FINAL
Groundwater Assessment, and Indirect Potable Reuse Feasibility Evaluation and Implementation Strategy

Northwest County Recycled Water Strategic Plan

November 2018

Prepared for:
City of Palo Alto
and
Santa Clara Valley Water District

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Appendix A Pumping Test Analyses

List of Acronyms

AF acre-feet
AFY acre-feet per year
AG agriculture
ABAG Association of Bay Area Governments
Bay San Francisco Bay
BAWSCA Bay Area Water Supply and Conservation Agency
CaCO$_3$ calcium carbonate
CECs Constituents of Emerging Concern
CEQA California Environmental Quality Act
CIMIS California Irrigation Management Information System
cis-1,2-DCE cis-1,2-dichloroethene
cfs cubic feet per second
City City of Palo Alto
COE California-Olive-Emerson
County DEH Santa Clara County Environmental Health Services
1,1-DCE 1,1-dichloroethene
DDW State Water Resources Control Board, Division of Drinking Water
District Santa Clara Valley Water District
DO domestic
DTSC California Department of Toxic Substances Control
DWR California Department of Water Resources
DWSAP Drinking Water Source Assessment Program
EDB ethylene dibromide
EOS European Observation Satellites
ET evapotranspiration
ET$_0$ reference evapotranspiration
FAT full advanced treatment
ft-bgs feet below ground surface
ft/ft foot per foot
ft-msl feet mean sea level
ft/d feet per day
ft$^2$/d square feet per day
GAMA Groundwater Ambient Monitoring and Assessment Program
GIS Geographical Information System
gpm  gallons per minute
gpm/ft  gallons per minute per foot
GWMP  Groundwater Management Plan
GWR  Groundwater Recharge with Recycled Water
Δh/Δl  hydraulic gradient: change in head divided by change in length
HP  Hewlett-Packard
in/yr  inches per year
InSAR  Interferometric Synthetic Aperture Radar
IPR  Indirect Potable Reuse
K  hydraulic conductivity
Kz  vertical hydraulic conductivity
LUST  leaking underground storage tank
MI  municipal/industrial
mg  million gallons
mgd  million gallons per day
mg/L  milligrams per liter
mi²  square miles
MCL  maximum contaminant level
mm  millimeter
MTBE  methyl tertiary butyl ether
n  effective porosity
N  nitrogen
NaCl  sodium chloride
NAD  North American Datum
NED  National Elevation Datum
NEPA  National Environmental Policy Act
NGVD 29  National Geodetic Vertical Datum of 1929
NOAA  National Oceanographic and Atmospheric Administration
NO₃  nitrate
NO₂  nitrite
NPDES  National Pollution Discharge Elimination System
NPL  National Priorities List
OEU  Oregon Expressway Underpass
O&M  Operations and Maintenance
PCE  tetrachloroethene
RRT  Response Retention Time
RWQCP  Regional Water Quality Control Plant
S  storativity
SFRWQCB  San Francisco Regional Water Quality Control Board
SFPUC  San Francisco Public Utilities Commission
SMCL  secondary maximum contaminant level
SNMP  Salt and Nutrient Management Plan
SVCW  Silicon Valley Clean Water
SVE  soil vapor extraction
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<td>SWRCB</td>
<td>State Water Resources Control Board</td>
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<tr>
<td>1,1,1-TCA</td>
<td>1,1,1-trichloroethane</td>
</tr>
<tr>
<td>TCE</td>
<td>trichloroethene</td>
</tr>
<tr>
<td>TDS</td>
<td>total dissolved solids</td>
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<td>TOC</td>
<td>total organic carbon</td>
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<tr>
<td>Todd</td>
<td>Todd Groundwater</td>
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<td>Todd/WC</td>
<td>Todd Groundwater and Woodard and Curran</td>
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<tr>
<td>µg/L</td>
<td>micrograms per liter</td>
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<tr>
<td>UIC</td>
<td>underground injection control</td>
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<tr>
<td>USEPA</td>
<td>United States Environmental Protection Agency</td>
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<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
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<tr>
<td>UST</td>
<td>underground storage tank</td>
</tr>
<tr>
<td>UWMP</td>
<td>Urban Water Management Plan</td>
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<tr>
<td>v</td>
<td>average linear velocity</td>
</tr>
<tr>
<td>VC</td>
<td>vinyl chloride</td>
</tr>
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<td>VOCs</td>
<td>volatile organic compounds</td>
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1 EXECUTIVE SUMMARY

The City of Palo Alto (City) owns and operates the Regional Water Quality Control Plant (RWQCP) providing wastewater treatment to the communities of East Palo Alto Sanitary District, Palo Alto, Mountain View, Los Altos, Los Altos Hills, and the Stanford University campus. The City, in collaboration with Santa Clara Valley Water District (District), is sponsoring various recycled water preliminary planning studies culminating in the Northwest County Recycled Water Strategic Plan. The feasibility of indirect potable reuse (IPR) of fully advanced-treated recycled water (purified recycled water), as well as expanded non-potable uses, are being assessed as part of the plan. This report includes an assessment of increased groundwater pumping to meet various percentages of the City’s 2020 demand as well as a technical evaluation of IPR feasibility within the City; results from this report will subsequently be incorporated into the final Northwest County Recycled Water Strategic Plan.

This assessment included a characterization of the hydrogeologic conditions in the City and surrounding areas. An initial evaluation of the feasibility of increased pumping by the City was based on historical and contemporary groundwater balances for the Study Area. Subsequently, groundwater modeling was conducted to refine the estimate of groundwater yield available to the City with and without managed aquifer recharge with purified recycled water from the City’s RWQCP (i.e., IPR).

The hydrogeologic setting of the Study Area (including East Palo Alto, Palo Alto, Mountain View, Stanford University, and portions of Menlo Park, Los Altos, Los Altos Hills, Atherton and Redwood City) includes portions of the San Mateo Plain Subbasin and Santa Clara Subbasin. There is no hydrogeologic boundary between these subbasins, which are divided mostly along San Francisquito Creek; however, the boundary also corresponds to the boundary between Santa Clara County and San Mateo County, representing a jurisdictional boundary. The Study Area adjoins the Niles Cone Subbasin to the northeast. The Study Area transitions from unconfined groundwater conditions near the foothills to increasingly confined conditions near San Francisco Bay, where clay layers are more prevalent. Subsurface materials in the Study Areas are composed of heterogeneous units with complex inter-fingering of fine- and coarse-grained layers and lenses. As a result of aquifer heterogeneity, well yields and groundwater quality can vary significantly across the Study Area and with depth.

Groundwater levels and flow have changed significantly over the history of development of the area. Between the nineteenth century and the early 1960s, significant groundwater pumping, mostly by the City, reduced groundwater levels to almost 150 feet below sea level, resulting in land subsidence and a significant downward vertical gradient between shallow and deep aquifers. In 1962, the City switched its source of supply from groundwater to 100% Hetch-Hetchy (imported) water, and groundwater levels rapidly began recovering to pre-development levels. In addition, the District began imported water and treated water deliveries in the Santa Clara Subbasin in the mid/late 1960s, and District customers reduced their groundwater usage which also likely influenced groundwater level recovery in the Santa Clara Subbasin. Currently, many deep wells in the confined aquifer exhibit artesian conditions and the vertical gradient is upward from the deep to shallow aquifer.
Natural groundwater quality in the Study Area varies spatially and with depth. Shallow groundwater tends to be similar in composition to recharge water (surface water, precipitation, imported water). Deeper groundwater varies in composition as a result of contact and residence time with formation sediments. In general, groundwater tends to be somewhat hard (i.e., high in calcium carbonate) with levels of iron, manganese, and total dissolved solids that can exceed secondary maximum contaminant levels in some wells. Generally, groundwater in the area is acceptable for both potable and irrigation uses; however, consumers would likely find untreated/unblended groundwater to be less aesthetically desirable when compared with Hetch-Hetchy water.

Hyper-saline water in the shallow aquifer in the Palo Alto Baylands area also poses a threat to groundwater quality. High chloride concentrations are also found in some shallow and deep aquifer wells, which are the result of dissolution from marine deposits.

There are a number of environmental contamination sites including Superfund sites in the Study Area. While water quality impacts are limited to shallow depths where confining layers are present, some sites in the unconfined area show contamination to depths greater than 150 feet below ground surface (ft-bgs). Groundwater development and surface spreading operations might affect the migration and containment of contamination plumes. Two City emergency supply wells (Fernando and Matadero) are located in close proximity to a significant solvent contamination plume with low level contamination detected to a depth of about 100 ft-bgs.

A comprehensive water balance of the Study Area was prepared for this report. The water balance considered historical conditions and previously prepared water balances. All sources of inflow and outflow to and from the Study Area were quantified to provide a preliminary estimate of the potential yield available for City pumping. Two methods were applied to estimate available yield from the water balance information. One estimate assumed that some of the groundwater outflows to sewers, creeks, storm drains, tidal marshes, San Francisco Bay and Niles Cone could be captured by increased pumping without creating undesirable results. Only a portion of the potential yield can be so captured, but the estimate provides a maximum value for preliminary discussion purposes. Those outflows were estimated to total 8,700 AFY. In fact, Palo Alto could pump only a portion of the estimated total yield because some outflow—perhaps one-third of the existing outflow—is required for habitat protection and to prevent saline intrusion. In addition, some yield might need to be reserved for potential increased pumping by other purveyors in the Study Area. For preliminary planning purposes, it was assumed that one-half of the yield available for pumping would be available to the City, or about 2,900 AFY. This amounts to about 24% of the City’s projected 2020 demand.

A groundwater flow model originally developed for a District study of IPR feasibility in the San Jose-Santa Clara area was refined and recalibrated for evaluating IPR feasibility in the Study Area. The model was used to assess the technical feasibility of various combinations of City pumping and IPR recharge. The model was used to assess the level of City pumping that could be developed without negative impacts, assuming no IPR. The model-determined level of pumping was 3,000 AFY, which compared well with the 2,900 AFY estimated with the water balance method.
General areas where surface spreading or injection of purified recycled water could occur based on hydrogeologic and regulatory considerations were developed. Due to the large land area required for recharge by surface spreading and the lack of suitable undeveloped sites, surface spreading was deemed infeasible and dropped from further evaluation. Preliminary general locations for injection wells were identified based on proximity to existing City supply wells.

Initially, five injection and City pumping scenarios were developed for feasibility evaluation. Modeling was used to refine these general scenarios to specific pumping and injection locations and volumes as summarized in Table ES-1.

Impacts criteria were developed to assess the feasibility of each scenario. Feasibility is based on evaluation of potential negative impacts related to aquifers and does not address costs. The quantitative criteria address the potential for saline water intrusion from the Bay, subsidence, stream flow depletion, and impacts to other nearby pumping wells due to lowered water levels. Potential raising of shallow groundwater was also considered; however, because injection will not occur in the shallow aquifer, no negative impacts are expected. Injection wells are located in the confined portion of the Study Area limiting the potential for injected purified recycled water to migrate to the shallow aquifer. Groundwater modeling was applied to simulate groundwater levels and stream flow to assess the feasibility of each scenario with findings presented in Table ES-1.

**Scenario 4** was selected to be carried forward for development of an implementation strategy. Scenario 4 was selected because the purified water delivery volume was deemed conservative and achievable while still providing a substantial volume for use, the injection wells are all located within City limits, costs for conveyance are lower compared with Scenario 2, it is technically feasible with no projected adverse impacts and more likely to be implemented compared with Scenario 2. The implementation strategy included identification of permitting, California Environmental Quality Act (CEQA), and regulatory requirements and costs for implementation. Capital costs for facilities needed to implement Scenario 4 are estimated to be $90.3 million with an annual operation and maintenance cost of $14.8 million, including District fees for extracting groundwater from the basin. Cost estimates reflect a Class 5 estimate as defined by the Association for the Advancement of Cost Engineering International (AACE) Recommended Practice No. 56R-08. Scenario 4 results will be incorporated into the Northwest County Recycled Water Strategic Plan for evaluation amongst other future water reuse expansion opportunities.
| Scenario No. | Description | City Pumping Volume (AFY) | Indirect Potable Reuse (IPR) Injection Volume (AFY) | Criteria 1 - Saline Intrusion: 12-year running average groundwater levels is not more than 10 feet below sea level | Criteria 2 - Saline Intrusion: Groundwater levels at locations between pumping well and the Bay are above sea level throughout period when water levels in pumping well are below sea level | Criteria 3 - Subsidence: Sustained (12-year) groundwater elevations are greater than -40 feet mean sea level | Criteria 4 - Streamflow Depletion: Streamflow depletion is <1 cubic foot per second and does not reduce steelhead passage opportunity by more than 10 percent in any 3-year period. | Criteria 5 - Impacts to Nearby Wells: Groundwater levels are not lowered to more than 70 feet below ground surface for more than 3 consecutive years. | Comments |
|-------------|-------------|--------------------------|-----------------------------------------------|------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0           | Baseline scenario. Goal is to model effects to the aquifer over the 30 year period from 2015-2044 at District-projected levels of pumping and recharge. | 0 | 0 | Yes | Yes | Yes | Yes | Yes | Yes |
| 1           | Preliminary yield estimate. Goal is to determine the operable City pumping over 30 years without IPR. This scenario is meant to refine the preliminary operable yield estimate of 3,900 AFY determined in the groundwater assessment. | 3,000 | 0 | Yes | Yes | Yes | Yes | Yes | Feasible |
| 2           | Determine maximum operable yield with injection. Goal is to model groundwater augmentation with maximum potentially available purified water based on Palo Alto's existing recycled water allocation. This scenario will use 60% of the City's total projected 2020 water demand for the initial model run. | 7,200 | 5,600 | No | Yes | Yes | Yes | Yes | Generally feasible, recommend monitoring to confirm modeled groundwater levels |
| 3           | Realistic near-term scenario. Goal is to model using El Camino Park Well only to supply 20% of the City's projected 2020 water demand, and determine if IPR is needed to support this scenario. El Camino Park Well is technically the most feasible location for long-term groundwater production due to available storage, blending facilities, and space for treatment. | 2,400 | 0 | No | Yes | Yes | Yes | Yes | Generally feasible, recommend monitoring to confirm modeled groundwater levels |
| 4           | Reduced IPR. Goal is to model injection at a reduced level and at fewer locations to determine the operable City pumping level with 2,800 AFY injection. This scenario will use 40% of the City's projected 2020 water demand for the initial model run. | 5,900 | 2,800 | Yes | Yes | Yes | Yes | Yes | Feasible, carry this selected scenario forward for travel time modeling |
| 5           | 100% Demand. Goal is to model complete City dependence on groundwater and to determine the IPR volume needed to support this scenario. Pumping is set at 100% of the City's projected 2020 demand. | 12,000 | 8,400 | No | No | No | No | Yes | Infeasible, would need more than 8,400 AFY of injection |

**AFY** Acre-feet per year

- a Pumping volumes are in addition to the study area outputs determined in the Groundwater Assessment, such as groundwater supply pumping and construction dewatering
- b Total projected 2020 water demand for Palo Alto is 12,000 acre feet based on the City's Urban Water Master Plan
- c IPR = Indirect potable reuse; groundwater augmentation with purified water (highly treated wastewater) via injection wells
- * Matadero and Fernando wells are not considered in Scenarios 2 through 5 due to their proximity to known groundwater contamination, distance from injection wells, and ability of remaining wells to provide needed capacity

**Criteria**

- **1 - Saline Intrusion:** 12-year running average groundwater levels is not more than 10 feet below sea level
- **2 - Saline Intrusion:** Groundwater levels at locations between pumping well and the Bay are above sea level throughout period when water levels in pumping well are below sea level
- **3 - Subsidence:** Sustained (12-year) groundwater elevations are greater than -40 feet mean sea level
- **4 - Streamflow Depletion:** Streamflow depletion is <1 cubic foot per second and does not reduce steelhead passage opportunity by more than 10 percent in any 3-year period.
- **5 - Impacts to Nearby Wells:** Groundwater levels are not lowered to more than 70 feet below ground surface for more than 3 consecutive years.
Recommended Actions Prior to Future Implementation of IPR

- If the City moves forward with IPR, additional site-specific studies should be conducted to refine recharge scenarios to better assess recharge rates, number of injection wells, refined parcel injection well sites; identify required monitoring well locations; determine potential for dissolution of naturally-occurring constituents; and determine overall project costs.

- Once accurate injection well locations are identified, it is recommended that the District review other databases to more accurately define groundwater use category and status of nearby existing wells. Well owners should be contacted to confirm the uses for the pumped groundwater. If domestic potable supply wells are found to be located within the RRT, the injection wells could be re-located or negotiations undertaken to destroy the domestic well.

- Once accurate injection well locations are identified and RRT confirmed or modified, groundwater modeling should be conducted to verify adequate subsurface residence time to meet regulatory requirements.

- The City/District should begin a process of information exchange with the DDW and SFRWQCB regarding IPR plans.

- DWSAP reports should be conducted for each planned pumping well to assess potential local environmental contamination sources.

- It is recommended that if Scenario 3 – pumping the El Camino Park Well at 2,400 AFY with no IPR – is implemented, that a sentry well be installed between the well and the Bay or an existing well(s) be identified to monitor for potential saline water intrusion.

- If IPR is implemented, the City should resample for a complete suite of water quality constituents in all City wells pumped prior to IPR implementation.

- An updated review of environmental site contamination should be performed prior to IPR implementation.

Several recommendations are made to improve hydrogeologic understanding in the Study Area including recommendations to refine information of groundwater levels & flow, aquifer parameters, ambient groundwater quality, environmental release site contamination, shallow saline water intrusion and sea level rise, subsidence, and production wells.
2 INTRODUCTION

The City of Palo Alto (City) owns and operates the Regional Water Quality Control Plant (RWQCP) providing wastewater treatment for the communities of East Palo Alto Sanitary District, Palo Alto, Mountain View, Los Altos, Los Altos Hills, and the Stanford University campus. The City in collaboration with Santa Clara Valley Water District (District) is sponsoring various recycled water preliminary planning studies culminating in the Northwest County Recycled Water Strategic Plan. The feasibility of recycled water direct and indirect potable reuse (as well as expanded non-potable uses) are being assessed as part of the plan.

One component of that work is an assessment of potential increased groundwater pumping by the City. Currently, the City typically receives 100% of its water supply from imported water purchased from the San Francisco Public Utilities Commission (SFPUC), which is predominantly delivered through the Hetch-Hetchy aqueduct system. In addition, the City has eight groundwater wells and a 2.5 million gallon (mg) underground water reservoir and pump station to meet emergency water supply and storage needs. While SFPUC supplies are adequate in normal years and better quality than groundwater, they are inadequate during drought years. Groundwater supplies are also stressed during drought periods. Moreover, circumstances could change in the future such that increased reliance on groundwater supplies might be warranted. Accordingly, the City wishes to evaluate the feasibility of increasing groundwater pumping by the City.

The feasibility and potential impacts of increased pumping and Indirect Potable Reuse (IPR) scenarios were evaluated through application of a groundwater flow model. One scenario was selected for development of an implementation strategy and subsequent inclusion into the final Northwest County Recycled Water Strategic Plan.

2.1 Study Objectives

The objective of the Northwest County IPR Feasibility Study is to compile and analyze baseline information on the current condition of groundwater resources in northwestern Santa Clara County and adjacent areas, including sources and quantities of recharge, groundwater pumping, and water quality. This information is used to evaluate whether increased groundwater utilization by the City is viable, and if so, to evaluate the feasibility of IPR of purified recycled water. IPR typically involves surface spreading basins or subsurface injection wells.

The Groundwater Use Assessment is a subtask of the Northwest County IPR Feasibility Study focused on assessment of increased groundwater use by the City to meet various percentages of its water demand and identification of the infrastructure needed to meet demands at each level. The potential adverse impacts of increased pumping are assessed including excessive drawdown in nearby wells, land subsidence, saline water intrusion, depletion of surface water, regional groundwater overdraft (including adverse effects on adjacent subbasins), and migration of environmental contaminants into supply wells. A detailed groundwater water balance was prepared to support the feasibility assessment of increased pumping. This
assessment also included characterization of hydrogeologic conditions with a critical reexamination of the existing hydrogeologic conceptualization.

