of facility. Additional information about LID is provided in TM3 (Kennedy/Jenks, 2010).

7.2. Assessment

The size of LID facilities is significantly smaller than large-scale aquifer recharge using percolation ponds. Therefore, these facilities are less sensitive to site specific conditions as these facilities can be successfully located in areas that would not be suitable for a large percolation pond. The conditions suitable for LID development include the following:

- Hydrologic Soil Group A or B soils,
- Santa Margarita near the surface, and
- Absence of the Santa Cruz Mudstone.

Figure 1B-6 provides a map of the study area showing the distribution of areas that are likely to have these characteristics suitable for LID. The areas shown on Figure 1B-6 as suitable for surface recharge using LID facilities meet the criteria listed above.

Because of the smaller scale of LID, it can be applied in more areas than the large-scale surface spreading. LID is applicable to many of the developed areas along Scotts Valley Drive and Mount Hermon Road in southern Scotts Valley. Those areas that coincide with the area where the Santa Margarita and Lompico are in direct contact would have the highest potential because recharge water could reach the Lompico.

7.3. Additional Data Needs

Testing should be performed to provide the following data that is needed prior to developing an LID facility:

- Site specific soil and geology conditions,
- Field tests of percolation rates,
- Field tests of clogging rate, and
- Site-specific geotechnical analysis.

8. Sustainable Rate Assessment of Injection Wells

The injection well option of indirect discharge consists of a series of wells drilled into a suitably transmissive zone in the underlying groundwater flow system. Discharge water is pumped under low pressures into these wells and allowed to flow into the aquifer. Recharge water is discharged directly to the saturated zone, bypassing the unsaturated zone. Therefore, the injection well option would produce water quality benefits from flow through the aquifer, but not the benefits that would result from flow through the unsaturated soils (Bouwer, 1985, 1997, 2002; Morris and Quinn, 1999).

The advantage of injection wells is that they require less land area than do percolation ponds. Additionally, the facility could be interspersed among existing land use areas, which would minimize the visual impact of the wells. The ground surface between the wells can either be left in its original state or landscaped. These wells could be designed as individual injection and extraction wells, or as dual-function injection and extraction wells depending on site-conditions and future operational design. The use of dual-function wells may save on capital costs, but may have higher operation and maintenance costs. However, dual-function wells may help SLVWD and SVWD with water management in the region.

8.1. Injection Well Sizing and Construction

Inside the well casing, the buildup of the water level in the well is a function of the injection rate of water into the well and the transmissivity of the aquifer. Injection rates would vary with water levels (Morris and Quinn, 1999). Actual flow rates for each well need to be developed based on testing after installation. Sizing of injection wells is based on the following assumptions:

- Recharge rate for each well is 0.2 mgd (about 150 gpm), or about half of the average pumping rate.
- Two-thirds of the installed wells operate at any given time to allow for maintenance.

The number of injection wells would vary depending on the intended volume of aquifer recharge. Additional injection wells would be needed to allow for maintenance. Spacing of the injection wells would depend on aquifer conditions and land use constraints. The estimated number of injection wells for different aquifer recharge volumes based on the assumptions above is estimated as the following:

- A 0.5 mgd aquifer recharge facility would require 4 wells,
- A 1.0 mgd aquifer recharge facility would require 8 wells,
- A 2.0 mgd aquifer recharge facility would require 15 wells, and
- A 3.0 mgd aquifer recharge facility would require 22 wells.

Each injection well would be drilled to the base of the Lompico to access the greatest thickness of aquifer material. The well depths would vary from 500 to 800 feet depending on the local site conditions.

8.2. Operations and Maintenance

In an injection well, water is added to the well through a drop pipe with some type of submerged hydraulic restriction. The restriction ensures that back pressure can be maintained on the drop pipe during operation to prevent the introduction of air (Morris and Quinn, 1999). A minimum pressure of 5 pounds per square inch (psi) needs to be maintained to avoid air entrainment in the well which would otherwise seriously impact performance.

Well operations can be very sensitive to clogging. Clogging occurs when sediments in the recharge water or biological growth cause a buildup on the well screen. This buildup reduces the open area of the well screen, thereby reducing the flow rate of water into the aquifer. Geochemical interactions with the aquifer can also cause buildup due to precipitation of iron and manganese oxides or hydroxides as dissolved oxygen levels change, and to solution and precipitation of calcium carbonate due to changes in pH and dissolved carbon dioxide levels (Bouwer, 2002). Testing of site-specific conditions would be required to understand the potential geochemical interactions.

Air entrapment can cause air binding in injection wells when the recharge water contains entrained or dissolved air and/or is cooler than the soil or aquifer with which it comes into contact. The injected water warms up in the soil or aquifer; air leaves solution and forms entrapped air, which reduces the hydraulic conductivity by reducing the amount of effective pore space available to groundwater flow (Bouwer, 2002). To monitor for the effects of clogging and air entrapment, each well would require automated level controls and shut-off valves. It is essential to have appropriate level controls to shut down the well in case of a problem. Unlike percolation ponds, injection wells essentially have no excess storage capacity that would be available to handle short term operation or maintenance issues. Level controls and shut off switches could be set either at a control box at each individual well site or at a central location.

Maintenance of injection wells typically constitutes periodic “backwashing” of each well to remove the buildup of sediments and organic materials. To facilitate this activity, each well would be equipped with a submersible pump at the bottom of the well casing to provide suction pressure and thus clean out any accumulated obstructions in the well screens.

More intensive maintenance activities, such as chemical cleaning or well redevelopment, may be necessary if a well demonstrates further deterioration in performance. Chemical cleaning would entail the application of hydrogen peroxide solution or equivalent to remove organic buildup on the well screen. Well development would entail using a drilling rig to mechanically swab the well screen to break up heavy buildup of mineral precipitates that resist other forms of maintenance. Ongoing maintenance and replacement of pumps and valves would also be required. A pump maintenance area may also be necessary for cleaning and maintaining the dedicated well pumps.

8.3. Assessment

The capacity of each well is estimated to be 0.2 mgd based on known groundwater extraction rates in the Scotts Valley area and assuming that groundwater injection is less efficient than groundwater pumping. Installation of injection wells for aquifer recharge would be best located in areas of significant historic drawdown so that there is sufficient groundwater storage capacity available. Due to the complex geologic structure of the Scotts Valley area, wells would best be located (from a cost standpoint) in the Lompico in areas where the Lompico is not too deep to reduce drilling costs. There may be some benefit to locating the wells in the area where the Santa Margarita is in direct contact with the Lompico because the Lompico is found at shallower depths and the Santa Margarita potentially provides additional storage capacity.

Figure 1B-7 provides a map of the study area showing the distribution of areas that are likely to have these characteristics suitable for injection wells. This includes a wide area of southern Scotts Valley.

The primary advantage of the injection well option is the flexibility of the wellfield layout. The wells are also less visible at the ground surface than the percolation ponds. The primary limitation of injection wells is the time and cost associated with operation and maintenance (Bouwer, 1985, 1997, 2002; Morris and Quinn, 1999). Injection wells would require more active management than percolation ponds or infiltration basins. Based on this analysis, injection wells are considered a viable option.

8.4. Additional Data Needs

Testing should be performed to provide the following additional data that is needed prior to developing an injection well facility:

- Installation of test wells,
- Aquifer injection tests,
- Site specific groundwater levels and characteristics,
- Potential geochemical interactions with the aquifer, and
- Groundwater modeling to evaluate long-term mounding and other effects.

9. Conclusions

Overall, the soils in the Scotts Valley area have high infiltration rates and the aquifer has high storage capacity and transmissivity which are favorable for aquifer recharge. Large-scale surface spreading options, including percolation ponds and leachfields, would be feasible in the Scotts Valley area. The primary factors for siting these types of facilities include the following:

- Hydrologic Soil Group A soils,
- Santa Margarita near the surface,
- Absence of the Santa Cruz Mudstone, and
- Absence of the Monterey where the Santa Margarita and Lompico are in direct contact.

In general, those areas that coincide with the area where the Santa Margarita and Lompico are in direct contact would have the highest potential because aquifer recharge from the surface would benefit both the Santa margarita and Lompico. This includes the southern portion of the Hanson Quarry. In the areas north of the direct contact area, surface recharge from percolation ponds would be restricted to only the Santa Margarita where there would be minimal increase in aquifer storage.

Smaller scale surface spreading options, best characterized by the LID facilities, could be feasible over a wider range including large portions within the City of Scotts Valley. LID facilities are less sensitive to site-specific conditions due to their smaller size so they can be sited in more areas. However, LID is associated with specific development and land use patterns that may not be optimal for aquifer recharge. The primary factors for siting LID facilities include the following:

- Hydrologic Soil Group A or B soils,
- Santa Margarita near the surface, and
- Absence of the Santa Cruz Mudstone.

LID facilities are less sensitive to site-specific conditions due to their smaller size so they can be sited in more areas. However, LID is associated with specific development and land use patterns that may not be optimal for aquifer recharge.

Injection wells are another feasible method for adding aquifer recharge. The anticipated capacity of injection wells completed in the Lompico is anticipated to be about 0.2 mgd or about 150 gpm. To achieve the potential aquifer recharge operation of 1.0 mgd would require 8 wells, including redundancy to accommodate down time of equipment, controlling development of local groundwater mounds, and variation in local conditions at wells (not all wells would be as efficient as others). A 1.0 mgd operation operated for 6 months per year. Injection well locations can be dispersed to minimize mounding, but this would cause of a more widely distributed recharge zone. A more compact well field would need to consider capacity for mounding.

The advantage of injection wells is that they can more efficiently emplace water in the Lompico which has the highest potential for groundwater storage. The wells are also less visible at the ground surface than the percolation ponds. The water quality benefit resulting from the filtering and biological activity associated with percolation through the vadose zone is lost with injection wells. For operation and maintenance, wells would require periodic backwash to remove fines and organics. If mineral or organics buildup up at the well screen is severe, chemical well development methods may be necessary. Injection wells are considered a viable option for indirect discharge.