A feasibility evaluation was conducted to assess five increased City pumping/IPR scenarios through use of a refined and recalibrated groundwater flow model of the local Study Area. Criteria were developed to assess the feasibility of each scenario and one scenario was selected for development of an implementation strategy. The implementation strategy describes the requirements for permitting, CEQA, and regulatory compliance; and estimated costs for implementation.
3 GROUNDWATER USE ASSESSMENT

3.1 Palo Alto Emergency Supply Wells

The City owns eight emergency supply wells including Hale, Rinconada, Peers Park, Fernando, Matadero, Eleanor Pardee, Main Library, and El Camino Park. Five are older wells constructed in the 1950s and three are newer wells constructed between 2009 and 2013. Table 3-1 provides the well construction and performance information. All of the wells are screened in both the shallow aquifer (less than 200 ft below ground surface [bgs]) and deep aquifer (greater than 200 ft-bgs). The well capacities vary from 600 to 3,300 gallons per minute (gpm), which is consistent with observed variability in aquifer properties. The total capacity of all wells is 11,300 gpm or 18,227 acre-feet per year (AFY), which is more than the City’s water demand projection for 2020 of 12,000 acre-feet (AF). The City’s demand projections decrease after 2020 to 11,000 AF in 2040 (SCVWD, 2016a). Therefore, in order, for example, to meet 25, 50, or 100% of the City’s 2020 demand, groundwater would need to provide 3,000, 6,000, or 12,000 AFY, respectively.

3.2 Hydrogeologic Conceptual Model

3.2.1 Hydrogeologic Study Area

To support groundwater flow modeling, the hydrogeologic study area (Study Area) needs to be large enough to account for modeled inflows and outflows and potential boundary effects. Therefore, the Study Area includes East Palo Alto and portions of the cities of Menlo Park, Atherton and Redwood City in the San Mateo Plain Groundwater Subbasin as well as Mountain View and the Stanford University campus and portions of the cities of Palo Alto, Los Altos and Los Altos Hills in the Santa Clara Subbasin. This 93-square-mile area was defined so that groundwater modeling can simulate increased pumping in these areas and potential impacts on those areas of increased pumping by the City. The Study Area also extends offshore in order to simulate the influence of seawater level rise and aquifer system inflows and outflows from and to San Francisco Bay (Bay), and to consider interactions with Niles Cone Subbasin. In addition, for purposes of the water balance estimates, hydrogeologic conditions in the creek upland watersheds may be considered for ungaged creeks although these areas are not within the groundwater flow model domain. Figure 3-1 shows the Study Area, the RWQCP service area, and the upland watershed area, while the inset map shows the Department of Water Resources (DWR) defined subbasins including the Santa Clara, San Mateo Plain, Niles Cone, and East Bay Plain subbasins of the greater Santa Clara Valley Basin. The Study Area includes portions of the Santa Clara and San Mateo Plain Subbasins; the boundary between the two subbasins is not a hydrogeologic boundary and groundwater can flow between the two subbasins.
### Table 3-1  City of Palo Alto Emergency Supply Well Construction and Performance Information

<table>
<thead>
<tr>
<th>Well</th>
<th>Hale</th>
<th>Rinconada</th>
<th>Peers Park</th>
<th>Fernando</th>
<th>Matadero</th>
<th>El Camino Park</th>
<th>Eleanor Pardee</th>
<th>Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling Method</td>
<td>Rotary</td>
<td>Rotary</td>
<td>Rotary</td>
<td>Rotary</td>
<td>Rotary</td>
<td>Rotary</td>
<td>Rotary</td>
<td>Rotary</td>
</tr>
<tr>
<td>Casing Diameter (in)</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Total Depth Drilled (ft-bgs)</td>
<td>935</td>
<td>1,080</td>
<td>950</td>
<td>1,179</td>
<td>1,186</td>
<td>500</td>
<td>460</td>
<td>545</td>
</tr>
<tr>
<td>Bedrock Encountered (ft-bgs)</td>
<td>927</td>
<td>895</td>
<td>NE</td>
<td>1,178</td>
<td>1,066</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>Casing Depth (ft)</td>
<td>840</td>
<td>540 (^a)</td>
<td>850</td>
<td>1,020</td>
<td>1,066</td>
<td>290</td>
<td>440</td>
<td>525</td>
</tr>
<tr>
<td>Seal Depth (ft-bgs)</td>
<td>100</td>
<td>140</td>
<td>102</td>
<td>91</td>
<td>60</td>
<td>145</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Filter Pack Interval (ft-bgs)</td>
<td>100-840</td>
<td>140-540</td>
<td>102-850</td>
<td>91-1,020</td>
<td>60-1,066</td>
<td>145-290</td>
<td>150-440</td>
<td>150-525</td>
</tr>
<tr>
<td>Screen Interval(s) (ft-bgs)</td>
<td>multiple intervals between 108 and 828</td>
<td>multiple intervals between 150 to 890; 150 to 540 after backfilling</td>
<td>150-320</td>
<td>350-845</td>
<td>NA presumed to be 100-1,020</td>
<td>142-1,066</td>
<td>152-174</td>
<td>204-280</td>
</tr>
<tr>
<td>Specific Capacity (gpm/ft)</td>
<td>10.5</td>
<td>24.4</td>
<td>12.0</td>
<td>2.8</td>
<td>3.2</td>
<td>51.1</td>
<td>5.9</td>
<td>2.1</td>
</tr>
<tr>
<td>Well Capacity (gpm)</td>
<td>1,450</td>
<td>3,300</td>
<td>1,700</td>
<td>700</td>
<td>700</td>
<td>1,850</td>
<td>1,000</td>
<td>600</td>
</tr>
</tbody>
</table>

\(^a\) - Rinconada casing original depth 900 feet, but reported backfilled to 540 ft

ft - feet
in - inches
bgs - below ground surface
gpm - gallons per minute
gpm/ft - gallons per minute per foot of drawdown

NA - information not available
NE - not encountered
S - shallow aquifer (less than 200 ft-bgs)
D - deep aquifer (greater than 200 ft-bgs)
3.2.2 Topography and Natural Features

The Santa Clara Valley Basin, which includes the Santa Clara, San Mateo Plain, East Bay Plain, and Niles Cone Subbasins, occupies an elongated trough between the Diablo Range on the east and the Santa Cruz Mountains on the west. The valley and upland areas trend in southeast-northwest directions.

The local Study Area is located along the eastern edge of the San Francisco Peninsula between San Francisco Bay and the Santa Cruz Mountains. The Santa Clara and San Mateo Subbasins consists of semi-consolidated sediments of the Santa Clara Formation along the subbasin edges and unconsolidated alluvial/fluvial sediments underneath a northeastward sloping plain. A broad band of flat intertidal marshland is present along the Bay Shore, reflecting the gradual rise in sea level since the last ice age. To the southwest of the groundwater subbasins, bedrock hills of the Santa Cruz Mountains ascend to the west.

All surface features visible today in the groundwater subbasins are the result of active stream erosion and deposition. The streams have deposited debris as alluvial fans and outwash plains. The most prominent alluvial fan in the Study Area was deposited by San Francisquito Creek and is referred to as the San Francisquito Cone.

The easternmost ridge of the Coast Ranges follows the east side of the San Andreas Fault and has crest elevations generally 500-700 feet above sea level (ft-msl). In the Palo Alto area, the bedrock hills slope downward to the northeast. The alluvial subbasin slopes gently to the northeast from about 200 ft-msl at the base of the foothills to about 20 ft-msl near Highway 101.

3.2.3 Climate

The climate in the Study Area is Mediterranean, with wet winters and dry summers. Average annual precipitation increases from about 14 inches per year (in/yr) at the Bay shoreline to about 42 in/yr along the crest of the main Coast Range ridge. Figure 3-2 is an isohyetal map showing contours of average annual precipitation (Rantz, 1971). Two other isohyetal maps were reviewed for this study (Rantz, 1969; SCVWD, 1989), and were less consistent with local rain gage data and less realistic in delineating the effect of mountains on rainfall distribution. Based on 85 years of precipitation records from Redwood City, the lowest annual rainfall during the period from 1931 to 2016 was 7.28 inches in water year 1976, and the highest was 42.19 inches in 1983. A water year is the period from October 1 through September 30 of the following year. Precipitation in the Study Area falls almost exclusively as rain, and on average 85% of annual rainfall occurs during November through March.

Maximum air temperatures average 81 degrees Fahrenheit (°F) in July through August, and minimum air temperatures average 40°F in December through January. The diurnal temperature range is 19°F in mid-winter increasing to 25°F in mid-summer. Temperature is one of several factors that determine the evaporative demand and the consumptive use of water by plants for transpiration. Evapotranspiration (ET) is the variable that specifically indicates plant water requirements and is derived from solar radiation, air temperature, wind speed and relative humidity. Reference evapotranspiration (ET₀) is based on an extensive well-watered
turf. The California Irrigation Management Information System (CIMIS) operates several hundred climate stations throughout California and records daily $ET_0$ in an on-line database (http://wwwcimis.water.ca.gov/). $ET_0$ is one of the variables used in the water balance analysis for this study to simulate groundwater recharge and irrigation demand. By correlation with CIMIS stations in Fremont, Union City and San Jose, a complete record of daily $ET_0$ for water years 1987-2015 was constructed, which is representative of conditions in the Bay plain portion of the Study Area. The spatial pattern of $ET_0$ in the Study Area is complex because of cool marine air and fog west of the Coast Range ridge and a smaller marine influence near San Francisco Bay. The statewide map of $ET_0$ zones developed by CIMIS shows the Study Area in Zone 8 and higher elevations along the Coast Ranges in Zone 3. By using the ratios of average monthly $ET_0$ for the two zones, a daily time series of $ET_0$ in the upper elevations of the watersheds was developed.

### 3.2.4 Watersheds and Surface Water Features

The upland watersheds and creeks, channels, and arroyos draining the Study Area are shown in Figure 3-3. The watershed boundaries were delineated by the Oakland Museum of California (Sowers, 2004; Tillery et al., 2007). Many of the creek channels have been straightened and lined with concrete where they cross the groundwater subbasins, which limits the interaction of surface water and groundwater. Creeks draining the Study Area include, from southeast to northwest: Stevens Creek; Hale Creek, a tributary of Permanente Creek; Adobe Creek and its tributary Barron Creek, Matadero Creek, San Francisquito Creek; Atherton Channel (or Creek); and Redwood Creek and its tributary Arroyo Ojo de Agua. Creeks with natural unlined stretches that can potentially directly recharge the groundwater subbasins include Stevens, Permanente, Hale, Adobe, Barron, Matadero and San Francisquito Creek. Lake Lagunita on the Stanford campus has been a source of recharge to groundwater.

San Francisquito Creek has the largest watershed (45 square miles (mi$^2$)) of creeks draining the Study Area and is the only riparian, unchannelized urban creek on the south Peninsula (Rofougaran et al., 2005) and thus has environmental significance. It is a documented source of recharge to both shallow and deep aquifers (Metzger, 2002; Newhouse, 2004). Metzger estimated recharge to groundwater from the creek totaling about 950 AFY during an average year with the greatest losses between the San Mateo Drive bike path and Middlefield Road. Water quality data indicate that the creek receives urban runoff in its lower reaches. Surface water in the creek and shallow and upper deep groundwater near the creek in its upper reaches near the foothills have similar water quality indicating recharge from the creek. Along the lower stretches of the creek, groundwater quality in the shallow and deep aquifers shows greater differences due to more extensive clay layers separating the aquifers (Metzger, 2002). Flooding in the lower reaches of San Francisquito Creek has been a problem, and the flood of 1998 led to the formation of the San Francisquito Creek Joint Powers Authority, which is implementing measures to reduce flood damage (among other improvements).

The Baylands exist along the Bayfront between the lines of high and low tide. They are the lands touched by the tides, plus the lands that the tides would touch in the absence of any levees or other unnatural structures.
Larger man-made lakes in the Study Area include Lake Lagunita and Shoreline Lake. Lake Lagunita on the Stanford Campus was created in the 1870s as a reservoir to provide irrigation for the Palo Alto Stock Farm. Stanford previously diverted water to Lake Lagunita for recreational purposes; however, since 2001 the University has filled the lake exclusively to support the well-being of the California tiger salamander population, an endangered species. While filled at its peak height, Lake Lagunita lost an estimated 500 gallons a minute (gpm) to percolation to groundwater (The Stanford Daily, 2012). These losses provide an indication of recharge potential within the alluvial recharge area of the Study Area.

### 3.2.5 Land Use

A map of Study Area land uses is shown as Figure 3-4. For the purpose of water balance analysis, land uses in the Study Area and tributary watershed areas were delineated on the basis of variables relevant to hydrology: impervious area, irrigated area, vegetation type, and the density of water and sewer pipe networks. Eleven land use categories were used: four types of natural cover (riparian, grassland, brush, and trees), three types of residential (rural, "typical" urban and "lush" - the latter classification includes larger lots and more irrigation), large irrigated turf areas (golf courses, cemeteries and some parks), commercial, industrial, and vacant. Delineation was accomplished through visual inspection of seamless, georeferenced high-resolution aerial imagery (National Agricultural Imagery Program, 2010). Supplemental corroboration of variations in impervious cover was obtained by comparing the photos with the 2011 National Land Cover Database raster image of percent impervious cover (Homer et al., 2015).

As shown on Figure 3-4, land use in the Study Area is almost entirely urban; the Study Area has been developed for many decades. Parts of the historical tidal marshes were diked, filled and converted to urban uses as early as 1873, which was the date of the earliest detailed and reliable topographic map (State Geological Survey of California, 1873). Even today, however, large areas remain as marshes or salt evaporation ponds. Residential land uses extend westward from the coastal plain into the uplands parts of the local watersheds.

**Figure 3-5** shows the city boundaries within the Hydrogeologic Study Area and RWQCP Service Area. The Study Area includes the cities of Mountain View and East Palo Alto; portions of the cities of Palo Alto, Menlo Park, Los Altos, Los Alto Hills, Redwood City, and Atherton; some unincorporated areas; Stanford University, and part of the Moffett Federal Airfield.

### 3.2.6 Geology

#### 3.2.6.1 Structural Setting

The Study Area and upland contributing watersheds are located in the Coast Range Physiographic Province, a region characterized by northwest-trending faults, mountain ranges, and valleys. Lateral movement along the San Andreas, Hayward, and Calaveras faults and down warping of the area between the fault zones formed a structural trough occupied by the San Francisco Bay (DWR, 1967). During the Pleistocene, the San Francisco Bay depression became connected to the Pacific Ocean during four inter-glacial episodes. Sea level rise increased the base level of streams resulting in deposition of silt and clay within the Bay. As sea level
declined, the base level fell and streams draining the mountains eroded channels into the silts and clays and laid down coarser material such as sands and gravels (Fio and Leighton, 1995).

**Figure 3-6** is a map of the geologic units present at the ground surface in the vicinity of the Study Area (Brabb, et al., 2000; California Department of Conservation, 2010) and **Figure 3-7** is a geologic explanation of the geologic units. Younger rocks of upper Pliocene and lower Pliocene Santa Clara Formation and overlying Pleistocene and Holocene age unconsolidated alluvial and fluvial deposits make up the groundwater subbasins. Bedrock crops out in the hills to the southwest of the subbasins and underlies the alluvial and fluvial deposits. The bedrock surface beneath the subbasin deposits has been mapped based on well logs and geophysical studies (Oliver, 1980; Wentworth et al., 2015) as shown in **Figure 3-8**. The thickness of subbasin deposits generally increases to the southeast along the Peninsula from about 100 feet under Sequoia High School in Redwood City to more than 700 feet at the USGS Leland well in Menlo Park to more than 1,100 feet at the City’s Fernando and Matadero wells. Other well logs indicate the depth to bedrock beneath the Stanford Campus is greater than 600 feet, more than 500 feet near the City’s Main Library well, greater than 900 feet at the Hale well and near the Eleanor Pardee well, greater than 950 feet at the Peers Park well, and more than 1,000 feet at the City’s Rinconada well. The bedrock surface dips more steeply near the base of the foothills. There is a 700 to more than 900-feet of alluvium in a trough in the bedrock surface beneath San Francisquito Creek. The trough is interpreted as either erosion of a stream that predates recent alluvial fan deposition or a fault-related structural low (Oliver, 1990). The maximum depths of alluvial deposits in the Santa Clara Valley are in excess of 1,500 feet. There is also a trough in the bedrock running east and roughly perpendicular to the creek.

**Figure 3-6** shows the Pulgas Fault running northwest to southeast crossing near the boundary between alluvial/fluvial deposits and bedrock in the Atherton, Menlo Park and Palo Alto area. The Pulgas Fault is the largest fault in the groundwater subbasin portion of the Study Area. It is a southwest-dipping reverse fault separating partly consolidated to consolidated bedrock assemblages (including the Santa Clara Formation) from the younger unconsolidated alluvium (Pampeyan, 1993). In the southern area of Palo Alto, another fault, referred to as the Hanover Fault by Pampeyan (1993) is mapped just northeast and parallel to the Pulgas Fault. The Pulgas Fault cuts the Santa Clara Formation with reported displacement of approximately 60 to 80 feet but no displacement of overlying alluvium (Brown and Caldwell, 1994). Brabb and Olsen (1986) reported that the Hanover Fault possibly also cuts Holocene alluvium.

Faults can form barriers or conduits affecting groundwater flow. Faulting in the Santa Clara Formation and alluvial recharge areas is a consideration in siting surface IPR recharge facilities. **Figure 3-9** shows the Pulgas and Hanover faults and other small mapped faults in the recharge area in the City of Palo Alto where surface recharge facilities could be sited. If the faults act as barriers to groundwater flow, surface recharge facilities southwest of the faults may not benefit the regional water supply aquifer leaving a relatively small area available to site surface recharge facilities northeast of the Hanover Fault. The existing groundwater level data are insufficient to show the potential influence of these two faults on groundwater flow in the areas where surface spreading is potentially possible (i.e., within the City boundaries in the recharge area). Where the Pulgas Fault crosses San Francisquito Creek, it separates partly consolidated and consolidated bedrock assemblages on the southwest from younger
unconsolidated alluvium on the northeast (Pampeyan, 1993). A series of five San Francisquito seepage runs conducted between April 1996 and May 1997 indicated that losses in San Francisquito Creek were negligible until it crossed the Pulgas Fault at Sand Hill Road. Therefore, the Pulgas Fault may impede subsurface flow between the foothills and the alluvial fan in this area (Metzger, 2002). Further to the southeast, where the fault crosses the Santa Clara Formation, it offsets massively folded consolidated to semi-consolidated bedrock units. It is concluded that the Pulgas Fault is likely a barrier to groundwater flow in this area and surface recharge facilities are not recommended southwest of the fault. Hydrogeologic cross sections presented in Section 3.2.7.1 show that the Hanover Fault only offsets alluvial beds at depth, and therefore, is not thought to be a barrier to groundwater flow in the upper aquifer, where surface recharge facilities would recharge the uppermost aquifer.

A complex thrust faulted area (Berrocol Fault) is shown in the uplands above the Santa Clara Formation (Figure 3-6). The San Andreas Fault represents the major fault system in the area with large late Tertiary right-lateral offsets. Based on geophysical work, Oliver (1990) suggested the possibility of two additional faults (not shown here): the Atherton Fault extending from Arroyo Ojo de Agua in Redwood City to San Francisquito Creek in Palo Alto and a northeast-southwest trending fault in the area of San Francisquito Creek (San Francisquito Fault), perpendicular to the dominant fault system orientation.

### 3.2.6.2 Geologic Units

The Santa Cruz Mountains located southwest of the subbasins are composed of older consolidated sedimentary and igneous rocks, where groundwater storage and flow are generally limited to fractures. Surface streams have flowed from the mountains and deposited sedimentary debris as alluvial fans and flood plains. These alluvial deposits compose the major aquifers of the region. Figure 3-6 shows the geologic units identified in the vicinity of the Study Area.