For these aquifer recharge facilities, the total annual aquifer recharge potential for various facility sizes would be as follows (assuming that they are operated for 6 months per year):

- A 0.5 mgd aquifer recharge facility would add 275 acre-feet per season;
- A 1.0 mgd aquifer recharge facility would add 550 acre-feet per season;
- A 2.0 mgd aquifer recharge facility would add 1,100 acre-feet per season; and

- A 3.0 mgd aquifer recharge facility would add 1,650 acre-feet per season.

The actual aquifer recharge would be dependent upon the availability of water and the any operational constraints.

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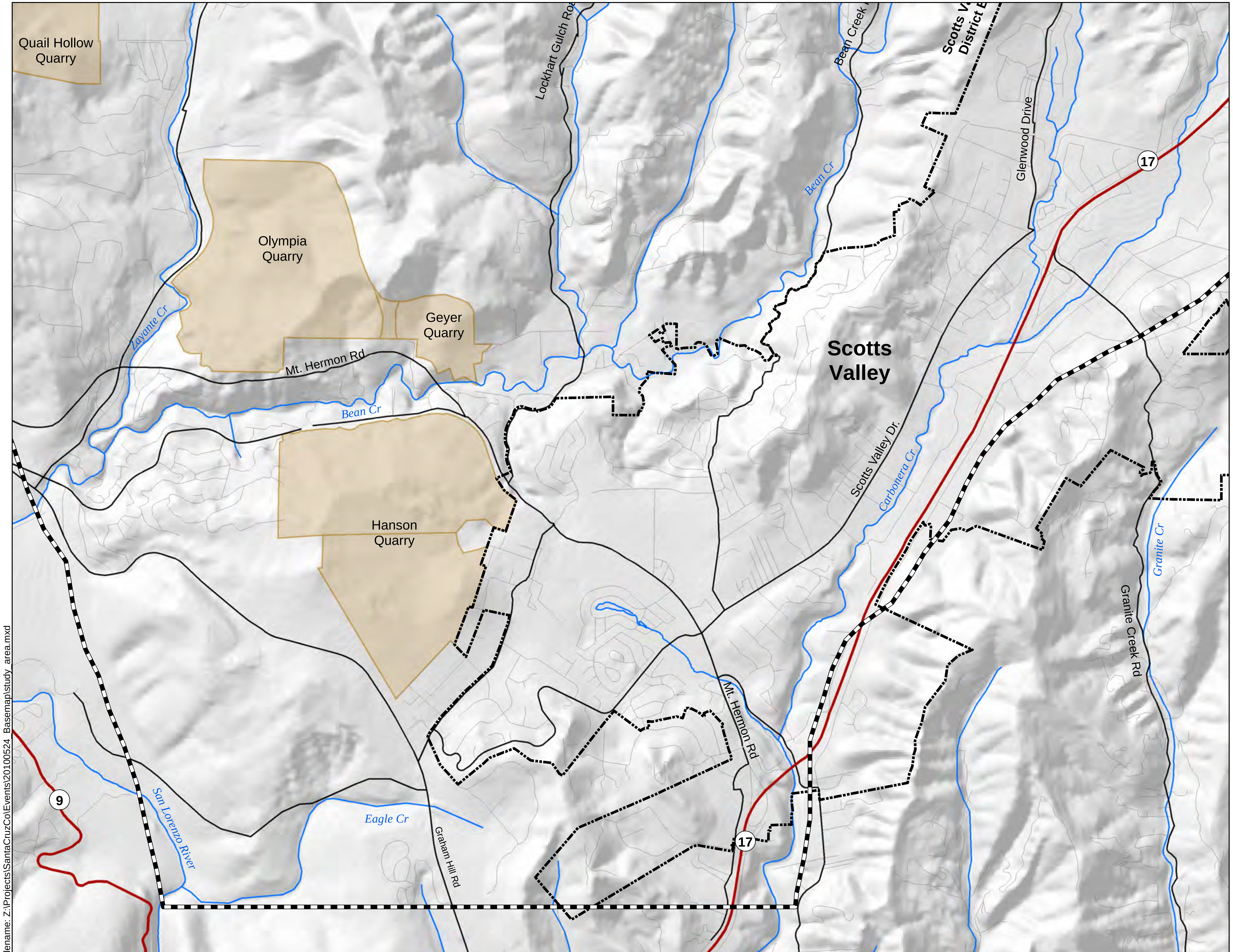
FIGURES



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DRAFT TM 1B - Regional Water Demand
Conjunctive Use and Enhanced Aquifer Recharge Project
Santa Cruz County, California

Conjunctive Use Project Study Area

K/J 0864005
November 2010

Figure 1B-1

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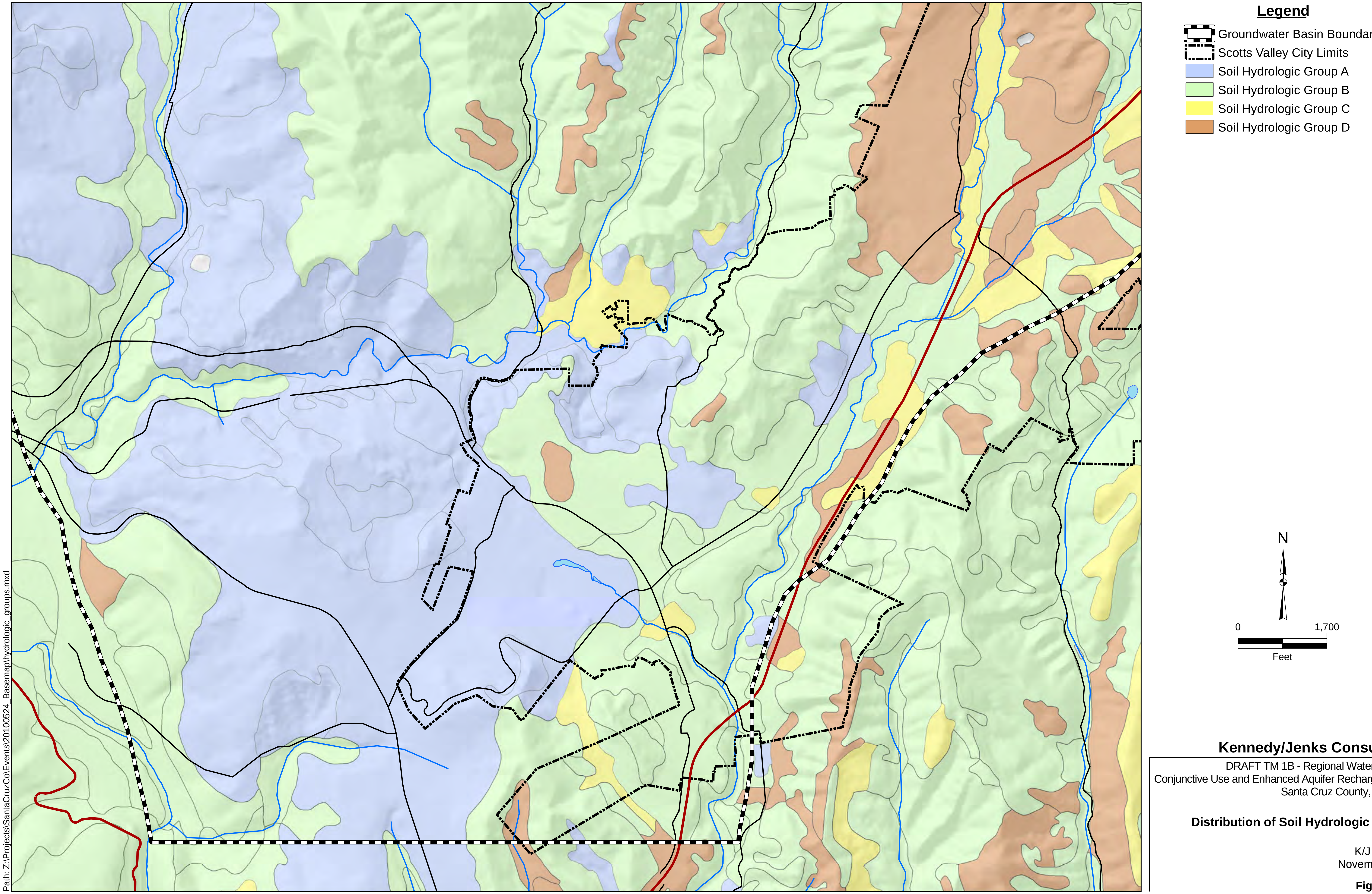