The bedrock formations within the Santa Cruz Mountain watersheds draining to the Study Area include several Cretaceous (around 65 to 140 million years) to Tertiary rock types, including mélange (predominantly greywacke sandstone, siltstone and shale), greenstone including altered basaltic rocks, greenish-grey to bluish-green serpentinite, and chert and shale. These formations have been lithified and altered over geologic time to the degree that they have very little original or primary porosity or permeability. However, secondary fractures in these rocks contain limited amounts of groundwater.

The principal groundwater-bearing formations of the subbasins are unconsolidated to semi-consolidated Quaternary-aged (less than 2 million years) alluvium composed of gravel, sand, silt and clay. The alluvium present within the Study Area originated primarily from erosion of the rocks in the Santa Cruz Mountains, and transportation of sediment via streams and deposition as alluvial/fluvial sedimentary deposits. Sediments from the East Bay (Niles Cone and Alameda Creek) have been transported and deposited beneath the Bay and possibly near the Study Area Bayfront and interfingered with sedimentary layers originating from the west, especially under San Francisco Bay. During the Pleistocene, rising and falling sea levels caused alternating
periods of continental (alluvial) and marine (bay) sediments, resulting in deposition of coarse- and fine-grained sediments.

The Quaternary alluvium formations mapped on Figure 3-6 represent the upper portions of the alluvial aquifer and roughly correspond to the basin boundaries (Figure 3-1). Groundwater is also present in the older Santa Clara Formation of Plio-Pleistocene age cropping out along the edge of the subbasins. Once thought to underlie much of the groundwater subbasins, recent studies conclude that the Santa Clara Formation is not present beneath the alluvial basin deposits (Hansen, 2015). The Santa Clara Formation is composed of poorly indurated conglomerate, massively-bedded sandstone, and mudstone. Iwamura (1980) characterized the Santa Clara Formation as non-water bearing and containing few aquifers and low flows while Fio and Leighton (1995) stated that the Santa Clara Formation in the upland area can be an important area for recharge to the deeper aquifers in the downslope valley areas. Characterizing the permeability of the Santa Clara Formation is important in assessing siting of surface recharge IPR facilities in this formation and is discussed in subsequent sections.

3.2.7 Hydrogeology

The Study Area subbasins cover approximately 76 square miles and are bounded by the Santa Cruz Mountains on the southwest, the remainder of the San Mateo Plain Subbasin (DWR basin number 2-9.03) on the northwest, the remainder of Santa Clara Subbasin (DWR basin number 2-9.02) to the southeast, and San Francisco Bay and the Niles Cone Subbasin (DWR basin number 2-9.01) on the northeast (see Figure 3-1). San Francisquito Creek forms most of the boundary between the San Mateo Plain Subbasin and the Santa Clara Subbasin.

There is no hydrogeologic separation between the San Mateo Plain and the Santa Clara Subbasins; groundwater may flow across this boundary based on recharge, pumping and groundwater flow patterns. The degree of hydraulic continuity between the San Mateo Plain and Santa Clara Subbasins and the Niles Cone Subbasin is less certain. DWR (1967) concluded that connectivity was indicated in the vicinity of the Dumbarton Bridge but not further south in the San Francisquito Cone area. Permeable aquifer zones in both the Study Area subbasins and Niles Cone Subbasin appear to thin as they approach the Study Area Bayfront, and some sand zones appear to pinch out near and beneath the Bay. This may indicate that the aquifer transmissivity and connectivity is limited to certain relatively thick and continuous aquifer zones. Some degree of connection was indicated based on the results of a pumping test conducted by DWR in 1963. During this test, wells located near the western landing of the Dumbarton Bridge were pumped at a combined rate of 580 gpm for a period of eight days, and drawdown of 3 feet was observed in a well located in the middle of the Bay (DWR, 1967). However, another pumping test conducted in the City’s Hale well in 1963 showed different results. The well was pumped at more than 1,000 gpm while drawdown effects were monitored in seven observation wells in the surrounding area. Because the extent of drawdown from the pumping well was not extensive, DWR concluded that groundwater conditions in the San Francisquito subarea are considerably less confined that those beneath San Francisco Bay in the Niles Cone. DWR (1967) also concluded based on the pumping test results in both the Niles Cone and the San Francisquito Cone areas, that below a depth of 180 feet there is little movement of ground water between the two subareas. The differing results of the two tests
suggest less connection between the subareas in the Palo Alto area than further north; this could reflect the high clay content of the distal ends of the respective alluvial fans.

The Santa Clara Subbasin portion of the Study Area is characterized as including an unconfined aquifer (or recharge area) system near the foothills and a shallow unconfined and deep confined (also referred to as pressure zone) system in the northeast where more extensive clay deposits form aquitards or confining layers. Figure 3-2 shows the Santa Clara Subbasin confined and recharge areas with different colors and stippling. The recharge area is comprised of the Santa Clara Formation and alluvial deposits (shown with different color stippling). The confined area is composed of alluvium. The boundary between confined and recharge areas in the San Mateo Plain Subbasin has not been defined in the literature, so the San Mateo Subbasin is shown by one color without differentiation of confined and recharge areas. The confined aquifers are overlain by relatively impervious strata and contain confined water exhibiting pressure characteristics (i.e., artesian water levels or water levels in or above the confining units). The aquifer systems are replenished by percolating rainfall, irrigation water, stream flow, surface water (lakes, ponds, and recharge basins), and sub-surface inflow. The recharge areas also supply inflow to the confined areas by underflow (SWRCB, 1955).

The State Water Resources Control Board (SWRCB, 1955) used several geologic and hydrogeologic criteria to delimit the boundary between confined and unconfined areas including patterns of groundwater level change, artesian conditions, and extent of subsidence. Currently groundwater flow within the Study Area is generally from southwest to northeast, from the edge of the Santa Cruz Mountains toward San Francisco Bay. Historically, during periods of high groundwater pumping and prior to the importation of water to the area, there was inland groundwater flow and ground subsidence associated with lowered groundwater levels. Groundwater is present in both the Santa Clara Formation and the Quaternary alluvial deposits, although Quaternary alluvium is the primary water bearing formation (DWR, 2004). In general, based on the depth to bedrock and the ground surface elevation, the alluvium is thinner near the foothills and thinner in the northwestern portion of the Study Area and thickens towards San Francisco Bay and to the southeast.

Various alluvial fan structures were deposited by streams draining the uplands. The most significant and most studied alluvial fan was deposited in the central area of the Study Area by San Francisquito Creek and is most commonly known as the San Francisquito Cone. The San Francisquito Cone or Alluvial Fan area has been depicted differently by different authors as shown in Figure 3-10. The DWR (1967) San Francisquito Creek Alluvial Fan area as modified by Metzger (2002) is shown in the figure. Killingsworth and Hyde (1932) and Sokol (1964) used a different area for water balances described in Section 3.4. The Sokol (1964) San Francisquito Creek Alluvial Fan, also referred to as the San Francisquito Creek Basin, is also shown on Figure 3-10. Figure 3-10 also shows the locations of the City’s emergency supply wells relative to the Cone.

Other creeks that drain the uplands and subbasins include Stevens Creek; Hale Creek, a tributary of Permanente Creek; Adobe Creek and its tributary Barron Creek, Matadero Creek; Atherton Channel; and Redwood Creek and its tributary Arroyo Ojo de Agua. The streams meandered through time, especially at the flatter and lower elevations closer to San Francisco
Bay, and formed interfingered and laterally discontinuous layers of gravel, sand, and clay material. The deposits are a heterogeneous mixture of fine- and coarse-grained materials; accordingly, it is difficult to distinguish aquifers and aquifer boundaries. Because of the structural trough in the bedrock beneath San Francisquito Creek, the creek would have been confined to this low resulting in deposition of coarse-grained sediments along the current creek path (Sokol, 1963). Fio and Leighton (1995) found that the percentage of coarse-grained sediments increases with distance from the Bay and proximity to San Francisquito Creek.

Continental deposition of alluvium during the Plio-Pleistocene and Quaternary periods was accompanied by periods of sea level transgressions (rise) and regressions (fall), associated with periods of climatic warming and cooling, respectively. During periods of sea-level rise, the paleo San Francisco Bay inundated a larger area between the Santa Cruz and Diablo Range Mountains, and fine-grained silt and clay layers were deposited over broad areas. The uppermost sequence of fine-grained material around the perimeter of the South Bay and in the eastern portion of the Study Area is commonly referred to as the "Bay Mud" aquitard. This aquitard is of low permeability, as much as 100- to 200-feet thick near the Bay perimeter, and is one of a series of confining layers that impede vertical flow of groundwater. This is evidenced by the historical and current presence of artesian wells in some downgradient portions of the Study Area. However, the aquitard does not appear to be regionally continuous, as incised sand channel deposits are present in many areas of the Study Area.

During sea level regressions, much of the area currently occupied by San Francisco Bay was dry, and coarser-grained alluvium was deposited, including stream channel deposits that incised the previously-deposited finer-grained material. The resulting sedimentary sequence includes interbedded fine- and coarse-grained layers reflecting those dynamic depositional environments. This aquifer and aquitard framework affects groundwater flow.

### 3.2.7.1 Cross Sections

Ten hydrogeologic cross sections were constructed to characterize the thickness and distribution of alluvial aquifer sediments and to delineate the hydrostratigraphy within the Study Area.

The goals of constructing cross sections were to identify any local hydrogeologic structures that may affect IPR siting and should be reflected in future assessments so that they accurately reflect groundwater flow, pond recharge, injection, and pumping distribution. Construction of the cross sections focused on conditions relevant to hydrostratigraphic layering in the Study Area. The assessment was designed to use and combine existing information in the ArcHydro Groundwater (Strassberg et al., 2011) data format that supports application of geographic evaluation tools within a Geographic Information System (GIS) platform. The information assessed in this evaluation included:

- Surficial geology,
- Faulting,
- Lithologic and geophysical well and borehole logs,
- Well construction logs,
- Bedrock surface elevations, and
• Previously completed local hydrogeologic conceptualizations.

This information was collected and translated into a unified GIS compatible database structure for cross section construction and geographic evaluation. This approach allows any hydrostratigraphic structures relevant to groundwater flow in the Study Area to be easily translated from GIS for use in other formats.

3.2.7.1.1 Available Data and Information

Existing datasets and information were collected from all available sources. These sources included the following:

• Surficial geology in GIS coverage format (Brabb et al., 2000).
• Fault locations and orientations (Brabb et al., 2000).
• Fault subsurface expressions (Pampayan, 1993).
• Bedrock elevations (Oliver, 1990; Wentworth, 2015)
• Locations, lithology, and well construction information for wells and boreholes in Santa Clara County (Todd, 2016).
• Locations, lithology, and well construction information for wells and boreholes in the Santa Mateo County portion of the Study Area (EKI et al., 2017).
• Drillers Log files from DWR.
• Additional lithologic logs for a portion of Santa Clara County from Fio and Leighton (2017).
• Lithologic, well construction, and geophysical logs from the City of Palo Alto (Feeney, 2004; Luhdorff & Scalmanini, 2010; CDM et al., 2011; Bonkowski, 2010a and 2010b), the City of Menlo Park (Clark GeoTechnical, 2012; Luhdorff & Scalmanini, 2017), the City of Mountain View (Luhdorff & Scalmanini, 2003; Luhdorff & Scalmanini, 2006), and the City of East Palo Alto (EKI, 2014).
• Lithologic, well construction, geophysical logs and hydrogeologic conceptualizations from previously completed local and regional hydrogeologic studies (Canonie, 1987; Oliver, 1990; Brown and Caldwell, 1991; Dames & Moore, 1992; Geomatrix, 1992; Wentworth, 2015).
• National Elevation Dataset (NED) ground surface digital elevation model data for San Mateo and Santa Clara Counties (USGS, 2017).
• San Francisco Bay bathymetric digital elevation model (NOAA, 2017).

These data and information sources resulted in a dataset of nearly 19,000 locatable wells and boreholes within and near the Study Area. Of these, lithologic records are available for 761 wells and boreholes and construction records are available for 997 wells (Figure 3-11). These location, lithologic, and well construction records were combined into a unified dataset extending well beyond the extents of the Study Area. The unified dataset is composed of a series of related tables in a geodatabase that follows the data storage conventions of ArcHydro Groundwater. Construction of the unified database required combination of well location, lithologic, and well construction data from multiple data sources. These data sources often
contained different information types. At each stage of the database construction process care was taken to include all of the data from each data source. In addition, many records were included in multiple data sources, and often the records from two or more data sources had differences in locations or information for wells. Duplicate well locations or records were combined into single records preserving all of the information from each individual data source.

Geophysical logs from wells and boreholes in the Study Area were identified from all available sources. The available geophysical logs were reviewed and all good quality logs from deep boreholes and wells were selected for use in cross section development. This data collection and review process resulted in the identification of 45 geophysical logs from wells and boreholes within the Study Area. The short-normal resistivity values from these geophysical logs were digitized so that the data from the logs would be available for use in a relational data structure and lithology within GIS. Digitization was limited to short-normal resistivity because it was the only geophysical data type present in all available geophysical logs. The digitized resistivity data were combined into tabular format within the unified ArcHydro Groundwater database. Resistivity logs are to define strata boundaries for correlation and to infer lithology as a function of permeability and resistivity. In general, logs show deflections to the right in relatively more permeable fresh water formations.

There are multiple faults in the southwestern portion of the Study Area, as discussed above. To portray these faults on cross sections, it was necessary to estimate orientations and approximate dip angles. Pampeyan (1993) includes representation of the subsurface expressions of local faults within the Study Area, and apparent fault dip angles were estimated from Pampeyan and converted to true dip angles for each fault/cross section intersection (Davis et al., 1996). These estimates indicated that the faults in and around the Study Area generally dip towards the west at angles ranging from 56 to 83 degrees from horizontal.

3.2.7.1.2 Cross Section Construction

Ten cross section transect locations were chosen based on available data to provide lithologic coverage throughout the Study Area and to show depth and extent of environmental release site contamination plumes (see Section 5.5.3). Figure 3-11 illustrates well locations with available geophysical, lithologic, and construction information throughout the Study Area and Figure 3-12 shows the selected cross section locations and orientations. These sections are designated as A-A’ through J-J’, as indicated on Figure 3-12. These ten cross sections cover and extend slightly beyond the Study Area.

The datasets incorporated into the database discussed above were used to populate the cross sections for use in hydrostratigraphic correlation. These data were applied to the sections using the ArchHydro Groundwater extension to ESRI’s ArcGIS Desktop software. ArchHydro Groundwater includes tools for plotting surficial geology, faults, lithologic, construction, and geophysical records, and elevation surfaces from a two-dimensional map to two-dimensional cross sections. The wells with lithologic, construction, and geophysical information in the vicinity of the sections are shown on Figure 3-12. Each cross section was populated with the following datasets:
• Ground surface elevations from the county NED files, converted from North American Vertical Datum of 1988 (NAVD 88) to National Geodetic Vertical Datum of 1929 (NGVD 29) for consistency with local elevation datasets,
• Surficial geology,
• Faults,
• Well and borehole lithology and well construction from all wells within 1,000 feet of each cross section,
• Short-normal resistivity for all wells within 2,000 feet of each cross section,
• Bay area bathymetry (also converted to NGVD 29), and
• Estimated bedrock elevations.

These data were plotted to the cross sections using the ArcHydro Groundwater toolset and then used to interpret and correlate hydrostratigraphy. Geophysical and lithologic data were used to interpret sand and gravel aquifer units throughout the Study Area. Sands and gravels were lumped together in the interpretation. Where geophysical and lithologic logs disagreed, the information from geophysical logs was used. In locations where multiple geophysical or lithologic logs were present on a cross section, preference was given to the closest logs. Mapped surface geology (Brabb et al., 2000) and subsurface conditions around the faults (Pampayan, 1993) were used to interpret the locations and relationships of older materials to one another and to local alluvium on the southwestern side of the Study Area. Bedrock elevations on each cross section were plotted from the contour data shown on Figure 3-8, with local modifications based on well and borehole log data.

The resulting cross sections are shown individually with lithology, faulting, bedrock, and well locations on Figures 3-13 through 3-22. Areas where there is no well or lithologic data in the alluvial subbasins are left white and the transition is indicated by a dashed line.

3.2.7.1.3 Hydrostratigraphic Evaluation

In general, the cross sections support and agree with the previous conceptual model described above. Alluvial thickness is generally greatest in the northeastern and southeastern portions of the Study Area. However, the percentage of coarse grained material (sands and gravels) is higher around San Francisquito Creek and in the southwest near the Santa Cruz Mountains. Additional discussion of observations from the cross sections is presented below.

The southwest to northeast cross sections (D-D’, E’E, F-F’, G-G’, H-H’, and I-I’) show bedrock elevations higher in the southwest and deeper in the northeast. The lowest bedrock elevations in the Study Area are projected to be on the northeast end of cross section H-H’, where the alluvium is estimated to extend to a depth of over 1,200 feet. However, there is a deep trough-like feature shown in many of the cross sections that appears to slope from cross section E-E’ midway between the intersections of B-B’ and C-C’, then proceed to cross section F-F’ just before the intersection with J-J’, on to J-J’ just before it intersects F-F’, then to G-G’ just after it crosses B-B’, and then to B-B’. It is unclear where this trough goes from B-B’, but the final expression may be present on the west side of I-I’. The trough begins at a depth of approximately 930 feet on cross section E-E’ and reaches a maximum depth of just over 1,180 feet on B-B’ and I-I’.
The Pulgas and Hanover faults appear to have caused vertical offset of bedrock, resulting in relatively deep alluvium immediately northeast of the fault zones as shown on cross sections D-D', E-E', F-F', G-G' I-I', and J-J'. As shown on cross section G-G', the Pulgas Fault offsets beds within the Santa Clara Formation and deeper units. As shown in cross sections I-I', and J-J', the Hanover Fault offsets bedrock units and the lower portions of the alluvial sediments. Understanding the extent of faulting in this area is relevant for siting surface recharge facilities because faults can act as barriers to groundwater flow. Because the Hanover Fault appears to only offset deeper alluvial units, the faulting does not likely limit down gradient flow from surficial or shallow recharge facilities potentially sited in the alluvial recharge area. As discussed in Section 3.2.6.1, the Pulgas Fault is thought to limit groundwater flows near San Francisquito Creek (Metzger, 2002). The effect of the Pulgas Fault on groundwater flow further to the southeast has not be demonstrated in the literature or by examination of groundwater elevation contour maps. While uncertain, because the fault offsets beds of folded semi-consolidated to consolidated bedrock, it is believed that it may likely act as a barrier to groundwater and it is not recommended to site surface recharge facilities on the upgradient (southwest side of the Pulgas Fault) without further field investigation.

As shown on cross section D-D' and E-E' (sections with available information beneath San Francisco Bay), the shallow sand and gravel units in the subbasins do not appear to connect with San Francisco Bay. This finding is relevant to the potential for saline water intrusion as the lack of coarse-grained units near the Bay limit potential migration of saline water inland to the groundwater subbasins. However, note that there are no available lithologic data beneath the Bay adjacent to the Santa Clara Subbasin portion of the Study Area and there is only limited lithologic and geophysical data available for the area around cross sections D-D' and E-E'. The apparent lack of connection between coarse-grained units and the Bay may simply be reflective of the limitations of the available data. However, pumping test findings documented in Section 3.2.8 postulate fine-grained units limiting the subsurface movement of groundwater across the Bay front. The lithologic interpretations on cross sections D-D' and E-E' combined with these previous findings suggest that groundwater discharge to the Bay may be limited in the Study Area. Nonetheless, it is possible that connections between shallow groundwater and the Bay exist but are not captured within the available data. In addition, other pathways exist for movement of shallow groundwater out of the Santa Clara Subbasin. Shallow groundwater can move as subsurface flow to adjacent subbasins, be removed through dewatering operations, discharge to creeks, infiltrate sewer lines, and given its shallow depth, be taken up by phreatophytes (deep-rooted plant that obtains a significant portion of their water supply from groundwater or the capillary fringe above the water table). The cross sections show heterogeneous conditions in the subsurface alluvium, with significant variability in the presence, thickness, and continuity of sand and gravel units. This is consistent with the conceptual model and with a depositional environment characterized by episodic alluvial and shallow marine or estuarian processes. There is a greater frequency of sand and gravel units in the southwest near the mountains and near San Francisquito Creek. The coarse deposits decrease in occurrence and thickness from southwest to northeast as streams lose energy and to the southeast as the creek drainages become smaller. The following summarizes key cross section observations:
• There appears to be a high concentration of sand and gravel units around San Francisquito Creek, as indicated on cross sections A-A’ and B-B’, and by comparing E-E’ to other northeast trending cross sections. This is generally consistent with the area identified as the San Francisquito Cone as shown on Figure 3-10.

• The San Mateo Plain portion of the Study Area north of San Francisquito Creek appears to have limited sand and gravel thickness, and the sands and gravels that are present are more lenticular and less extensive than those further to the southeast. This is shown by comparing cross sections D-D’ and E-E’. This is consistent with the previous conceptual model, which indicates that the area around the San Francisquito Creek has long been a source of coarse-grained deposits.

• Comparing cross sections A-A’ and B-B’ to C-C’ shows more sand and gravel in the southwest against the Santa Cruz Mountains than in the northeast near San Francisco Bay. This trend is also illustrated in the northeast trending cross sections.

• The presence of sand and gravel units at or near ground surface is limited to the southwestern portion of the Study Area, as shown in cross sections A-A’ and B-B’ and most of the northeast trending cross sections.

• Cross sections A-A’, B-B’, C-C’ and J-J’ also show slightly less sand and gravel in the southeastern portion of the Study Area.

• There is limited vertical cross connection between sand and gravel units. Most of the significant sand and gravel layers don’t appear to connect to sand and gravel layers above or below them either directly or indirectly.

• The Hanover Fault appears to offset some deeper, older sand and gravel units, as shown on cross sections G-G’, I-I’, and J-J’.

• None of the sand and gravel units present on the northeastern side of the Study Area appear to connect to San Francisco Bay. This suggests that groundwater discharge to the Bay may be limited in the Study Area. However, note that there is limited lithologic and geophysical data adjacent to and within the Bay. It is possible that connections between shallow groundwater and the Bay exist but are not captured within the available data.

### 3.2.8 Aquifer Hydraulic Properties

#### 3.2.8.1 Deep Aquifer

Aquifer hydraulic properties affect the rates of groundwater flow, rates of percolation of natural and artificial recharge, production rates of wells, and amounts of groundwater in storage. The major aquifer hydraulic parameters are horizontal and vertical hydraulic conductivity, transmissivity, specific capacity, and storativity (referred to as specific yield for unconfined aquifers, and storage coefficient for confined aquifers). Hydraulic conductivity is a measure of the aquifer’s intrinsic permeability and controls the linear rate at which water moves through the medium under a unit hydraulic gradient. Transmissivity is equal to the hydraulic conductivity multiplied by the aquifer’s saturated thickness and is the rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient. Specific capacity is the amount of water produced by a well per foot of drawdown (drop in water level).
over a specified period of pumping. Storativity is the volume of water an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in head. Typically, aquifer hydraulic parameters are determined based on pumping tests of wells that include measurements of pumping rates and water levels in the production well and nearby observation wells (Todd and Mays, 2005).

A wide range in aquifer properties are reported for the Study Area. Reported transmissivity values from pumping tests and estimated from well specific capacity (Fio and Leighton, 1995; Todd, 2012) range from 50 to 11,000 square feet per day (ft²/d) indicating a wide range from poor to very good yielding wells; this supports the characterization of heterogeneous conditions.

Pumping test data for local larger-capacity wells completed in the deep aquifer were compiled from previous studies and are summarized on Table 3-2. Additional shallow aquifer pumping tests were performed for several of the environmental release sites within the City and these shallow aquifer data are discussed in the following section.

Deeper aquifer hydraulic properties are available from testing of 32 larger-capacity wells located in the Study Area. Testing of the shallow and deep aquifer was also conducted in the Palo Alto Baylands area as part of an evaluation of injection wells to mitigate saline water intrusion from the Baylands (Hamlin, 1985). These 33 tests were evaluated to estimate deep aquifer hydraulic conductivity, transmissivity, specific capacity, and storativity. Figures 3-23 and 3-24 illustrate the deep aquifer hydraulic conductivity and transmissivity values, respectively. Note that hydraulic property values at USGS Leland well, presented on Table 3-2, are orders of magnitude higher than the rest of the data and are not included on the figures or statistical summaries discussed below.

Hydraulic conductivities and transmissivities for wells in the Study Area were calculated using different methods. Some of the values were estimated from the well specific capacities, which is considered an approximate method. Other aquifer property values were determined using more rigorous analysis of pumping tests, and in some cases, including observation wells. Estimates from both methods are included in Table 3-2.

Hydraulic conductivity values are within the expected range for the alluvial aquifer materials. The minimum end of the range (0.27 feet per day (ft/day)) is representative of silty sands while the maximum end of the range (149 ft/day) is representative of clean sands and gravels (Todd and Mays, 2005). The mean values (27 and 29 ft/day for the pumping test and specific capacity methods, respectively) are representative of clean sands (Todd and Mays, 2005). As presented on Figure 3-23, the highest values of hydraulic conductivity (greater than 100 ft/day) are generally located along San Francisquito Creek. However, there is some variability in the distribution of hydraulic conductivity values within the Study Area. This variability is consistent with the heterogeneity of the alluvial deposits.

Values of transmissivity range from 122 to 42,130 ft²/day, with mean values of 6,950 and 4,266 ft²/day for the pumping test and specific capacity methods, respectively. As presented on Figure 3-24, the pattern of transmissivity values is relatively similar to the hydraulic conductivity data.
Table 3-2  Aquifer Properties for Production Wells and Pumping Test Data

<table>
<thead>
<tr>
<th>Owner Well Name</th>
<th>Owner</th>
<th>Use</th>
<th>Date Drilled</th>
<th>Well or Boring Depth (ft)</th>
<th>Casing Diameter (in)</th>
<th>Screen Interval (ft)</th>
<th>Screen Length (ft)</th>
<th>Specific Capacity (gpm)</th>
<th>Specific Capacity Transmissivity (R2/d)</th>
<th>Specific Capacity Hydraulic Conductivity (R2/d)</th>
<th>Pumping Rate (gpm)</th>
<th>Pumping Test Transmissivity (R2/d)</th>
<th>Pumping Test Hydraulic Conductivity (R2/d)</th>
<th>Pumping Test Storage Coefficient</th>
<th>Source</th>
</tr>
</thead>
<tbody>
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<td>City of Palo Alto</td>
<td>Library Municipal</td>
<td></td>
<td>Oct-09</td>
<td>283</td>
<td>18</td>
<td>165-285</td>
<td>120</td>
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<td>579</td>
<td>5</td>
<td>600</td>
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</tr>
<tr>
<td>City of Palo Alto</td>
<td>Eleanor Parade Municipal</td>
<td></td>
<td>Dec-39</td>
<td>460</td>
<td>18</td>
<td>180-280</td>
<td>120</td>
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<td>1,682</td>
<td>14</td>
<td>1,000</td>
<td>3,000</td>
<td>9</td>
<td>0.00299</td>
<td>Bonkowski 2010</td>
</tr>
<tr>
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<td>Rinconada Municipal</td>
<td></td>
<td>May-54</td>
<td>900</td>
<td>14</td>
<td>156-900</td>
<td>744</td>
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<td>13,903</td>
<td>19</td>
<td>920</td>
<td>4,597</td>
<td>7</td>
<td>0.025</td>
<td>CHG;MILL 1992 (older) City (newer)</td>
</tr>
<tr>
<td>City of Palo Alto</td>
<td>Middlefield Municipal</td>
<td></td>
<td>Apr-05</td>
<td>750</td>
<td>14</td>
<td>165-592</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td>CHIM 1992</td>
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<tr>
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<td>Apr-05</td>
<td>480</td>
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<td>Feb-13</td>
<td>280</td>
<td>16</td>
<td>152-204</td>
<td>98</td>
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<td>149</td>
<td>1,864</td>
<td>42,130</td>
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<td>LAS: untraced; analysis by Todd</td>
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<td></td>
<td>Oct-56</td>
<td>1186</td>
<td>14</td>
<td>142-1066</td>
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<td></td>
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<tr>
<td>City of Palo Alto</td>
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<td>Sep-55</td>
<td>828</td>
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<td>Oct-56</td>
<td>1056</td>
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<td>144-1056</td>
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<td>Apr-17</td>
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<td>DWR Log; HDR, 2004</td>
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<td>DWR log; City (newer)</td>
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<td>No. 1 Domestic</td>
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<td>12</td>
<td>181-532</td>
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<td>12,833</td>
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<td>No. 2 Municipal</td>
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<td>Palo Alto Park Mutual Water Co.</td>
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<td>#7 Municipal</td>
<td>Jun-87</td>
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<td>8</td>
<td>248-398</td>
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<td>3 Domestic</td>
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<td>12</td>
<td>160-420</td>
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<tr>
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<td>35D2 and Sep-65</td>
<td>450</td>
<td>12</td>
<td>140-440</td>
<td>200</td>
<td>16.8</td>
<td>4,492</td>
<td>22</td>
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<td>DWR log; City (newer)</td>
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<td>Stanford U</td>
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<td>W1 Municipal</td>
<td>Jan-34</td>
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<td>12</td>
<td>179-574</td>
<td>395</td>
<td>14.60</td>
<td>3,780</td>
<td>16,642</td>
<td>9.5</td>
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<td>Stanford U</td>
<td></td>
<td></td>
<td>W3R Irrigation</td>
<td>Nov-02</td>
<td>355</td>
<td>16</td>
<td>150-350</td>
<td>200</td>
<td>32.6</td>
<td>8,718</td>
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<td>8,718</td>
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<td>Stanford U</td>
<td></td>
<td></td>
<td>W4R Irrigation</td>
<td>Aug-03</td>
<td>310</td>
<td>18</td>
<td>150-305</td>
<td>125</td>
<td>8.9</td>
<td>2,387</td>
<td>19</td>
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<td></td>
<td>5 Other</td>
<td>Feb-57</td>
<td>626</td>
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<td>144-624</td>
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<tr>
<td>Stanford U</td>
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<td>1 Test Hole</td>
<td>301</td>
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<td>142-301</td>
<td>159</td>
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<td>100,000</td>
<td>42.84</td>
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<td>Stanford U</td>
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<tr>
<td>SCVWD</td>
<td></td>
<td></td>
<td>Leland Well Domestic</td>
<td>Oct-77</td>
<td>310</td>
<td>18</td>
<td>280-270</td>
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<td>2,142</td>
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<tr>
<td>SCVWD</td>
<td></td>
<td></td>
<td>Injection Wells Injection</td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ft/d - feet per day</th>
<th>ft - feet</th>
<th>ft/d - square feet per day</th>
<th>gpm/ft - gallons per minute per foot of drawdown</th>
<th>U - university</th>
<th>in - inches</th>
<th>SCVWD - San Jose Valley Water District</th>
<th>DWR - California Department of Water Resources</th>
</tr>
</thead>
</table>

**Note:** This table provides aquifer properties for production wells and pumping test data related to various locations and operators. The data includes details such as owner names, use, date drilled, well or boring depth, casing diameter, screen intervals, screen lengths, specific capacities, and various coefficients related to pumping tests. The data is sourced from various reports and studies. The table is part of a larger document discussing groundwater assessment and implementation strategy.
Storativity values range from 0.00019 to 0.195, with mean value of 0.04. The higher storativity values are representative of unconfined or partially-confined conditions while the low values are indicative of confined conditions. This is consistent with the presence of both confined and unconfined conditions in the Study Area.

Stanford University conducted an 8-day pumping and recovery test in one of its production wells while monitoring water levels in five observation wells located at various distances from the pumping well. These data were analyzed to determine aquifer parameters. Pumping test analyses are presented in Appendix A. The testing showed responses in all observation wells even those at distances greater than 5,000 feet from the pumping well. These responses, as well as the storativity (0.0007), indicate confined conditions as the cone of depression associated with the pumping well in the confined aquifer is deeper and much more extensive compared to the cone of depression in the unconfined aquifer. The pumping well is located near the boundary of the confined and unconfined zones in the confined area. The pumping test confirms the existing interpretation of the extent of confinement in this area.

The City’s El Camino Park well pumping test was also analyzed as the Well Completion Report (Luhdorff and Scalmanini, 2013) did not provide an analysis of aquifer parameters other than specific capacity. The analysis is provided in Appendix A and results are shown in Table 3-2. Values of specific capacity provided in Table 3-2 range from 0.5 to 55 gallons per minute per foot (gal/min/ft), with a mean value of 16 gal/min/ft.

3.2.8.2 Shallow Aquifer and Santa Clara Formation

Available shallow aquifer hydraulic property data were reviewed to assess potential aquifer recharge capacities in the unconfined forebay portion of the Study Area underlain by Santa Clara Formation. As shown in Figure 3-25, the area of unconfined alluvial aquifer within Palo Alto available for IPR surface spreading facilities is narrow. In addition, several large environmental contaminant plumes (discussed in Section 3.5.3) further limit areas where recharge facilities may be located without potential mobilization of contamination. The recharge potential of the Santa Clara Formation has been characterized as both a significant recharge area (Fio and Leighton, 1995) and as having low yields to wells (Iwamura, 1995) indicating limited recharge potential.

This review focused on near-surface aquifer properties at environmental release sites located in the Santa Clara Formation and confined aquifer near the unconfined alluvial aquifer boundary. Available shallow aquifer hydraulic property data in this area primarily consist of horizontal hydraulic conductivities measured during the performance of aquifer pumping and slug tests, although limited vertical hydraulic conductivity and storage property data are also available from a few of the pumping tests.

Numerous shallow well pumping tests were performed at contaminated sites with significant groundwater contamination plumes, including the 1501 Page Mill Road, Hillview-Porter, and 4100 Miranda Avenue cleanup sites. Pumping tests of shallow wells completed in both the recent Alluvium and in the Santa Clara Formation were conducted at these sites. At the 1501
Page Mill Road site, six shallow Santa Clara Formation aquifer pumping and recovery tests were performed. At the Hillview-Porter site, three pumping tests and 14 slug tests were performed in wells completed in the alluvium and Santa Clara Formation. At the 4100 Miranda Avenue site, eight pumping tests were performed for wells completed in the alluvium only. A pair of shallow well pumping tests for wells completed in the Santa Clara Formation were also reported in Sokol (1964).

Table 3-3 lists the shallow aquifer pumping test wells and estimated hydraulic conductivities. At the 1501 Page Mill Road site, the average (mean) reported hydraulic conductivity of the shallow Santa Clara Formation aquifer was 7.6 ft/day. At the Hillview-Porter site, the average reported hydraulic conductivity of the shallow Santa Clara Formation aquifer was 4.0 ft/day, while the average reported hydraulic conductivity of the shallow alluvium was 2.0 ft/day. At the 4100 Miranda Avenue site, the average reported hydraulic conductivity of the shallow alluvium was 6.7 ft/day.

These mean values are illustrated on Figure 3-23, the hydraulic conductivity map. The shallow hydraulic conductivities for both alluvium and Santa Clara Formation are similar to the values for deeper wells in the Study Area.

The results of these pumping and slug tests indicate that both the alluvium and Santa Clara Formation in the foothills at the edge of the Santa Clara Subbasin have moderate horizontal hydraulic conductivity. Vertical hydraulic conductivities are expected to be lower than horizontal, due to stratification and anisotropy. However, the estimated conductivities indicate that moderate rates of surface recharge can be achieved in the uplands Santa Clara Formation area. Because of uncertainty in the hydraulic connection between the Santa Clara Formation and alluvium, if surface recharge facility sites can be sited in the formation, additional field work should be performed to assess its recharge potential and connectivity to the alluvium prior to moving forward in the planning process beyond this Northwest County Recycled Water Strategic Plan. Similarly, field investigations of potential recharge sites in the alluvial recharge area are also recommended.

### 3.2.8.3 Confining Layer

Hamlin (1985) conducted a pumping test in the Palo Alto Baylands and estimated the vertical hydraulic conductivity of the confining layer between the shallow and deep aquifers at 0.08 ft/d.
Table 3-3  Summary of Shallow Aquifer Hydraulic Conductivity in Unconfined Recharge Area

<table>
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<tr>
<th>Site Area</th>
<th>Aquifer Formation</th>
<th>Test Date</th>
<th>Pumping Well</th>
<th>Observation Well</th>
<th>Horizontal Hydraulic Conductivity (feet/day)</th>
<th>Notes</th>
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</thead>
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<tr>
<td>(20 conductivity values)</td>
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</tr>
<tr>
<td></td>
<td>Santa Clara - Gamma 1</td>
<td>10/10/1991</td>
<td>MW-28</td>
<td>MW-23</td>
<td>8.2 pumping test</td>
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<td></td>
<td>Santa Clara - Gamma 1</td>
<td>10/10/1991</td>
<td>MW-28</td>
<td>MW-24</td>
<td>16.6 pumping test</td>
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</tr>
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<td></td>
<td>Santa Clara - Gamma 1</td>
<td>10/10/1991</td>
<td>MW-28</td>
<td>MW-24</td>
<td>19.8 pumping test</td>
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</tr>
<tr>
<td></td>
<td>Santa Clara - Gamma 1</td>
<td>10/10/1991</td>
<td>MW-28</td>
<td>MW-28</td>
<td>8.8 pumping test</td>
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</tr>
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<td></td>
<td>Santa Clara - Gamma 1</td>
<td>10/10/1991</td>
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<td>10.7 pumping test</td>
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</tr>
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<td>Santa Clara - Gamma 1</td>
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<td>MW-88</td>
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<td>Santa Clara - S Zone</td>
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Mean Horizontal Hydraulic Conductivity Santa Clara Formation (feet/day) 7.6
Median Horizontal Hydraulic Conductivity Santa Clara Formation (feet/day) 8.2
Table 3-3  Summary of Shallow Aquifer Hydraulic Conductivity in Unconfined Recharge Area  
(continued)

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<tr>
<th>Site Area</th>
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<th>Pumping Well</th>
<th>Observation Well</th>
<th>Horizontal Hydraulic Conductivity (feet/day)</th>
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Mean Horizontal Hydraulic Conductivity Alluvium (feet/day)  2.0  
Median Horizontal Hydraulic Conductivity Alluvium (feet/day)  0.9  
Mean Horizontal Hydraulic Conductivity Santa Clara Formation (feet/day)  4.0  
Median Horizontal Hydraulic Conductivity Santa Clara Formation (feet/day)  2.5
### Table 3-3  Summary of Shallow Aquifer Hydraulic Conductivity in Unconfined Recharge Area (continued)

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<thead>
<tr>
<th>Site Area</th>
<th>Aquifer Formation</th>
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<th>Pumping Well</th>
<th>Observation Well</th>
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<tr>
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<td>RW-1A</td>
<td>RW-1B</td>
<td>0.1  pumping test</td>
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<td>Alluvium</td>
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**Mean Horizontal Hydraulic Conductivity Alluvium (feet/day):** 6.7

**Median Horizontal Hydraulic Conductivity Alluvium (feet/day):** 1.0

<p>| Stanford University        | Santa Clara        | 4/1/1960  | 10L1         | 10L1             | 89.1 pumping test                           |                     |
| (2 conductivity values)     | Santa Clara        | 5/23/1962 | 18H1         | 18H1             | 29.0 pumping test                           |                     |</p>
<table>
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<th>Site Area</th>
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<th>Mean Horizontal Hydraulic Conductivity (feet/day)</th>
<th>Notes</th>
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<td>Recovery Test Program - 20 tests</td>
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<td>A2 Zone</td>
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3.2.9  Groundwater Levels and Flow

An evaluation of the Santa Clara County portion of the Study Area groundwater levels and flow was conducted using water level data provided by the District. Data provided by the District include water levels from the 1960s through May 2017. Data for San Mateo County were available from the San Mateo Groundwater Basin Assessment (EKI et al., 2017) through March 2016. The San Mateo County data were primarily compiled from environmental site investigations, and therefore include mostly short water level records from shallow wells. This analysis, therefore, primarily relies on data provided by the District. Some older groundwater level data and historical pumping for the City wells from Carollo (2003) was also used. Groundwater elevation contour maps were prepared using data from shallow wells (screened less than or equal to 200 ft-bgs) and deep wells (screened greater than 200 ft-bgs), and hydrographs of water levels over time were constructed and evaluated. While the District uses 150 ft-bgs to differentiate between shallow and deep wells for their reporting, 200 ft-bgs was used for this study based on groundwater elevation data in the District’s Eleanor (ELNR) multi-completion monitoring well located in central Palo Alto. The upper-most screened interval from 180 to 200 ft-bgs clearly shows a groundwater head response indicative of the shallow aquifer.