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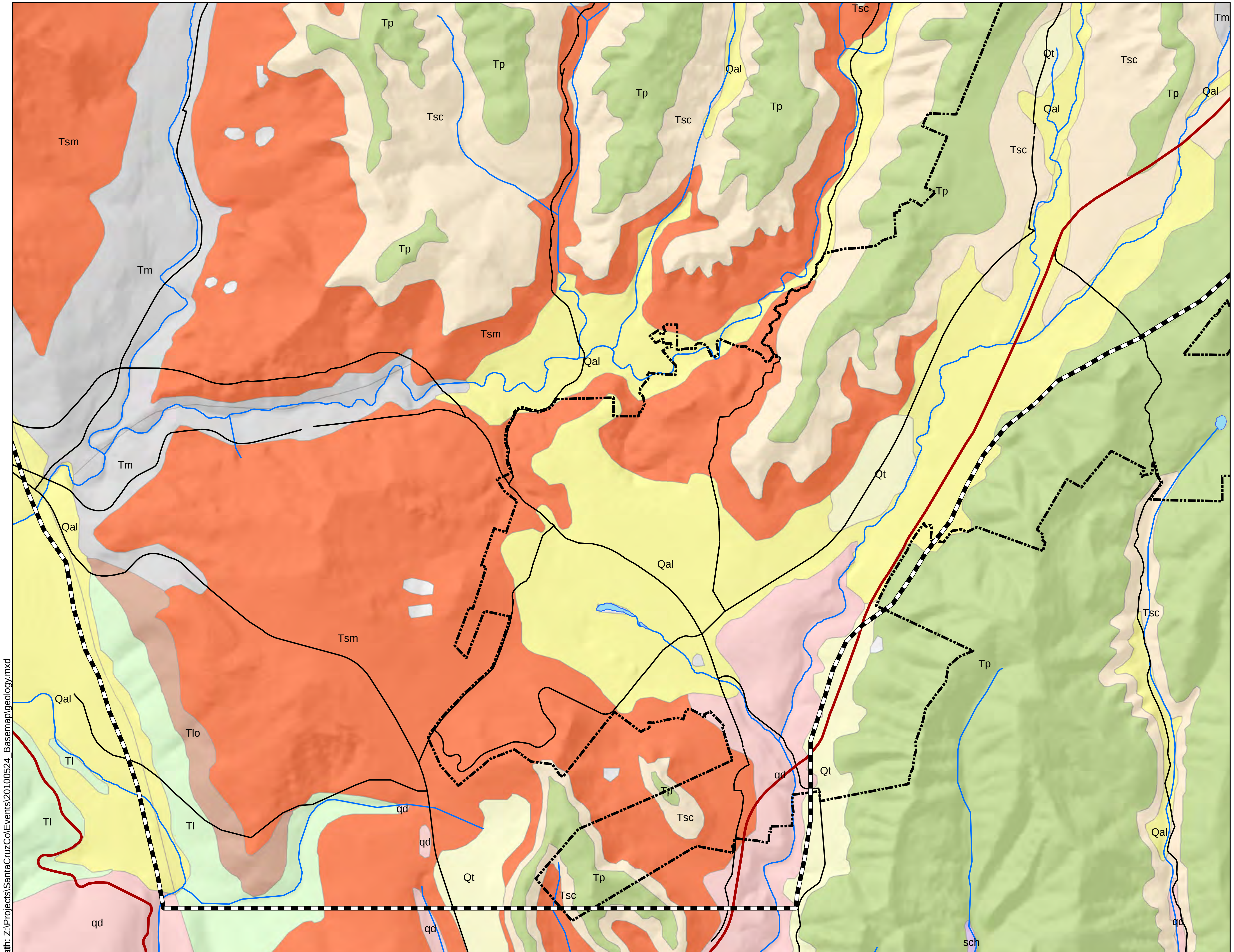
Conjunctive Use and Enhanced Aquifer Recharge Project
Santa Cruz County, California

Distribution of Soil Hydrologic Groups

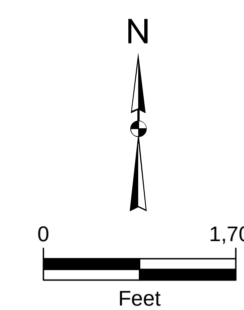
K/J 0864005
November 2010

Figure 1B-2



Legend

- Groundwater Basin Boundary
- Scotts Valley City Limits
- Alluvium
- Purisima
- Marine Terrace
- Santa Cruz Mudstone/Purisima
- Santa Margarita
- Monterey
- Lompico
- Zayante
- Butano
- Locatelli
- Granite
- Metasedimentary



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Conjunctive Use and Enhanced Aquifer Recharge Project
Santa Cruz County, California

Geologic Map for Conjunctive Use Project Study Area

K/J 0864005
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Figure 1B-3

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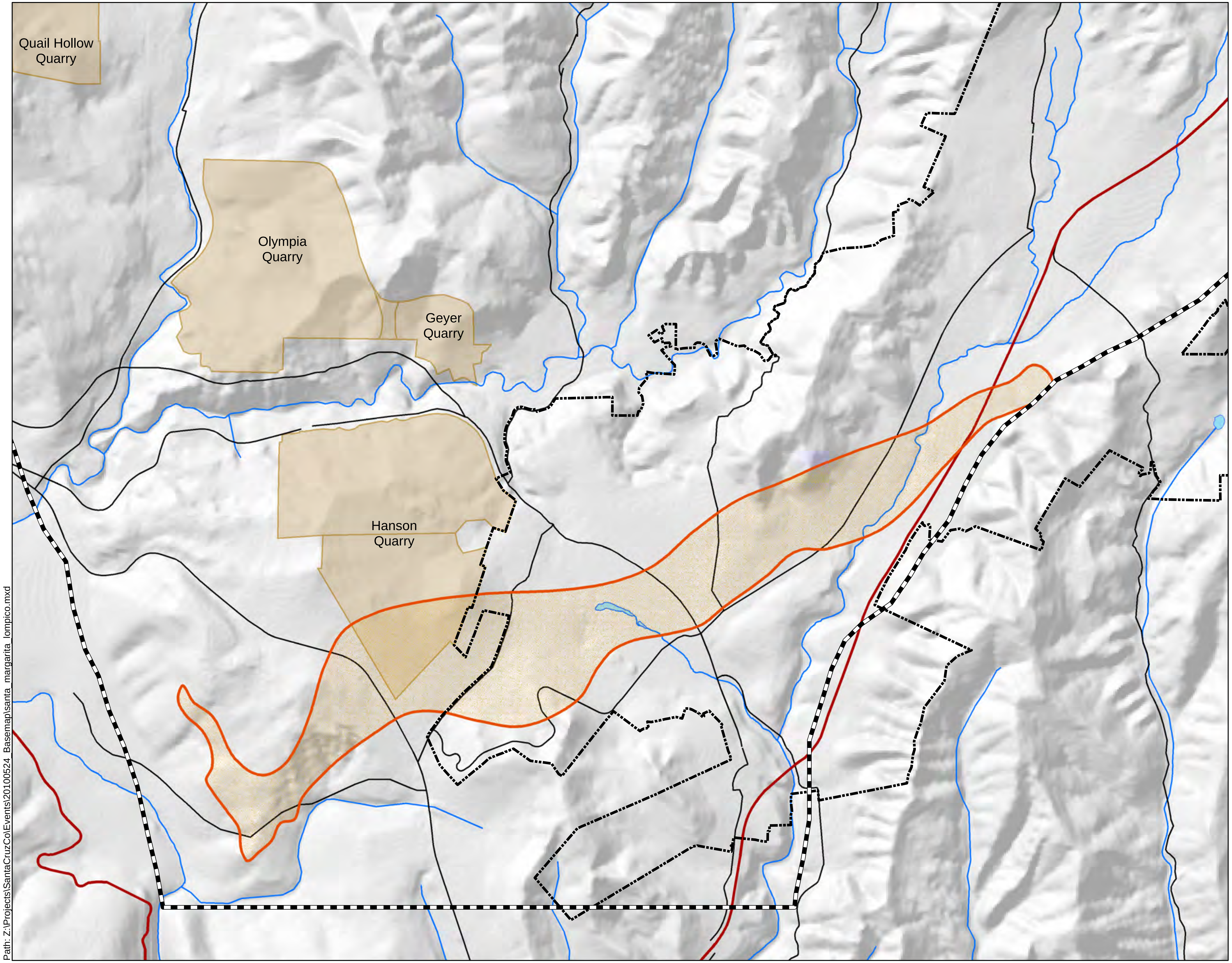