It is noted that the depth of the shallow aquifer likely varies based on location in the Study Area.

3.2.9.1  Groundwater Elevation Contours

Groundwater level data for shallow and deep wells were contoured for two recent time periods, fall 2016 and spring 2017. Fall 2016 contour maps are based on water levels measured between October 1 and October 22, 2016 and represent groundwater elevations at the end of the multi-year drought. Spring 2017 contour maps are based on water levels measured between March 28 and April 4, 2017 and represent groundwater elevations near the end of the recent unusually wet winter season. Rainfall at the District’s San Jose weather station (6131) was 17.2 inches between July 1, 2016 and June 30, 2017, or 120% of the annual average of 14.3 inches. The contour maps do not include water levels measured at the City of Palo Alto production wells because they are constructed in both the shallow and deep aquifers. Well construction for the City emergency supply wells is summarized on Table 3-1. Although the City wells are screened primarily in the deep zone, the top of the screens begin in the shallow zone (between 108 and 165 ft-bgs) with gravel packs that begin even shallower (between 60 and 150 ft-bgs). Wells that are exposed to the effect of more than one aquifer reflect the water levels of each aquifer in direct proportion to the transmissivity of the aquifer. Therefore, water levels measured at the City wells are influenced by groundwater flow in both the shallow and deep aquifers. This is likely why the City wells do not show artesian conditions, while some nearby wells screened solely in the deep aquifer do.

The groundwater elevation map based on fall 2016 shallow water level measurements is presented on Figure 3-25. Groundwater elevations range from 72.9 feet NGVD (National Geodetic Vertical Datum of 1929) along the southeastern border of the Study Area in Mountain View to 1.1 foot below NGVD or -1.1 feet NGVD 29 near the Bay in Palo Alto. Based on the contours, groundwater flows towards the Bay, from the south-southeast to the north-
northwest. The shallow horizontal hydraulic gradient is approximately 0.0027 foot per foot (ft/ft). The gradient is steeper near the foothills and flatter near the Bay.

Deep groundwater elevations measured in fall 2016 are presented as Figure 3-26. Groundwater elevations range from 76.2 feet NGVD 29 in the southeastern corner of the Study Area in Mountain View to -3.6 feet NGVD 29 on the Stanford campus. Artesian conditions were observed in one well near the Bay in Palo Alto (7.4 feet NGVD 29), and four wells in Mountain View. Two of the artesian wells in Mountain View have pressure gauges and groundwater elevations are known (62.5 and 62.6 feet NGVD 29). The other two of the artesian wells in Mountain View do not have pressure gauges, and therefore, the groundwater elevations are not known and therefore not contoured. Groundwater flow is from the south-southeast to the north-northwest towards the Bay. There is a localized cone of depression near San Francisquito Creek from pumping of Stanford irrigation wells. The deep aquifer horizontal gradient in the eastern Study Area is 0.0034 ft/ft.

Shallow groundwater elevations measured in spring 2017 are illustrated on Figure 3-27. Groundwater elevations range from 82.4 feet NGVD 29 in the southeastern corner of the Study Area in Mountain View to 0.9 feet NGVD 29 near the Bay in Palo Alto. Similar to fall 2016, the groundwater flow direction is towards the Bay, from south-southeast to north-northwest. The shallow aquifer hydraulic gradient is 0.0027 ft/ft, the same as in fall 2016. The gradient is steeper near the foothills than closer to the Bay.

Shallow groundwater elevations are higher in spring 2017 than in the fall 2016, with the exception of one well in Mountain View where the water level declined 1.3 foot (from 28.9 to 27.6 feet NGVD 29). The shallow contour maps are based on data from the same wells and the average increase in water level at these wells from fall 2016 to spring 2017 is 6.5 feet. The maximum increase of 16.9 feet (from 3.9 to 20.8 feet NGVD 29) was measured in the shallowest screen of the multi-completion well (ELNR 4).

Deep groundwater elevations measured in spring 2017 are presented as Figure 3-28. Groundwater elevations range from 76 feet NGVD 29 in the southeastern Study Area in Mountain View to 7.6 feet NGVD 29 near the Bay in Palo Alto. As in fall 2016, artesian conditions persist next to the Bay in Palo Alto (7.6 feet NGVD 29) and in Mountain View (62.7 and 66.1 feet NGVD 29). Artesian conditions were also observed in the same two wells without pressure gauges in Mountain View. Similar to fall 2016, groundwater flow is towards the Bay and there remains a localized cone of depression near San Francisquito Creek due to pumping at Stanford. The deep aquifer horizontal gradient in the eastern Study Area is 0.0031 ft/ft, which is similar to fall 2016.

Deep groundwater elevations rose from fall 2016 to spring 2017. Fourteen deep wells were measured during both seasons, and the average increase in groundwater elevation among these wells was 10.6 feet. The most significant rise in deep groundwater elevations occurred near San Francisquito Creek, where water levels increased approximately 20 feet. The change in groundwater levels is likely due to reduced irrigation pumping by Stanford and surface water recharge to groundwater along the upper reach of San Francisquito Creek in the subbasins. Water levels in Mountain View rose an average of approximately 5 feet. Water levels in Palo Alto near the Bay did not change.
3.2.9.2 Hydrographs

Groundwater levels are also presented as hydrographs at select wells within the Study Area. A map of well locations with hydrographs is presented as Figure 3-29.

Hydrographs for the Hale well and a composite of historical data for two nearby wells are presented as Figure 3-30. These illustrate deep groundwater level trends for almost 100 years in the vicinity of San Francisquito Creek. Water levels from approximately 1920 to the early 1960s were obtained from Sokol (1964) based on a composite of water levels from the Stanford Corporate Yard well and the City of Palo Alto Engineer well. The exact locations of these wells are uncertain, but they are screened in the deep aquifer near San Francisquito Creek. The Hale well water levels are available from 1956 to April 2017, and water levels from a USGS well (005S003W34H001) from about 1997 to 1995 are overlaid onto the Hale well hydrograph. Water levels at the USGS well are similar to the Hale Well during the period of overlap.

The Sokol and Hale well hydrographs illustrate historical to current water level patterns. Before 1890, groundwater was not yet developed, and groundwater flow was presumably towards the Bay. Groundwater development began between 1890 and 1910. Wells north of San Francisquito Creek were primarily used domestically for residential estates, while wells south of the creek were used for crop irrigation (Sokol, 1964). During this time, many deep wells exhibited artesian conditions. By 1920, groundwater development increased, and groundwater levels dropped below sea level. By the early 1930s, there was a cone of depression north of San Francisquito Creek and the hydraulic gradient had reversed with groundwater flowing from the Bay toward the foothills. By 1932, the City was operating eight production wells. In 1937, imported water from Hetch-Hetchy was available in the area although the City continued to rely on groundwater for a large portion of its water supply. There was some recovery in groundwater levels between the 1930s and early 1940s. Nonetheless, regional groundwater demand increased between 1940 and 1960 and the area experienced an extended dry period between 1945 and 1965 (SWRCB, 1955) and water levels declined to depths of more than -125 feet NGVD 29. In 1962, the City stopped using groundwater and began relying on Hetch-Hetchy imported water for 100% of its supply. In addition, the District began imported and treated water distribution in the Santa Clara Subbasin in the early/mid 1960s, and District customers reduced groundwater pumping. As a result, groundwater levels began to recover in the Santa Clara Subbasin. Water levels in the Hale well rose almost 150 feet from the early 1960s to the late 1970s, from approximately -130 feet NGVD 29 to approximately 15 to 20 feet NGVD 29. Groundwater elevations rose above sea level for the first time since pre-development and groundwater flow was towards the Bay. Since the 1970s, water levels in the Hale well and the USGS well have been relatively stable, fluctuating between approximately sea level and 25 feet NGVD 29. Water levels in the Hale well dropped below sea level during the drought in the late 1980s and during the most recent drought but have rebounded over 20 feet since May 2014. A sharp drop in the groundwater level in the Hale well occurred in 1988 when the well was put into service and 400 AF of groundwater were pumped from the well (Carollo, 2003).

Deep groundwater elevation contours from April 1962 were adapted from Sokol (1964) and are illustrated on Figure 3-31. As described above, groundwater elevations were at historical lows during this time and the contours show groundwater elevations between -100 and -150 feet.
NGVD 29 in the Palo Alto and Stanford area. A groundwater mound, at an elevation of approximately -100 feet NGVD 29, was present south of San Francisquito Creek. Groundwater flowed from the mound to the southeast, northwest, and to the east towards the Bay. Inland flow from the Bay was likely occurring closer to the Bay.

Additional hydrographs illustrating long-term water level trends in different regions of the Study Area are presented on Figure 3-32. Wells 06S03W03L010 and 06S03W11B010, on the upper half of Figure 3-32, are pumping wells on the Stanford campus showing rising water levels from the early 1960s to the mid-1980s. Water levels in well 06S03WL010, located next to San Francisquito Creek, decreased from the late 1940s to the early 1960s, and then increased about 150 feet, from approximately -125 feet NGVD 29 in 1961 to approximately 25 feet NGVD 29 in the early 1980s. Water levels in 06S03W11B010, located over a mile southeast of the creek, increased approximately 190 feet, from about -170 feet NGVD 29 in the early 1960s to approximately 20 feet NGVD 29 in the mid-1980s.

Wells 06S02W22G001/004 and 06S02W28N002, on the lower half of Figure 3-32, illustrate water level trends since 1970 in the southeastern Study Area, in Mountain View and Los Altos. Water levels at wells 06S02W22G001/004 in Mountain View increased approximately 180 feet, from -120 feet NGVD 29 in the early 1970s to above ground surface (60 feet NGVD 29) by the late 1990s. Water levels at well 06S02W28N002, located in the foothills of Los Altos, increased about 155 feet, from approximately -80 feet NGVD 29 in the early 1970s to approximately 75 feet NGVD 29 by the late 1990s. Water levels in both wells were relatively stable after the late 1990s.

Hydrographs and historical pumping for the eight City emergency supply wells are illustrated on Figures 3-33 The pumping and groundwater level records for the older City wells (Hale, Rinconada, Peers Park, Fernando, and Matadero) date back to the 1950s. Three wells – Eleanor Pardee, El Camino Park, and Library – were installed within the last 10 years and therefore have relatively short water level records and have not been used for supply. The older production well hydrographs illustrate rising groundwater levels during the 1960s and 1970s associated with cessation of pumping by the City and relatively stable water levels after that. The record of available annual pumping for each of the older wells is shown below each hydrograph (Carollo, 2003). The impacts of significant pumping during the 1950s and 1960s are shown in significant drawdown in the wells. The Hale and Rinconada wells also both show a sharp decline in groundwater levels associated with pumping during 1988. Recent water levels in several wells are near the ground surface (Eleanor Pardee, Library, Rinconada, and Matadero). No City well water levels are artesian, presumably because all the wells are screened in both the shallow and deep aquifers.

As shown on Figure 3-29, all of the hydrographs are from wells located in the confined area of the subbasin. Water levels within the confined area vary with depth and illustrate the presence of vertical gradients. Groundwater level hydrographs for shallow/deep well clusters from three locations are presented on Figure 3-34. The well clusters are shown as blue symbols on Figure 3-29.

Water levels in District’s Eleanor nested well cluster (ELNR), located near the City’s Eleanor Pardee well are shown on the top left of Figure 3-34. Water levels in the four separate
monitoring wells (which are screened at different depth intervals) are monitored by transducer and have near continuous records. These high frequency and depth discrete records allow for examination of short-term water level fluctuations in each well and a comparison of water level behavior at different depths. The largest fluctuations and deepest water levels are observed in the shallowest well screened in the shallow aquifer. Groundwater level elevations in the deeper wells are progressively higher with increasing depth and occasionally exhibit artesian conditions. This multi-completion well clearly shows an upward vertical gradient from the shallow to deep aquifer with water levels increasing with depth in the deep aquifer.

Water levels in Wells 052SW35R001/002, located next the Bay in Mountain View, are shown on the bottom left of Figure 3-34. Water levels in the two monitoring wells, one screened at a depth of 80 feet (R002) and the other screened at a depth of 300 feet (R001), show differences in water level trends since the 1970s. The shallow well groundwater elevations have remained relatively stable, having risen from a few feet below sea level in the 1970s to a few feet above sea level in 2015. The deeper well, however, has increased more dramatically, from an elevation of about -40 feet NGVD 29 in the early 1970s to above ground surface (artesian) since the mid-1990s. The two hydrographs cross each other in 1992, representing a change in the direction of the vertical gradient. Before 1992, water level elevations were greater in the shallow well, indicating a downwards vertical gradient. After 1992, water level elevations were greater in the deeper well, indicating an upwards vertical gradient. Presumably, as groundwater pumping in the confined zone decreased, water levels recovered and vertical gradients changed.

Water levels in Wells 06S02W05F001/002/003, located near the Bay in Palo Alto, are shown on the top right of Figure 3-34. These three wells are screened at various depths: 25 feet (F001), 50 feet (F002), and 200 feet (F003). The two shallowest wells exhibit relatively stable water level trends, while water levels in the deepest well increased approximately 40 feet, from approximately -25 feet NGVD 29 in the early 1970s to over 20 feet NGVD 29 in 2011. The deep well has been artesian (ground surface elevation is approximately 7 feet NGVD 29) since the late 1990s. While, a criterion of 200 ft-bgs has been used in this report as the depth differentiating the shallow aquifer from the deep aquifer, it is clear that F003 is screened in the deep aquifer based on the hydrograph. As noted above, the depth that separates the shallow and deep aquifers likely varies across the study area. At this location, the deep aquifer occurs at shallower depth than in the ELNR multi-completion well. Throughout most of the 1970s, water levels in this deep well were lower than in the intermediate well, indicating a downwards vertical gradient. Between the late 1970s and the late 1990s, deep well water levels fluctuated above and below the shallow well (F002) water levels. After the late 1990s, deep water levels remained above the water levels in the shallow wells, indicating an upwards vertical gradient. These hydrographs illustrate again that as deep aquifer pumping decreased, water levels recovered and vertical gradients changed from downwards to upwards.

Based on the District’s 2016 Groundwater Management Plan (SCVWD, 2016c), over 50 monitored wells are currently under artesian conditions at least part of the year. There are 17 wells that have been under artesian conditions in the Study Area. These wells are illustrated on Figure 3-35. Several of these wells are clustered, and therefore are displayed as one symbol on
As shown on the figure, wells with artesian conditions are within the confined area of the subbasin.

3.2.10 Confined/Unconfined Determination

The confined and unconfined areas within the Santa Clara Valley portion of the Study Area were first defined by the SWRCB (1955). Methods used by the SWRCB for confirming the presence of and delimiting the boundaries between forebay area (unconfined or recharge zone) and pressure zones (confined zone) were primarily geologic and hydrologic. In connection with the geologic studies, the SWRCB obtained and located 1,100 well logs. The limits of blue clay described on well logs were one criterion for locating pressure zone boundaries.

A hydrologic method utilized by the SWRCB for differentiating between the confined and unconfined zones was based upon the characteristics exhibited by these aquifers under conditions of change in rate of pumping drawdown. Over a period of several days, water level transducers were installed in abandoned wells to differentiate the high amplitude and cyclic piezometric surface fluctuation (associated with daily pressure changes) in the confined aquifer from the gradual unconfined water table elevation changes. Another method consisted of the preparation of a groundwater map showing lines of equal change in groundwater elevation for the period from summer to fall in 1949, which differentiated characteristic positive changes in levels in the confined aquifer from characteristic negative changes in the unconfined aquifer. (Note that the described pattern in the confined aquifer is not supported by the long-term hydrograph shown on Figure 3-30 or other supporting hydrographs in Sokol (1964). The described pattern is more typical of agricultural areas, where irrigation pumping peaks around July and groundwater levels begin to rise after peak pumping. In addition to the foregoing criteria, the SWRCB noted the limits of the area within which artesian wells were reported in Clark (1924). Finally, the area over which land surface subsidence occurred between 1933 and 1948 was considered. The area of subsidence is related to the zone of confined aquifer, assuming that ground surface lowering has resulted from compaction of the confining clay layers under reduced hydrostatic pressures. The foregoing considerations resulted in several lines of demarcation between confined and unconfined zones, which agreed within reasonable limits. SWRCB concluded that evidence indicated that the confined aquifer may extend beyond the limits defined in their investigation.

For this current assessment, focus was given to definition of the division between confined and unconfined conditions in order to accurately delineate the recharge area available for surface recharge IPR facilities. The criteria used include SWRCB (1955) defined confined and unconfined areas discussed above, recent observed artesian conditions, thickness and extent of confining layers in cross sections, and the response of pumping test. Wells that exhibit artesian conditions are shown in Figure 3-35. The wells showing artesian conditions are in the confined aquifer as defined by the SWRCB (1955). Review of the map indicates no artesian wells in/or close to the division of the confined/unconfined areas that would help further differentiate the two areas. The City’s Matadero and Fernando wells, 06S03W11B010, and 06S02W28N002 are located close to the SWRCB confined/unconfined boundary (see Figure 3-29); however, because the Matadero and Fernando wells and 06S03W11B010 are screened both in the unconfined and confined aquifers, they are not expected to exhibit artesian water levels due to
the mixed influence of groundwater levels from multiple aquifers. However, the Matadero and Fernando well groundwater levels do approach very close to the ground surface as shown in Figure 3-33 indicating likely confined conditions at depth. Well 06S02W28N002 is screened solely in the confined aquifer and yet does not show artesian conditions; this indicates that the recharge area might be extend into this area. As this well is located in Los Altos, it does not help define a larger area to site surface recharge facilities.

Examination of cross sections crossing the SWRCB confined/unconfined divide shows numerous alternating course- and fine-grained units or lenses making it difficult to characterize confined and unconfined conditions based solely on lithology.

The pumping test conducted in Stanford Well No. 4R and the responses of observation wells at considerable distance from the pumping well indicate that the pumping and observation wells are located in the confined portion of the subbasin, consistent with the SWRCB interpretation.

Based on this analysis, the data do not justify any change in the SWRCB-defined confined/unconfined areas. As shown on Figure 3-31, the boundary between the recharge (unconfined) and confined zone in the San Mateo Subbasin is not shown (ending abruptly at the Santa Clara Subbasin boundary with the San Mateo Subbasin). This is because the boundary has not been defined in the literature and previous studies of the area and the analysis from this study were inadequate to define the boundary, noting that the data and supporting studies in the San Mateo Basin are considerably more limited compared with the Santa Clara Subbasin.

### 3.3 Subsidence History

Land subsidence is the settling or sinking of the Earth’s surface due to compaction of sediments in the subsurface. The Santa Clara Plain area is vulnerable to land subsidence with about 13 feet of land subsidence observed in San Jose between 1915 and 1969 due to groundwater overdraft (Poland, 1971, Poland and Ireland, 1988). Serious problems developed as a result of land subsidence, including flooding of lands adjacent to San Francisco Bay, decreased ability of local streams to carry away winter flood waters, and damage to utilities and infrastructure. This necessitated the construction of additional dikes, levees, and flood control facilities to protect properties from flooding (SCVWD, 2016b).

Significant land subsidence was essentially halted across the Santa Clara Plain by about 1970 through expanded groundwater management programs including increased importation of surface water sources and implementation of groundwater recharge projects (SCVWD, 2016b) that reduced groundwater pumping and allowed groundwater levels to recover.

Land subsidence is caused by the subsurface deformation of sediments and includes both an elastic and inelastic component. Of these two, the inelastic deformation is the primary cause of concern. The following provides a brief description of these two components of deformation:

- **Elastic deformation** occurs when sediment grains compress as pore pressures decrease, but then expand by an equal amount when pore pressures increase again. Because elastic deformation is relatively minor and fully recoverable, its effects are negligible.

- **Inelastic deformation**, or compaction, occurs when the sediment grains rearrange into a tighter configuration that reduces the volume of the affected sediment layer. The
volumetric compaction of the subsurface sediments leads to the sinking of the overlying ground surface. Inelastic deformation does not recover as pore pressures increase so its effects are permanent.

Land subsidence may occur as a result of chronic lowering of groundwater levels (overdraft) due to pumping. During pumping, declining water levels lower the water pressure within the pore space (pore pressure) of the sediments forming the aquifer. Because the pore pressure helps to support the weight of the overlying aquifer, decreasing the pore pressure causes more of the overlying aquifer weight to be transferred to the sediments grains. Inelastic deformation is initiated if the overlying aquifer weight (effective stress) exceeds the structural strength of the subsurface sediment layer.

Sediment type also strongly controls the potential magnitude and type of compaction. Coarse-grained deposits (e.g. sand and gravels) generally have sufficient intergranular strength so that inelastic deformation is negligible. Fine-grained sediments, primarily clays, are the most highly compressible sediments and are the most susceptible to compaction. Poorly consolidated clay layers, such as bay muds or lakebed deposits, may have the potential for several feet to tens of feet of compaction. Inelastic compaction is permanent and remains even after water levels recover.

Land subsidence is initiated when compressible clay layers are subjected to an effective stress beyond their previous maximum stress. With respect to pumping, this generally occurs when groundwater levels decline past historical low levels. In general, sediments have already been compacted in response to previous maximum stress; however, in the case of some thick clay layers, there may be time lag such that some residual compaction may occur after reaching the previous maximum stress.

Figure 3-36 shows the distribution of land subsidence within the Study Area between 1934 and 1967 (Poland and Ireland, 1988, Metzger and Fio, 1997). As shown on Figure 3-36, land subsidence in the Study Area during this time ranged from about 7 feet in Mountain View, 4 feet in Palo Alto to less than 0.5 foot in Menlo Park, Atherton and Redwood City. Areas along the western basin margin, including Los Altos and Atherton, have limited to no land subsidence due to the lack of compressible clay layers.

Historical low groundwater levels occurred in the Study Area in the early 1960s ranging from about 100 to 140 feet below sea level in Mountain View and Palo Alto, respectively. It is estimated that total annual pumping in the area amounted to approximately 7,500 AFY prior to 1962, most of which occurred in vicinity of Palo Alto (Sokol, 1964). In the 1960s, groundwater pumping declined with importation of Hetch-Hetchy supplies and conversion of agricultural lands to urban land uses that use less water. Since then, groundwater levels have recovered to pre-pumping levels. As a result, no significant additional land subsidence has occurred in the Study Area since the mid-to-late 1960s. However, a 1991 study identified the potential for an additional 8.5 feet of land subsidence in the Study Area (Geoscience, 1991, SCVWD, 2016b).

Satellite Interferometric Synthetic Aperture Radar (InSAR) has also been used to monitor subsidence in the region. InSAR is a relatively new technique allowing measurement and mapping of changes on the Earth’s surface as small as a few millimeters (mm). To evaluate
seasonal and multi-year deformation patterns in Santa Clara Valley, the USGS used European Observation Satellites (EOS) five-year InSAR data from September 1992 through August 1997. The data showed small amounts (5 to 10 mm) of regional uplift that corresponded with water-level recovery throughout the Santa Clara Valley. An eight-month interferogram (January to August 1997) showed seasonal subsidence of about 30 mm (1.2 inches) near San Jose that corresponded to about a 30-foot decline in water levels. In the Study Area, significantly smaller seasonal declines were noted (Galloway, et al., 2000; Bawden, et al., 2003).

3.4 Basin Water Balance

3.4.1 Methodology

Average annual water balances for the Study Area under current and historical conditions were developed by quantifying individual inflows and outflows that reflect both natural processes and the effects of urbanization. Historical water balances from the early 1930s and early 1960s were compiled from previous studies. Although those water balances were for a sub-region of the Study Area; the San Francisquito Creek Cone area as delineated by Killingsworth and Hyde (1932) and the San Francisquito Creek Basin as defined by Sokol (1964), they reflected periods of much more intensive use of groundwater. Consequently, the historical water balances shed more light on yield than the current water balance with its relatively small amount of pumping. A variety of methods was used to quantify the individual Study Area inflows and outflows for the contemporary water balance. This included use of a recharge simulation model that produced estimates of rainfall recharge, irrigation and irrigation return flow. The program calculated those estimates for numerous small recharge zones and also allocated recharge from pipe leaks to the zones. The details of the recharge zone delineation and hydrologic process simulation are described below. The water balance estimates presented in this section do not include estimates obtained from the groundwater flow model described in Section 4.4, which for some budget items produced more reliable estimates. Those budget items include percolation to and from streams, groundwater flow to and from San Francisco Bay, and subsurface flows across Study Area boundaries. See Section 4.4 for details of the model water balance and a discussion of vertical flow between the shallow and deep aquifers within the Study Area.

3.4.2 Water Balance in the Early 1930s

A study of groundwater conditions in the San Francisquito Cone area was completed by two Stanford geologists in 1932 (Killingsworth and Hyde, 1932). As described by Killingsworth and Hyde (1932), the San Francisquito Cone included the territory from Atherton on the northwest to Mayfield on the southeast; from the base of the low hills on the southwest to the waters of San Francisco Bay on the northeast; in all a total area of 20 square miles. The Killingsworth and Hyde (1932) Cone area differs from more recent delineations of the San Francisquito Creek Alluvial Fan (DWR, 1967; Metzger, 2002) and more closely conformed to the Sokol (1964) San Francisquito Creek Basin area as shown Figure 3-10.

Groundwater levels near Palo Alto and Stanford had been declining rapidly since 1916 due to increased pumping and drought. Based largely on geologic evidence, they conceptualized the
groundwater system as having a shallow and deep zone. These were separated by thick clay confining layers that were presumed to allow negligible amounts of downward leakage. The confining layers extended from San Francisco Bay inland to about midway across the Stanford campus. Between the western edge of the confined area and the western edge of the alluvial deposits, the shallow and deep zones were connected. This “forebay” area was considered the primary opportunity for recharge of the deep zone. However, rainfall infiltration and percolation from San Francisquito Creek were both estimated to be small. By a process of elimination, rather than by a lake water balance, Lake Lagunita was deduced to be “the largest contributor to our underground water supply”.

Table 3-3 presents the water balance described by Killingsworth and Hyde. The table includes all of the items included in the contemporary water balance tabulation, even though most of them were not specifically addressed by Killingsworth and Hyde. The authors completed an extensive inventory of wells and pumping and estimated total pumping from the San Francisquito Cone to be 7,218 AFY. The authors did not calculate the annual rate of storage depletion, but using numbers they presented for average water-level decline and average specific yield, an estimate of 1,890 AFY can be calculated (and is included in the table). This leaves an imbalance of 5,328 AFY, which is far too large to be accounted for by percolation from Lake Lagunita. For example, diversions from San Francisquito Creek to the lake were gaged during 1931-1941 and averaged 1,198 AFY. Runoff from the 321-acre local watershed tributary to Lake Lagunita generated approximately 158 AFY of additional inflow based on a correlation with gaged flows in Sharon Creek (a watershed of similar size and low elevation in western Menlo Park). After allowing for evaporation losses, these inflows produced on average about 1,017 AFY of groundwater recharge. This leaves a budget imbalance of 4,311 AFY that could have derived from groundwater inflow or underestimation of the aforementioned recharge sources.

3.4.3 Water Balance in the Early 1960s

Groundwater elevations in the San Francisquito Cone area recovered some during 1938-1944 as a result of the availability of imported water from San Francisco’s Hetch-Hetchy system and several wet years. Beginning in 1945, however, pumping again exceeded recharge and groundwater levels steadily declined through 1962 (Figure 3-30). In 1962, the City of Palo Alto switched its entire water supply from groundwater to imported water. Given that the City had been the largest pumper in the San Francisquito Cone area, water levels rapidly recovered thereafter (see Figure 3-30). Daniel Sokol, a geology graduate student, completed his PhD dissertation on the hydrogeology of the San Francisquito Creek watershed and “Alluvial Fan” area (Sokol, 1964). Sokol developed a water balance somewhat more complete than the one developed by Killingsworth and Hyde (1932); this is reproduced in Table 3-4. It reflects recharge and pumping conditions of the 1950s through 1962.
### Table 3-3 Early 1930s Average Annual Water Balance (Killingsworth and Hyde, 1932)

<table>
<thead>
<tr>
<th>Inflow or Outflow</th>
<th>San Francisquito Cone (AFY)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inflows</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep percolation through soils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall - runoff from impervious areas</td>
<td>0</td>
<td>Rainfall recharge assumed negligible (page 33).</td>
</tr>
<tr>
<td>Rainfall - nonirrigated areas</td>
<td>0</td>
<td>Rainfall recharge assumed negligible (page 33).</td>
</tr>
<tr>
<td>Irrigated areas</td>
<td>0</td>
<td>Rainfall recharge assumed negligible (page 33).</td>
</tr>
<tr>
<td>Pipe leaks</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Sewer</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Stream percolation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>San Francisco Creek</td>
<td>“small”</td>
<td>“No appreciable effect” of creek percolation on deep aquifer recharge (p. 38)</td>
</tr>
<tr>
<td>San Mateo County creeks</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Santa Clara County creeks</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Lagunita percolation</td>
<td>1,017</td>
<td>Described by authors as &quot;the largest contributor to our underground water supply&quot;, but not quantified. The value shown here equals average gaged diversions from SF Creek WY 1931-1941 plus average annual runoff from Lagunita’s 321-acre local watershed scaled by drainage area from gaged flows for Sharon Creek in Menlo Park (243-acre watershed), minus 25% for evaporation.</td>
</tr>
<tr>
<td>Bedrock inflow</td>
<td>0</td>
<td>Blocked by Pulgas or &quot;Stanford&quot; Fault</td>
</tr>
<tr>
<td>Groundwater inflow from Santa Clara Plain</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Groundwater inflow from SF Bay/Niles Cone</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Groundwater inflow from San Mateo Plain</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Clay compaction yield</td>
<td>n.m.</td>
<td>Note that applying the average 1912-1934 subsidence in the eastern 2/3 of SF Cone (1.3 ft, from Poland and Green, 1963) divided into 18 years (1917-1934) when water levels declined the most would produce a clay compaction yield of 616 AFY.</td>
</tr>
<tr>
<td><strong>Total inflows</strong></td>
<td>1,017</td>
<td></td>
</tr>
<tr>
<td><strong>Outflows</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water supply</td>
<td>7,218</td>
<td>p. 65</td>
</tr>
<tr>
<td>Remediation</td>
<td>n.m.</td>
<td>Presumably zero.</td>
</tr>
<tr>
<td>Dewatering</td>
<td>n.m.</td>
<td>Probably close to zero.</td>
</tr>
<tr>
<td>Riparian/wetland evapotranspiration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater seepage to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sanitary sewers</td>
<td>n.m.</td>
<td>Possibly close to zero due to low groundwater levels.</td>
</tr>
<tr>
<td>Creeks and storm drains</td>
<td>n.m.</td>
<td>Possibly close to zero due to low groundwater levels.</td>
</tr>
<tr>
<td>Groundwater outflow to Santa Clara Plain</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Groundwater outflow to SF Bay or Niles Cone</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td>Groundwater outflow to San Mateo Plain</td>
<td>n.m.</td>
<td></td>
</tr>
<tr>
<td><strong>Total outflows</strong></td>
<td>7,218</td>
<td></td>
</tr>
<tr>
<td><strong>Storage Change</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflows minus outflows</td>
<td>-6,201</td>
<td></td>
</tr>
<tr>
<td>Estimate from change in water levels</td>
<td>-1,890</td>
<td>Subtracted contoured 1916 and 1932 water levels within SF Cone. Multiplied volume by Sy=0.0564 and divided by 16 years to estimate 1,890 AFY of storage depletion.</td>
</tr>
</tbody>
</table>

AFY - acre-feet per year  
WY - water year  
Sy - specific yield  
SF Cone - San Francisquito Creek Cone as delineated by Killingsworth and Hyde (1932).  
\(^a\) The water balance represents land and water use conditions from the mid-1920's to 1932, with average annual rainfall. The budget is for the San Francisquito Cone area as delineated by Killingsworth and Hyde (1932).  
\(^b\) Totals may not equal sum of items due to rounding.
Table 3-4 Early 1960s Average Annual Water Balance (Sokol, 1964)

<table>
<thead>
<tr>
<th>Inflow or Outflow</th>
<th>San Francisco Creek Alluvial Fan (AFY)</th>
<th>Extrapolation to Groundwater Study Area (AFY)</th>
<th>Sources and Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inflows</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep percolation through soils</td>
<td>n.m.</td>
<td>1,500 Study area estimate = (non-tidal basin area)(% impervious)(annual rain minus interception and depression storage)(% of impervious that is disconnected)</td>
<td></td>
</tr>
<tr>
<td>Rainfall - runoff from impervious areas</td>
<td>n.m.</td>
<td>2,000 SF Cone forebay area only (Sokol [1964] Table 19). Study Area estimate = (non-tidal PAIPR Study Area)(% non-irrig)(1-D rainfall recharge on non-irrigated vegetation)</td>
<td></td>
</tr>
<tr>
<td>Irrigated areas</td>
<td>38</td>
<td>1,700 SF Cone forebay area only (Sokol [1964] Table 19). Study Area estimate assumes 15% of non-tidal part is irrigated with 34-40 in/yr applied water and 90% irrigation efficiency. Including rainfall recharge brings total recharge to 13.06 in/yr.</td>
<td></td>
</tr>
<tr>
<td><strong>Pipe leaks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>n.m.</td>
<td>1,500 For Study Area: muni water use = double the Palo Alto + Menlo Park use; assume 10% pipe leak rate.</td>
<td></td>
</tr>
<tr>
<td>Sewer</td>
<td>n.m.</td>
<td>300 For Study Area: estimate indoor use = 40% of total use; assume 5% leak rate.</td>
<td></td>
</tr>
<tr>
<td><strong>Stream percolation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>San Francisco Creek</td>
<td>658</td>
<td>700 Sokol ([1964] text. p. 90 and Tables 13 and 19.</td>
<td></td>
</tr>
<tr>
<td>San Mateo County creeks</td>
<td>113</td>
<td>200 Sokol ([1964] Table 19, divided equally between the two counties. Assumes all small-stream recharge is in the &quot;forebay&quot; area. Study Area estimate assumes Sokol's Alluvial Fan budget included Atherton Creek and Matadero Creek. It adds contemporary estimate of percolation from other small creeks.</td>
<td></td>
</tr>
<tr>
<td>Santa Clara County creeks</td>
<td>114</td>
<td>2,900</td>
<td></td>
</tr>
<tr>
<td>Laguna percolation</td>
<td>710</td>
<td>700 Sokol ([1964] Table 19. For Study Area, estimate is 3 times greater, in proportion to length of western boundary.</td>
<td></td>
</tr>
<tr>
<td>Bedrock inflow</td>
<td>35</td>
<td>100 Sokol ([1964] Table 19. For Study Area, estimate is 3 times greater, in proportion to length of western boundary.</td>
<td></td>
</tr>
<tr>
<td><strong>Groundwater inflow from Santa Clara Plain</strong></td>
<td>654</td>
<td>0 Sokol ([1964] pp. 84 and 90 mentioned as possible but did not quantify. The estimate shown here equals the remainder needed to reach Sokol's total estimated recharge of 3,000 AFY (divided equally between San Mateo and Santa Clara Plains). Study Area estimate is 0; groundwater elevation contours indicate groundwater flow is parallel to the Study Area boundary.</td>
<td></td>
</tr>
<tr>
<td><strong>Groundwater inflow from SF Bay/Niles Cone</strong></td>
<td>small</td>
<td>200 Sokol: Saltwater intrusion restricted by clay layers. Mostly where clays are penetrated by long-screen wells or &quot;broken&quot; by stream incision. (p. 178). Study Area estimate is a small number that recognizes the presence of landward gradients combined with a high percentage of clay and poor connection with the Bay.</td>
<td></td>
</tr>
<tr>
<td><strong>Groundwater inflow from San Mateo Plain</strong></td>
<td>654</td>
<td>0 See note for &quot;Groundwater inflow from Santa Clara Plain&quot;.</td>
<td></td>
</tr>
<tr>
<td><strong>Clay compaction yield</strong></td>
<td>n.m.</td>
<td>1,400 Not mentioned specifically by Sokol (1964). Study Area estimate equals average 1934-1954 subsidence over eastern 2/3 of the Alluvial Fan (0.8 ft, from Poland and Green, 1962) divided into 20 years and increase by factor of 4 to account for the additional area inside the Study Area but south of the Alluvial Fan and the larger amount of subsidence south of Palo Alto (Poland and Green, 1963).</td>
<td></td>
</tr>
<tr>
<td><strong>Total inflows</strong></td>
<td>3,000</td>
<td>13,200 Sokol p. 90: equals pumping (7,500 AFY) minus storage depletion (4,500 AFY).</td>
<td></td>
</tr>
<tr>
<td><strong>Outflows</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water supply</td>
<td>7,500</td>
<td>15,000 Sokol p. 90: 5,500 AFY by City of Palo Alto up to 1962; 920 AFY by Stanford; 920 AFY by others. He rounded up to 7500 AFY. For Study Area, estimate is double the Alluvial Fan estimate based on 1960 census population distribution.</td>
<td></td>
</tr>
<tr>
<td>Remediation</td>
<td>0</td>
<td>0 Presumably zero.</td>
<td></td>
</tr>
<tr>
<td>Dewatering</td>
<td>0</td>
<td>0 Probably close to zero due to low groundwater levels.</td>
<td></td>
</tr>
<tr>
<td>Riparian/wetland evapotranspiration</td>
<td>n.m.</td>
<td>500 Assume same as existing condition</td>
<td></td>
</tr>
<tr>
<td><strong>Groundwater seepage to</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sanitary sewers</td>
<td>n.m.</td>
<td>1,000 Area near the Bay was nearly as developed in 1960 as it is today. Deep water levels were much lower, shallow levels probably were lower, too. Assume a flow equal to half of existing flow.</td>
<td></td>
</tr>
<tr>
<td>Creeks and storm drains</td>
<td>n.m.</td>
<td>2,200 Area near the Bay was nearly as developed in 1960 as it is today. Deep water levels were much lower, shallow levels probably were lower, too. Assume a flow equal to half of existing flow.</td>
<td></td>
</tr>
<tr>
<td><strong>Groundwater outflow to Santa Clara Plain</strong></td>
<td>n.m.</td>
<td>0 Water level contours for 1966 indicate a flow divide along Stevens Creek due to pumping troughs (Page and Wire, 1969).</td>
<td></td>
</tr>
<tr>
<td><strong>Groundwater outflow to SF Bay or Niles Cone</strong></td>
<td>n.m.</td>
<td>0 Gradient is from SF Bay toward inland areas. Therefore no outflow.</td>
<td></td>
</tr>
<tr>
<td><strong>Groundwater outflow to San Mateo Plain</strong></td>
<td>n.m.</td>
<td>0 Historical water level declines were small toward Redwood City and large toward Sunnyvale, so northern Study Area boundary flow was not likely outward.</td>
<td></td>
</tr>
<tr>
<td><strong>Total outflows</strong></td>
<td>7,500</td>
<td>18,700</td>
<td></td>
</tr>
<tr>
<td><strong>Storage Change</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflows minus outflows</td>
<td>-4,500</td>
<td>-5,500 Sokol (1964, p. 90) estimated total inflows from his water-level estimate of storage change, so the inflow-outflow and water-level estimates match. For Study Area, the difference between the two storage change estimates reflects uncertainty in both methods of estimation.</td>
<td></td>
</tr>
<tr>
<td>Estimate from change in water levels</td>
<td>-4,500</td>
<td>-9,000 Sokol (p. 90) rounded down the product of his factors: 5 ft/yr x 18 mi x 0.082 = 4,723 AFY. For Study Area, water-level decline during 1915-1967 in Study Area south of the Alluvial Fan was about the same as in the eastern part of the Fan (Poland and Ireland, 1988, Fig 14) even though subsidence was greater (Fig. 21). So double the Alluvial Fan estimate to account for increased area.</td>
<td></td>
</tr>
</tbody>
</table>
The Sokol study area, referred to as the San Francisquito Creek Basin or San Francisquito Alluvial Fan was described as including parts of Palo Alto, Menlo Park, Atherton, and Redwood City and most of the land of Stanford University encompassing an area of 21.6 square miles. The approximate Sokol (1964) study area is shown on Figure 3-10. The Sokol study area was similar to, but slightly larger than the area used by Killingsworth and Hyde (20 square miles). The water budget carried forward the assumption of Killingsworth and Hyde that recharge to the deep zone does not occur in the confined part of the groundwater system. Except for San Francisquito Creek percolation, Sokol’s estimates of recharge were for the “forebay” part of the Alluvial Fan. Pumping, on the other hand, was for the entire Alluvial Fan. Compared to the Killingsworth and Hyde budget, Sokol’s budget had similarly negligible amounts of rainfall and irrigation recharge but included an explicit estimate of recharge from Lake Lagunita and a more generous estimate of creek recharge (885 AFY).