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Legend

- Groundwater Basin Boundary
- Scotts Valley City Limits
- Quarry
- Location of Direct Contact Between the Santa Margarita Sandstone and the Lompico Sandstone

N

0 1,700

Feet

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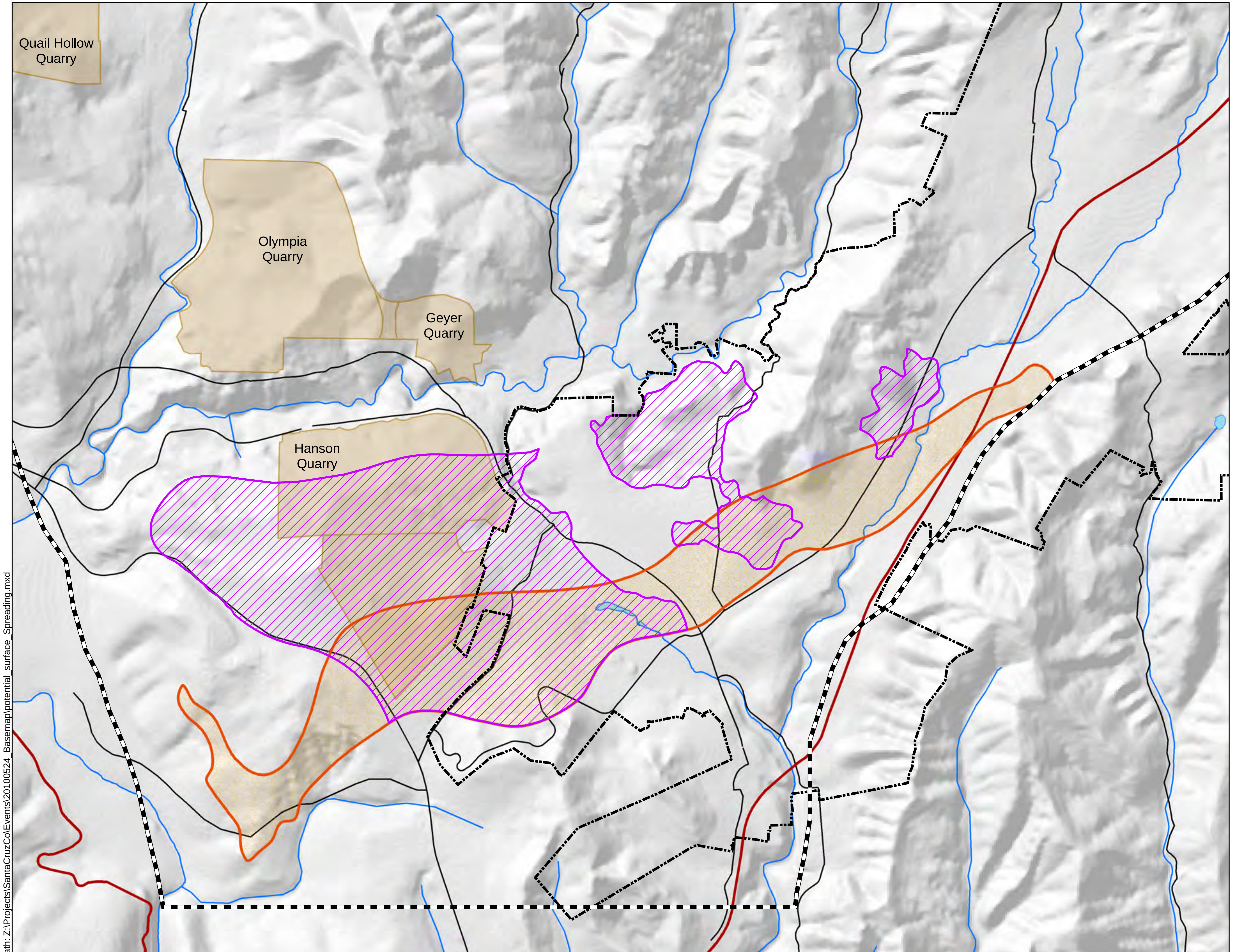
DRAFT TM 1B - Regional Water Demand
Conjunctive Use and Enhanced Aquifer Recharge Project
Santa Cruz County, California