Sokol calculated that storage depletion amounted to 4,500 AFY, which supplied over half of the estimated 7,500 AFY of pumping. Groundwater yield from compaction of clays during subsidence was not mentioned by Sokol. Groundwater inflow was implicitly the residual in his water budget but “storage from adjacent areas” was mentioned only in passing and without quantification. In Table 3-4, the residual of Sokol’s alluvial fan water budget was divided equally into groundwater inflow from the north and south.

An estimate of the water balance for the entire Palo Alto IPR Study Area in the early 1960s was developed to estimate yield at a time when pumping greatly exceeded contemporary pumping and water levels were declining. The result is shown in a separate column in Table 3-4. The study area water balance was developed partly by extrapolating Sokol’s flow estimates from the San Francisquito Creek Alluvial Fan to the larger Study Area, and partly by including some flow items from the contemporary water balance that were not explicitly tabulated by Sokol. The total Study Area is about three times larger than the alluvial fan, and the onshore, nontidal parts of the two regions differ by a similar ratio. Accordingly, the Study Area water balance would be expected to be several times larger than the San Francisquito Alluvial Fan water balance. For rainfall recharge and deep percolation of applied irrigation water, methods used for the contemporary water balance (see Section 3.4.4) were applied to estimated impervious, irrigated and non-irrigated areas as of 1962. Water pipe leaks were assumed to equal 10% of annual water deliveries, which for the Study Area were assumed to equal twice the amount of municipal pumping by the City of Palo Alto (based on local city populations reported in the 1960 census). The sewer pipe leak rate was assumed to equal half the water pipe leak rate and was applied to indoor water use (estimated to equal 40% of total municipal water use). Historical water-level declines and subsidence increased from Menlo Park toward San Jose.

Part of the yield in the early 1960s was water released by clay layers as they compacted during subsidence. Poland and Green (1962) showed an average of about 0.8 foot of cumulative subsidence over the eastern two-thirds of the San Francisquito Cone area during 1934-1954. This corresponds to 340 AFY of water released from clays during that period. Average water-level declines in the part of the Study Area south of the San Francisquito Creek Alluvial Fan were similar to the declines within the Fan (Poland and Ireland, 1988), but subsidence was two to three times greater (Poland and Green, 1962). Storage depletion in the Study Area was assumed to be proportional to water-level decline. The Study Area region south of the San
Francisquito Creek Alluvial Fan is about the same size as the fan itself, so the Alluvial Fan estimate of clay compaction yield was scaled up by a factor of four to obtain the Study Area estimate.

Groundwater pumping in the Study Area was estimated to be double the amount in the Sokol study area, based on 1960 population data. Evapotranspiration by riparian vegetation was included as an outflow (rather than subtracted from stream recharge) and was assumed to equal the contemporary flow. Groundwater flows across the northern, eastern and southern boundaries of the Study Area are difficult to estimate due to sparse and variable water-level contour information and uncertain aquifer thicknesses and hydraulic conductivities to associate with the water-level gradients to obtain estimates of flow. For lack of clear evidence to the contrary, the budget table lists these flows as zero except for 200 AFY of inflow from the east (reflecting clearly westward water level gradients but low average hydraulic conductivity).

For the Study Area water balance, average annual outflows exceeded average annual inflows by 5,500 AFY. A separate estimate based on water-level declines was 9,000 AFY. The latter estimate was simply double Sokol’s estimate for the Alluvial Fan area. All items in the water balance and the factors in the water-level estimate of storage change are subject to uncertainty. The discrepancy between the storage change estimates indicates that substantial errors are present in the calculations. It is not clear which details are in error, however. The difference between pumping and storage depletion can provide a rough estimate of operable yield. If no other budget items responded to a decrease in pumping, the estimate of operable yield would be 6,000 to 9,500 AFY. However, all head-dependent flows change in response to pumping, not just the storage change. A reduction in pumping would raise water levels, which would tend to decrease groundwater inflows, decrease percolation from streams and increase groundwater discharge into streams. All of those changes would diminish yield. Thus, the amount of pumping associated with no long-term decrease in storage would be less than the 6,000 to 9,500 AFY range. This adjustment cannot be estimated without tools that account for groundwater hydraulics, such as a groundwater flow model.

### 3.4.4 Contemporary Water Balance

A water balance was prepared representing average annual groundwater inflows, outflows and storage changes under land use and water use conditions present in 2017. Compared to the historical water balances, the contemporary water balance has relatively little groundwater pumping and relatively high groundwater levels. The contemporary water balance is the starting point for flow modeling scenarios for future groundwater development and management feasibility analysis. Also, differences between the contemporary and historical water balances provide useful information for estimating the operable yield available under future conditions.

#### 3.4.4.1 Recharge Zones

A recharge simulation model was applied to the entire watershed area of all streams that cross the San Mateo Plain and Santa Clara Plain Subbasins in addition to the subbasin areas themselves. This provided estimates of stream flow and subsurface flow entering the Study Area based on water balance calculations for tributary watershed areas. It also enabled correct
accounting for mass balance in water service areas and wastewater sewer areas, many of which extend beyond the Study Area boundary into tributary watershed areas and adjoining parts of the subbasins.

A total of 740 individual recharge zones were delineated by overlaying the geographic distributions of the following factors in GIS:

*Groundwater basin.* The unconsolidated deposits in the San Mateo Plain and Santa Clara Subbasins are bounded to the southwest by upland terrain underlain by consolidated rocks. The edge of the Subbasin materials is the basin boundary delineated in DWR Bulletin 118. For this water balance analysis, the San Francisquito Creek alluvium upstream of the Pulgas Fault (near Alameda de las Pulgas) is considered part of the upland region because groundwater outflow from that alluvium becomes surface flow in San Francisquito Creek where it crosses the fault. The Bay plain groundwater subbasin areas were further divided along the inland extent of tidal marshes as of 1873. Although aquifers containing fresh groundwater extend east beneath the marshes, any “recharge” in that area that would actually accrue to the Bay via tidal channels in the marshes. 1873 is the date of the oldest detailed map of the pre-development extent of tidal marshes (State Geological Survey of California, 1873).

*Watersheds.* The locations of watersheds tributary to or within the Study Area (Figure 3-3) were used primarily for subtotaling recharge results by watershed.

*City boundaries.* The boundaries of cities and unincorporated areas (Figure 3-5) were used primarily for subtotaling recharge results by city.

*Water purveyor service areas.* Eleven water purveyors deliver water to retail customers in the Study Area. Their service areas are shown in Figure 3-37. Information from urban water management plans (UWMPs) for individual purveyors was used to estimate groundwater recharge from water and sewer pipe leaks. Recharge zones within each service area were assigned pipe leak recharge rates based on the area and density of development in the zone relative to the average density for the service area.

*Wastewater collection areas.* The Study Area includes parts of six sewer service areas that convey wastewater to three wastewater treatment plants, as shown on the map in Figure 3-38. Metered flow data are available for some of the wastewater collection areas and were evaluated for indications of groundwater infiltration.

*Land use.* Land use categories and a map of land use relative to hydrologic characteristics (Figure 3-4) were discussed in Section 3.2.5.

*Rainfall.* Some of the recharge zones delineated on the basis of the foregoing variables were quite large and spanned a wide range of annual rainfall. These large zones were divided along rainfall isohyets (Figure 3-2) to span a range of no more than about two inches per year of average annual rainfall.

Intersecting these variables in GIS resulted in hundreds of tiny sliver polygons where similar polygon edges among the various layers did not quite match up. Polygons less than about five acres in size were merged with adjoining larger polygons.
3.4.4.2 Study Period

The contemporary water balance represents the average annual groundwater balance in the Study Area under current land use and water use conditions. The various sources of data used to develop the water balance have different periods of record and/or monitoring intervals. For some variables, such as bedrock inflow, attempting to develop a historical time series with monthly or even annual time steps would be speculative at best, and long-term average rates were used for all time periods. The recharge simulation model simulates rainfall, interception, runoff, evapotranspiration, irrigation and deep percolation on a daily basis. The two transient input data sets are rainfall and ET0. For this study, complete daily time series were developed for calendar years 1985-2014 by correlation among stations. The cumulative departure plots of annual rainfall at Redwood City and San Jose shown in Figure 3-39 indicate that average annual rainfall during 1985-2014 was 97% of the long-term average for Redwood City and 103% of the long-term average for San Jose. Thus, that period is reasonable for estimating rainfall-related recharge flows.

The extent of urban development in the Study Area has been fairly stable over the past 10 years, although infill development occurs at a gradual rate. Accordingly, estimates of impervious area, irrigated area and pipe leaks based on data from that period reasonably represent current conditions.

3.4.4.3 Inflows

The estimated average annual water balance of the Study Area under current land and water use conditions is shown in Table 3-5. The assumptions, data and calculations used to quantify each flow item are described in the following sections.

3.4.4.3.1 Rainfall Percolation

Each recharge zone was divided into three land cover categories expressed as percentages of the total zone area: impervious, irrigated and non-irrigated. In non-irrigated areas, rainfall is the only source of soil moisture. Rainfall infiltration into the soil was calculated by subtracting interception and runoff losses from rainfall. Interception ranged from 0.00 inch for industrial and vacant areas with little vegetative cover to 0.08 inch for land uses with predominantly tree cover (Maidment, 1993). This loss was applied to each day in which rainfall occurred. Rainfall was extrapolated to individual zones from the Redwood City and San Jose gages based on the ratio of average annual rainfall at the zone location to average annual rainfall at the gage. Runoff was calculated using a stepwise linear function. Runoff was assumed to be zero below a specified threshold of daily rainfall, above which a specified percentage of the additional rainfall was assumed to infiltrate. Infiltration was also capped at a maximum daily amount, with any excess rainfall becoming runoff. Runoff thresholds ranged from 0.3 inch in industrial areas to 0.8 inch on turf areas. For any excess rainfall, infiltration ranged from 70% in industrial areas to 90% in residential areas. Infiltration was capped at 3 inches per day. The values of these parameters were merged from separate similar analyses of recharge in the Santa Clara Subbasin and San Mateo Plain Subbasin (Todd, 2016; EKI et al., 2017).
### Table 3-5 Contemporary Average Annual Water Balance

<table>
<thead>
<tr>
<th>Inflow or Outflow</th>
<th>Groundwater Study Area (AFY)</th>
<th>Plausible Range (AFY)</th>
<th>Location</th>
<th>Period of Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inflows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep percolation through soils</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall - runoff from impervious areas</td>
<td>2,300</td>
<td>1,100 to 3,400</td>
<td>By recharge zones</td>
<td>1985-2014</td>
<td>Recharge zone simulations. Runoff from impervious surfaces to adjacent pervious soils.</td>
</tr>
<tr>
<td>Rainfall - nonirrigated areas</td>
<td>1,500</td>
<td>700 to 2,300</td>
<td>By recharge zones</td>
<td>1985-2014</td>
<td>Recharge zone simulations.</td>
</tr>
<tr>
<td>Irrigated areas</td>
<td>5,800</td>
<td>2,000 to 8,700</td>
<td>By recharge zones</td>
<td>1985-2014</td>
<td>Recharge zone simulations. Includes rainfall recharge on irrigated areas.</td>
</tr>
<tr>
<td>Pipe leaks</td>
<td></td>
<td></td>
<td></td>
<td>1985-2014</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1,800</td>
<td>900 to 3,600</td>
<td>By purveyor</td>
<td>1985-2014</td>
<td>Estimated real loss percentages per purveyors' 2015 UWMPs; pro-rated to service area within IPR Study Area and adjusted for evapotranspiration losses.</td>
</tr>
<tr>
<td>Sewer</td>
<td>400</td>
<td>200 to 800</td>
<td>By purveyor</td>
<td>1985-2014</td>
<td>Indoor use for individual purveyors estimated by seasonal water use curve separation. Sewer leak rate assumed half of water pipe leak rate.</td>
</tr>
<tr>
<td><strong>Stream percolation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>San Franciscoquto Creek</td>
<td>1,100</td>
<td>700 to 1,500</td>
<td>Below Pulgas Fault</td>
<td>1997, 2017</td>
<td>Metzger (2002) and 2017 measurements.</td>
</tr>
<tr>
<td>San Mateo County creeks</td>
<td>100</td>
<td>50 to 300</td>
<td>Unlined reaches</td>
<td>2016-2017</td>
<td>Extrapolation of streamflow losses measured on 5/5/16 and 6/12/17 to long-term average values.</td>
</tr>
<tr>
<td>Santa Clara County creeks</td>
<td>3,100</td>
<td>2,000 to 4,200</td>
<td>Unlined reaches</td>
<td>2016-2017</td>
<td>Extrapolation of streamflow losses measured on 5/5/16 and 6/12/17 to long-term average values; plus 1,420 AFY of percolation releases by SCVWD along Stevens Creek.</td>
</tr>
<tr>
<td><strong>Lagunita percolation</strong></td>
<td>400</td>
<td>200 to 600</td>
<td></td>
<td>2002-present</td>
<td>Reflects operations since 2002 (for habitat, not recreation)</td>
</tr>
<tr>
<td><strong>Bedrock inflow</strong></td>
<td>900</td>
<td>300 to 1,500</td>
<td>Western Study Area boundary</td>
<td>1985-2014</td>
<td>Average annual total recharge in zones adjacent to basin but not near creeks.</td>
</tr>
<tr>
<td><strong>Groundwater inflow from Santa Clara Plain</strong></td>
<td>0</td>
<td>0 to 2,000</td>
<td></td>
<td>2016-2017</td>
<td>Groundwater elevation contours parallel to Bay based on assessment of historical contour maps prepared by the District, for the San Mateo Study, and prepared by Todd as presented herein in Figures 3-25 through 3-28. These maps represent the end of an extended dry period (Fall 2016) and a very wet period (Spring 2017).</td>
</tr>
<tr>
<td><strong>Groundwater inflow from SF Bay/Niles Cone</strong></td>
<td>0</td>
<td>0 to 1,000</td>
<td></td>
<td>2010-2017</td>
<td>Assumed. Shallow and deep water-level gradients in 2010, 2016 and 2017 were toward San Francisco Bay.</td>
</tr>
<tr>
<td><strong>Groundwater inflow from San Mateo Plain</strong></td>
<td>0</td>
<td>0 to 300</td>
<td></td>
<td>2010</td>
<td>2010 contours from San Mateo Plain study were perpendicular to boundary line.</td>
</tr>
<tr>
<td><strong>Clay compaction yield</strong></td>
<td>0</td>
<td>0 to 100</td>
<td></td>
<td>1985-2014</td>
<td>Water levels now much higher than historical lows, so assume no subsidence.</td>
</tr>
<tr>
<td><strong>Total inflows</strong></td>
<td>17,400</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Outflows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wells</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water supply</td>
<td>5,500</td>
<td>4,000 to 7,000</td>
<td>By well</td>
<td>2005-2014</td>
<td>1,877 AFY in San Mateo County and 3,630 AFY for AG, DO and MI users in SCVWD database.</td>
</tr>
<tr>
<td>Remediation</td>
<td>1,100</td>
<td>900 to 2,500</td>
<td>By well</td>
<td>2005-2016</td>
<td>1,027 AFY in SCVWD (2005-2014); 90 AFY for San Mateo County (2012-2014).</td>
</tr>
<tr>
<td>Dewatering</td>
<td>1,600</td>
<td>1,300 to 3,200</td>
<td>By well</td>
<td>2016</td>
<td>Palo Alto: 417 AFY construction + 205 AFY industrial + 161 AFY Oregon Expressway underpass = 783 AFY. Mt. View and San Mateo County dewatering each assumed to equal half the Palo Alto amount.</td>
</tr>
<tr>
<td>Riparian/wetland evapotranspiration</td>
<td>500</td>
<td>200 to 600</td>
<td>By creek</td>
<td>2012</td>
<td>Riparian canopy area x groundwater evapotranspiration rate.</td>
</tr>
<tr>
<td><strong>Groundwater seepage to</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sanitary sewers</td>
<td>2,000</td>
<td>1,000 to 3,000</td>
<td>By WWTP or pump station</td>
<td>2010-2016</td>
<td>Dry-season recession of treatment plant inflows, increased by one-third to obtain annual estimate.</td>
</tr>
<tr>
<td><strong>Groundwater outflow to Santa Clara Plain</strong></td>
<td>0</td>
<td>0 to 2,000</td>
<td>Southern Study Area boundary</td>
<td>2016-2017</td>
<td>On average, SCVWD contours are perpendicular to boundary line. See Source for Groundwater inflow from Santa Clara Plain.</td>
</tr>
<tr>
<td><strong>Groundwater outflow to SF Bay or Niles Cone</strong></td>
<td>2,200</td>
<td>1,100 to 3,300</td>
<td>Eastern Study Area boundary</td>
<td>2010-2017</td>
<td>Residual: allocate 2/3 to creeks and wetlands and 1/3 to SF Bay and Niles Cone.</td>
</tr>
<tr>
<td><strong>Groundwater outflow to San Mateo Plain</strong></td>
<td>0</td>
<td>0 to 300</td>
<td>Northern Study Area boundary</td>
<td>2010</td>
<td>2010 contours from San Mateo Plain study were perpendicular to boundary line.</td>
</tr>
<tr>
<td><strong>Total outflows</strong></td>
<td>17,400</td>
<td>10,500 to 28,900</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Storage Change</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflows minus outflows</td>
<td>0</td>
<td>-3,000 to 3,000</td>
<td>Study Area</td>
<td>1985-2014</td>
<td>Assumed zero average annual storage change. Water balance residual is outflow to creeks and SF Bay or Niles Cone.</td>
</tr>
<tr>
<td>Estimate from change in water levels</td>
<td>0</td>
<td>-3,000 to 3,000</td>
<td>Study Area</td>
<td>2010-2017</td>
<td>Current long-term water-level trend is level, indicating no long-term storage change.</td>
</tr>
</tbody>
</table>

**AFY** - acre-feet per year  
**WY** - water year  
**UWMP** - Urban Water Management Plan  
**n.m.** - not mentioned in historical report  
**SCVWD** - Santa Clara Valley Water District  
**MI** - municipal/industrial  
**AG** - agricultural  
**DO** - domestic  

* The water balance is for the Palo Alto IPR Groundwater Study area. The water balance represents land and water use conditions as of 2016 during a period of average annual water use.  
* Totals may not equal sum of items due to rounding.  
* Extrapolation of streamflow losses measured on 5/5/16 and 6/12/17 to long-term average values.  
* The water balance is for the Palo Alto IPR Groundwater Study area. The water balance represents land and water use conditions as of 2016 during a period of average annual water use.  
* Groundwater outflow to Santa Clara Plain and Niles Cone because the extent of the subbasins isn't defined under the Bay and they are all connected.
The amount and type of impervious area strongly influence rainfall recharge. Total impervious area can be divided into "connected" and "disconnected" categories, which have opposite effects on rainfall recharge. Impervious areas are "connected" if runoff flows to a storm drainage system consisting of gutters, pipes and concrete channels that remove runoff from the Study Area with little opportunity for infiltration. Connected impervious areas decrease groundwater recharge. Impervious areas are "disconnected" if runoff flows to adjacent pervious soils and largely infiltrates. These areas tend to increase groundwater recharge because the runoff is focused into a relatively small pervious area, where the additional infiltration tends to rapidly saturate the soil moisture profile and initiate deep percolation below the root zone. Common examples include patios, walkways, sidewalks and roof downspouts that discharge to landscaping.