Location of Direct Contact of Santa Margarita and Lampico Sandstones

K/J 0864005
November 2010

Figure 1B-4



Legend

- Groundwater Basin Boundary
- Scotts Valley City Limits
- Quarry
- Location of Direct Contact Between the Santa Margarita Sandstone and the Lompico Sandstone
- Area of Potentially Suitable for Large Scale Surface Spreading

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Conjunctive Use and Enhanced Aquifer Recharge Project
Santa Cruz County, California

Area Potentially Suitable for Large Scale Surface Spreading

K/J 0864005
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Figure 1B-5

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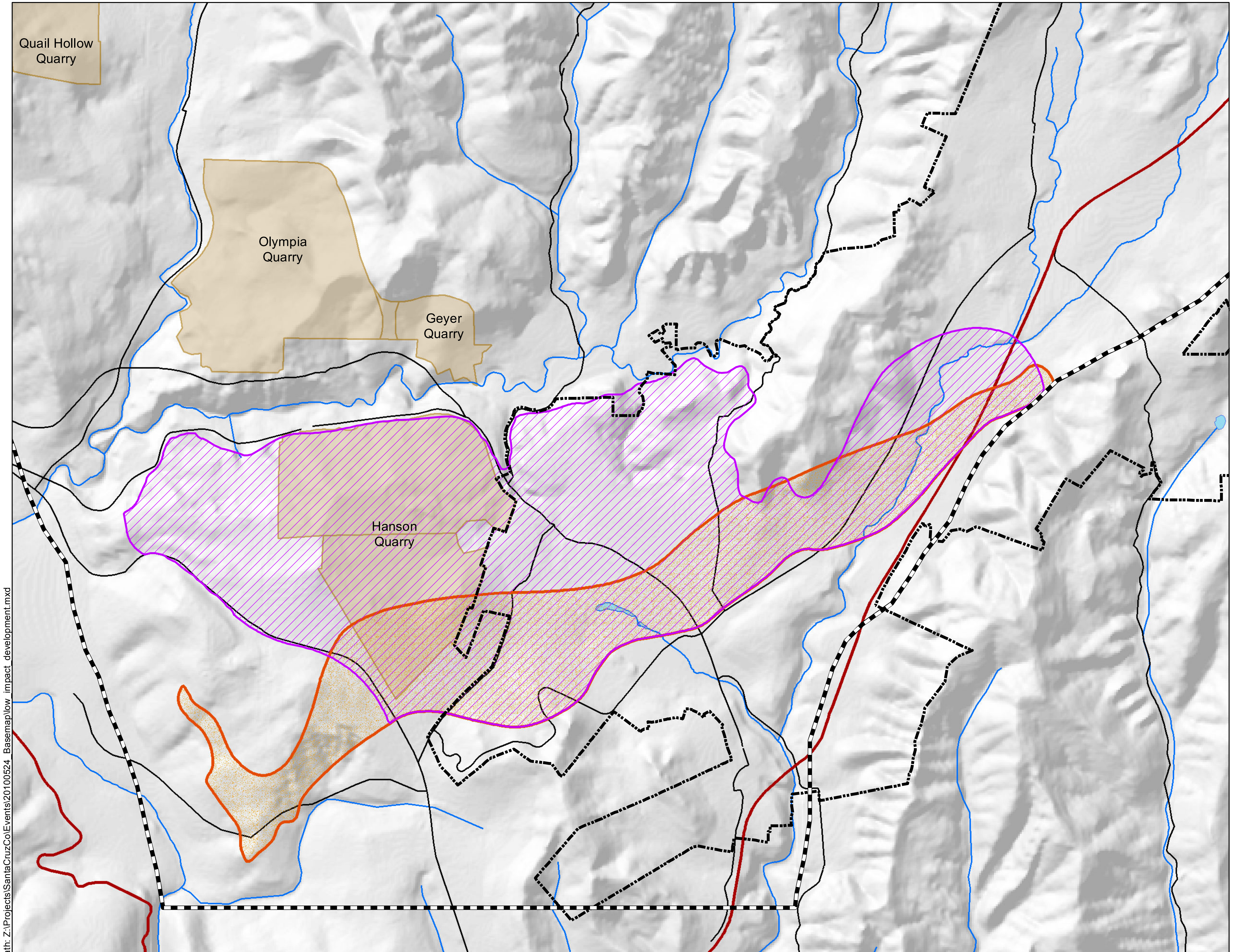

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Legend

- Groundwater Basin Boundary
- Scotts Valley City Limits
- Quarry
- Location of Direct Contact Between the Santa Margarita Sandstone and the Lompico Sandstone
- Area of Potentially Suitable for Low Impact Development for Aquifer Recharge

N

0 1,700

Feet

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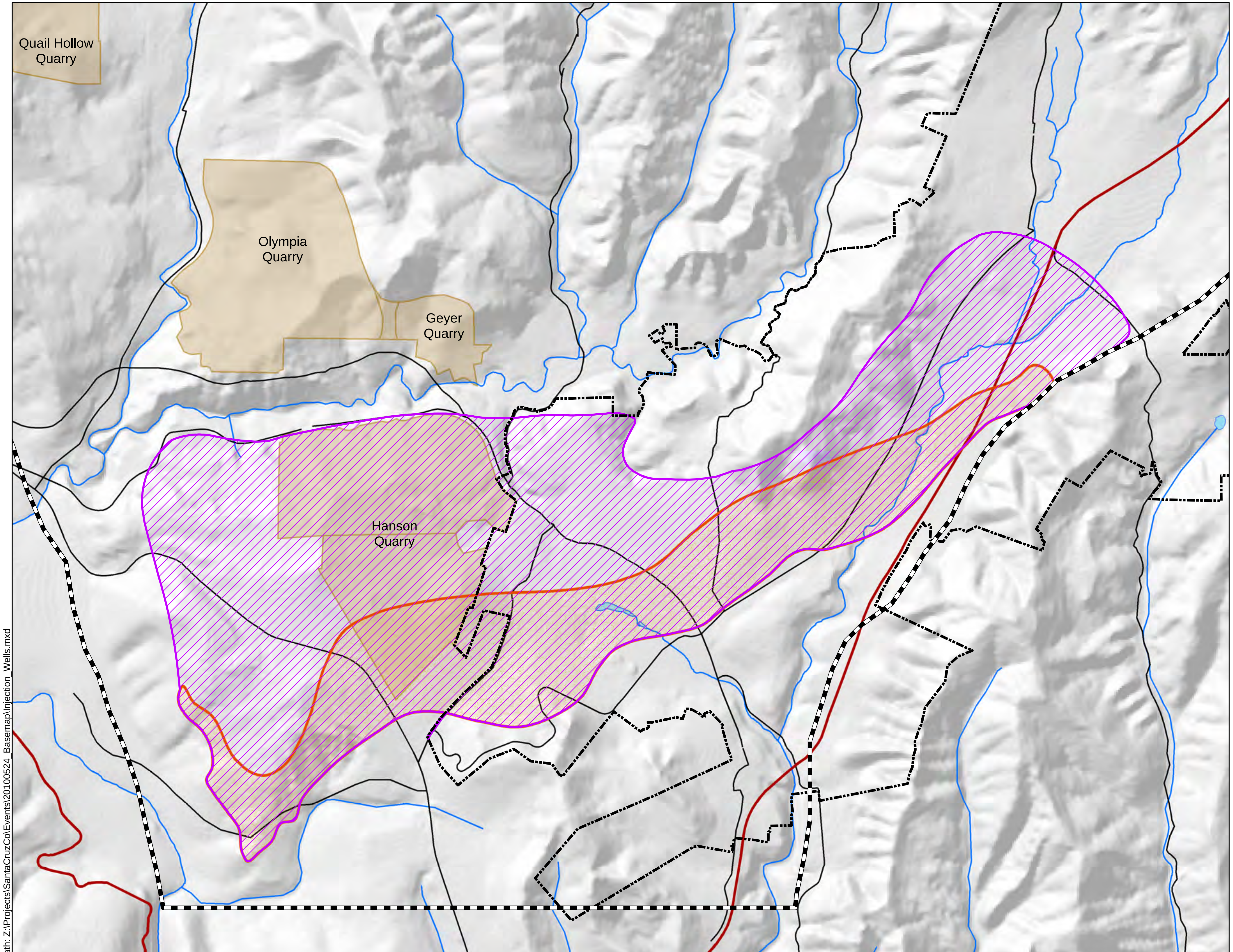
Conjunctive Use and Enhanced Aquifer Recharge Project
Santa Cruz County, California

Area Potentially Suitable for Low Impact Development

K/J 0864005
November 2010

Figure 1B-6



Legend

Groundwater Basin Boundary
Scotts Valley City Limits
Quarry
Location of Direct Contact Between the Santa Margarita Sandstone and the Lompico Sandstone
Area Potentially Suitable for Injection Wells

N

0 1,700
Feet

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Conjunctive Use and Enhanced Aquifer Recharge Project
Santa Cruz County, California

Area Potentially Suitable for Injection Wells

K/J 0864005
November 2010

Figure 1B-7

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