Various methods are available to measure either total or connected impervious percentage of an urban area, and they all have limitations. For example, the percent total impervious area in 17 San Mateo County watersheds was estimated by the San Mateo County Stormwater Pollution Prevention Program (2005) by delineating subareas with specific land uses on aerial photographs and assigning impervious percentages from tables compiled by the Association of Bay Area Governments (ABAG). For some categories, the impervious percentage was obtained by digitizing all impervious surfaces on a single block from high-resolution aerial photographs. The derivation of the ABAG percentages was not discussed, and as with all remote-sensing methods, tree canopy can interfere with the delineation of impervious surfaces. There are also variations among different areas with the same land use and difficulties identifying land use from aerial photographs. This method obtains an estimate of total impervious area.

Spectral analysis of reflected light for each pixel of a satellite image can also be used to estimate impervious area. The National Land Cover Dataset contains the estimated impervious percentage for 30 x 30-meter grid cells covering the entire continental United States (http://www.mrlc.gov/nlcd2011.php). This method produces estimates of total impervious area. The method applies spectral "fingerprints" developed from the statistical distributions of wavelengths in "training" areas. Errors arise from differences in spectral patterns between the training areas and the area of interest, and the method does not detect impervious areas beneath tree canopy (Xian, 2016). For example, total impervious area in residential areas with many mature trees, such as Atherton, would tend to be underestimated relative to impervious percentage in other parts of the Study Area. Inspection of individual pixel values in the Study Area revealed a large degree of variability among adjacent pixels within areas that would be classified as having the same land use; however, averaging over an independently-delineated land use area could provide a reasonable estimate of total impervious area.

Connected and disconnected impervious areas cannot be differentiated using remote sensing methods. The amount of connected impervious area can be estimated if stream flow data are available for rainfall runoff from an urban catchment. In this approach, all runoff during small rain storms is assumed to be from impervious areas, and the volume of runoff for the storm event (usually one to three days using daily data) is compared with the volume of rainfall. This approach was applied to several suitable gaged valley floor subwatersheds in the Santa Clara Subbasin and to the Colma Creek watershed in South San Francisco. For a groundwater model of the Santa Clara Subbasin, rainfall and runoff for about 20 small storm events were calculated
for four urban catchments. Land use within the catchments was delineated from aerial photographs, and the connected impervious percentages for each land use were adjusted by calibration to obtain the best possible match between simulated and gaged runoff across all of the catchments and storm events (Todd, 2016). Those percentages were used as initial estimates for the same land uses in the Study Area.

For the San Mateo Plain groundwater study (EKI et al., 2017), land uses within the developed part of the Colma Creek watershed were similarly delineated, and the linear relationship between rainfall and runoff for a range of small storm events indicated that connected impervious area covered 68% of the developed watershed area. Matching this overall average with percentages by land use (residential, commercial and vacant) required values much higher than the ones obtained from the Santa Clara Subbasin analysis.

A possible explanation for the differing estimates of impervious percentage is that some rainfall runoff flows to sanitary or storm sewers, bypassing gages in creeks. In San Mateo, for example, the sanitary sewer system receives a substantial percentage of impervious area runoff. A flow survey of 36 subareas in the sewer collection area for the San Mateo wastewater treatment plant found that the percent of rainfall entering the sanitary sewer system ranged from 2 to 88% of the rain falling on the entire sewered area, not just the impervious part of the sewered area (West Yost Associates, 2016). The area-weighted average over the entire sewered area was approximately 20% of total rainfall. This indicates that the amount of runoff entering the sanitary sewer system was of the same order of magnitude as runoff to creeks. Because rainfall inflow reflects the design and age of the sewer system, the results for the San Mateo wastewater treatment plant do not necessarily apply to impervious runoff in the entire Study Area.

The Study Area straddles the Santa Clara and San Mateo Plain Subbasins. For this study, a single consistent set of recharge zones and parameters was developed for both subbasins, and results were extracted for the Study Area. Parameter values from the two prior studies were selected or averaged depending on the quality of supporting data and the water balance calibration results. Table 3-6 summarizes the estimates of total and connected impervious area by land use category and lists the values used in the recharge simulation model for this study.

The recharge simulation model simulates soil moisture storage as a "bathtub" with a maximum storage capacity equal to the plant root depth multiplied by the available water capacity of the soil (which is texture-dependent). A range of available water capacity typical of sandy to clay loams (0.10 to 0.22 inch per inch, with most values between 0.13 and 0.17) was assigned to recharge zones based on a partial soils map. Root depth represented an average over the vegetated area given the estimated mix of plant types and the root distribution beneath and between individual plants. Most urban irrigation is for lawns, for which a root depth of 18 inches was assumed. For non-irrigated vegetation in urban areas a root depth of 72 inches was assumed. For areas of non-irrigated natural vegetation, root depths were assumed to be 48 inches for grass/weeds, 72 inches for brush, and 84 inches for trees.
Table 3-6  Impervious Land Cover Percentages

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Santa Clara Plain Runoff&lt;sup&gt;a&lt;/sup&gt;</th>
<th>ABAG Table&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Colma Creek Runoff&lt;sup&gt;c&lt;/sup&gt;</th>
<th>San Mateo WWTP Inflow&lt;sup&gt;d&lt;/sup&gt;</th>
<th>National Land Cover Database&lt;sup&gt;e&lt;/sup&gt;</th>
<th>Handbook of Hydrology&lt;sup&gt;f&lt;/sup&gt;</th>
<th>Selected Values for San Mateo Plain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Connected</td>
<td>Total</td>
<td>Connected</td>
<td>Partial Connected</td>
<td>Total</td>
<td>Connected</td>
<td>Disconnected</td>
</tr>
<tr>
<td>Natural vegetation - grass</td>
<td>2</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>7</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Natural vegetation - brush</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Natural vegetation - trees</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Open water</td>
<td>--</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Rural residential</td>
<td>--</td>
<td>10</td>
<td>--</td>
<td>--</td>
<td>7</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Urban residential</td>
<td>25</td>
<td>47</td>
<td>63</td>
<td>20</td>
<td>45</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Urban residential - lush</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>15</td>
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<td>39</td>
</tr>
<tr>
<td>Urban commercial</td>
<td>30</td>
<td>93</td>
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<td>65</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>Urban industrial</td>
<td>30</td>
<td>91</td>
<td>85</td>
<td>20</td>
<td>61</td>
<td>72</td>
<td>80</td>
</tr>
<tr>
<td>Urban vacant</td>
<td>40</td>
<td>66</td>
<td>70</td>
<td>--</td>
<td>57</td>
<td>--</td>
<td>50</td>
</tr>
<tr>
<td>Large turf areas</td>
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<td>--</td>
<td>0</td>
<td>--</td>
<td>0</td>
</tr>
</tbody>
</table>

<sup>a</sup> - Comparison of rainfall and runoff in four catchments by Todd Groundwater (2016).
<sup>b</sup> - ABAG table values cited in San Mateo Countywide Pollution Prevention Program (2002).
<sup>c</sup> - Comparison of rainfall and runoff in Colma Creek watershed for this study.
<sup>d</sup> - Comparison of rainfall and WWTP inflows by West Yost Associates (2016).
<sup>e</sup> - Spectral analysis of satellite imagery in San Mateo basin (Homer et al., 2007). 30-meter pixel values averaged by land use.
<sup>f</sup> - Textbook values in Handbook of Hydrology (Maidment, 1993).

Values in table indicate percent of total land area that is impervious.

ABAG - Association of Bay Area Governments
WWTP - wastewater treatment plant
Water consumed by plant transpiration was simulated by multiplying daily ET₀ by a crop coefficient that reflects the difference in water use between the vegetation and the reference well-watered turf (which defines ET₀). In winter, when rainfall infiltration exceeds evapotranspiration, soil moisture increases. When simulated soil moisture exceeds the soil moisture storage capacity, the excess is assumed to become deep percolation. In tributary watersheds, the deep percolation accrues to shallow groundwater storage that flows laterally and becomes stream base flow. For zones overlying the Study Area, all of the deep percolation was assumed to become groundwater recharge. Average annual rainfall recharge on non-irrigated lands and from disconnected impervious areas was estimated to be 3,800 AFY. Recharge on irrigated lands within the Study Area averaged 5,800 AFY, which derived from a combination of rainfall infiltration and deep percolation of irrigation water.

### 3.4.4.3.2 Irrigation Deep Percolation

When simulated soil moisture in irrigated areas falls below a specified percentage, the recharge simulation model assumes an irrigation event occurs. Irrigation is assumed to fully replenish soil moisture storage. Because of non-uniformity of application, however, irrigation is not 100% efficient. In order to fully replenish soil moisture throughout the irrigated area, some locations will receive more than enough water, and the excess is assumed to become deep percolation. Because of the small, irregular shapes of typical irrigation zones in residential and commercial settings, sprinkler overspray and runoff are common. An overall efficiency of 75% was assumed for residential and commercial land uses, meaning only 75% of the applied water is actually transpired by plants. Studies have found that even lower efficiencies are common (Baum et al., 2005; Xiao et al., 2007; Kumar et al., 2009). The 25% of applied water not consumed by plants was assumed to become deep percolation (10%) and runoff into storm drains (15%). For the average annual water balance table, irrigation water use was averaged over the 32-year simulation period and summed for all of the recharge zones in the Study Area.

For the San Mateo Plain groundwater study (EKI et al., 2017), the amount of irrigation estimated by the recharge simulation program was compared with a second estimate obtained by the curve separation method, which is an analysis of seasonal variations in municipal water use. In the month of minimum water use, usually February, all water is assumed to be used indoors, and irrigation is assumed to be zero. In northern California, this assumption is reasonably accurate. Furthermore, indoor use is assumed to be constant in all months, and the additional water use in March through January is assumed to be for irrigation. When this procedure was applied to 2004-2014 water use in eight purveyor service areas in the San Mateo Plain Subbasin, the resulting estimate of overall irrigation water use was within 0.2% of the recharge simulator estimate and within 3% for each of the three largest purveyors. The similarity of the two estimates provides increased confidence in the values.

For the Study Area, total irrigation estimated by the recharge simulation program was 13,300 AFY, and deep percolation of applied water was approximately 2,000 AFY. This is included in the 5,800 AFY of deep percolation from rainfall and irrigation described in the previous section.

### 3.4.4.3.3 Water and Sewer Pipe Leaks

Water, sewer and storm drain pipes in urban areas leak to some extent, creating a source of recharge to the underlying groundwater system. Conversely, sewer and storm drain pipes can
gain flow from infiltration of groundwater where the water table is high. Leaks are often small and difficult to detect. Of the three types of pipelines, municipal water distribution systems are typically the most studied and best maintained. Leak rates are relatively high because the pipes are pressurized, but leak detection is relatively aggressive because the leakage can be a significant economic loss and leak detection is a best management practice for water conservation. One leak detection program audited 47 California water utilities and found an average loss of 10%, with a range of 30% to less than 5% of the total annual flow. Another study monitored water use at numerous individual residences in ten medium to large California water systems using data loggers, and it found an average leak rate of 18% of the delivered volume (Aquacraft, 2011). A U.S. Environmental Protection Agency (USEPA) study found that "unaccounted for water" (which includes incidental unmetered uses in addition to leaks) in the range of 10% to 20% of total volume delivered is normal (Lahlou, 2001).

Large water purveyors are required to update their UWMPs every five years, and recent updates include breakdowns of unaccounted for water into apparent and real losses. Apparent losses are known unmetered uses of water, such as for fire hydrants and water main flushing. All remaining unaccounted-for water is assumed to be leakage from the distribution system. For the twelve water purveyors whose service areas at least partly overlap the Study Area, estimated distribution system leakage (real, not apparent losses) ranged from 0.5% to 4.4% of delivered water. The water system leak rate is expressed as a percentage of flow because of the water-balance approach used to estimate it. However, it is actually independent of flow because the network of pressurized pipes would leak even if all faucets and other outlets were turned off.

Not all water pipe leakage becomes groundwater recharge. Because leaks generate soil moisture year-round at a slow, steady rate, it is very likely that substantial amounts of the water are intercepted by tree roots, where trees are present. For the water balance analysis, trees were assumed to intercept one-third of the annual leakage, with the remainder becoming groundwater recharge. The estimated average annual groundwater recharge from water pipe leaks in the Study Area was 1,800 AFY and is broken down by month and purveyor in Table 3-7.

Sewer pipes also leak, and the volume of leakage was estimated in a two-step process. First, as described above, indoor water use was estimated by curve separation of monthly purveyor water production. Almost all water used indoors leaves the building as wastewater in drains; only about 2% is consumed (Mitchell et al., 2001). Sewer leaks receive less attention than water pipe leaks, and few studies are available in the literature. Because sewer pipes are mostly gravity flow, and leaks probably self-seal to some extent due to clogging by solids and biofilms, the sewer pipe leak rate was assumed to be half the water pipe leak rate. Based on these assumptions, the average annual groundwater recharge from sewer pipe leaks in the Study Area was estimated to be 400 AFY. Estimated groundwater recharge from sewer pipe leaks is listed by month and purveyor in Table 3-8. Note that sewer system service areas have different boundaries than water service areas, but both types of pipes are present throughout the urban areas and for groundwater recharge calculations it does not matter to which treatment plant the sewer is flowing.
### Table 3-7  Average Monthly water Pipe Leaks in Study Area (in acre-feet)

<table>
<thead>
<tr>
<th>Purveyor</th>
<th>Percent in IPR Study Area</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
<th>YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Los Altos</td>
<td>69%</td>
<td>9.19</td>
<td>9.67</td>
<td>12.12</td>
<td>12.56</td>
<td>17.49</td>
<td>22.08</td>
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<td>25.26</td>
<td>20.16</td>
<td>12.55</td>
<td>8.04</td>
<td></td>
<td>200.0</td>
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<tr>
<td>City of Mountain view</td>
<td>100%</td>
<td>25.86</td>
<td>27.20</td>
<td>34.09</td>
<td>35.31</td>
<td>49.19</td>
<td>62.09</td>
<td>72.57</td>
<td>70.52</td>
<td>71.05</td>
<td>56.69</td>
<td>35.30</td>
<td>22.61</td>
<td>562.5</td>
</tr>
<tr>
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<td>100%</td>
<td>23.95</td>
<td>25.19</td>
<td>31.57</td>
<td>32.70</td>
<td>45.56</td>
<td>57.50</td>
<td>67.21</td>
<td>65.31</td>
<td>65.80</td>
<td>52.50</td>
<td>32.69</td>
<td>20.94</td>
<td>520.9</td>
</tr>
<tr>
<td>City of Sunnyvale</td>
<td>6%</td>
<td>1.83</td>
<td>1.93</td>
<td>2.41</td>
<td>2.50</td>
<td>3.48</td>
<td>4.40</td>
<td>5.14</td>
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<td>2.50</td>
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<tr>
<td>Purissima Hills Water District</td>
<td>50%</td>
<td>1.59</td>
<td>1.68</td>
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<td>2.18</td>
<td>3.03</td>
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<td>3.49</td>
<td>2.18</td>
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</tr>
<tr>
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<td>1.50</td>
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<td>2.69</td>
<td>3.80</td>
<td>4.27</td>
<td>5.29</td>
<td>5.53</td>
<td>5.63</td>
<td>4.57</td>
<td>1.95</td>
<td>1.73</td>
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<tr>
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<td>4.09</td>
<td>3.47</td>
<td>3.27</td>
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<td>5.46</td>
<td>5.60</td>
<td>6.10</td>
<td>5.57</td>
<td>6.34</td>
<td>4.73</td>
<td>3.62</td>
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<tr>
<td>Menlo Park MWD</td>
<td>55%</td>
<td>3.02</td>
<td>2.78</td>
<td>2.61</td>
<td>4.54</td>
<td>5.60</td>
<td>6.00</td>
<td>6.90</td>
<td>6.00</td>
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<td>4.98</td>
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<td>1.76</td>
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<td>2.55</td>
<td>2.24</td>
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<td>1.82</td>
<td>1.36</td>
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<td>7.47</td>
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<td>1.95</td>
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<td>187.26</td>
<td>217.09</td>
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<td>213.28</td>
<td>171.68</td>
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<td>1,720.1</td>
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</table>

### Table 3-8  Average Monthly Sewer Pipe Leaks in Study Area (in acre-feet)

<table>
<thead>
<tr>
<th>Purveyor</th>
<th>Percent in IPR Study Area</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
<th>YEAR</th>
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<tbody>
<tr>
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<td>69%</td>
<td>2.17</td>
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<td>2.85</td>
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<td>4.12</td>
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<td>7.53</td>
<td>10.48</td>
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<td>City of Sunnyvale</td>
<td>6%</td>
<td>0.43</td>
<td>0.45</td>
<td>0.56</td>
<td>0.58</td>
<td>0.81</td>
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</tr>
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<td>50%</td>
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<td>1.01</td>
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<td>0.51</td>
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<tr>
<td>CWS - Bear Gulch</td>
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<td>0.25</td>
<td>0.25</td>
<td>0.23</td>
<td>0.45</td>
<td>0.63</td>
<td>0.71</td>
<td>0.88</td>
<td>0.91</td>
<td>0.93</td>
<td>0.76</td>
<td>0.32</td>
<td>0.29</td>
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</tr>
<tr>
<td>East Palo Alto</td>
<td>100%</td>
<td>1.42</td>
<td>1.21</td>
<td>1.14</td>
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<td>1.90</td>
<td>1.95</td>
<td>2.12</td>
<td>1.94</td>
<td>2.20</td>
<td>1.65</td>
<td>1.26</td>
<td>1.18</td>
<td>19.6</td>
</tr>
<tr>
<td>Menlo Park MWD</td>
<td>55%</td>
<td>0.83</td>
<td>0.76</td>
<td>0.71</td>
<td>1.24</td>
<td>1.54</td>
<td>1.65</td>
<td>1.89</td>
<td>1.65</td>
<td>1.80</td>
<td>1.37</td>
<td>0.86</td>
<td>0.77</td>
<td>15.1</td>
</tr>
<tr>
<td>O'Connor Tract Co-operative WC</td>
<td>100%</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.06</td>
<td>0.08</td>
<td>0.09</td>
<td>0.11</td>
<td>0.10</td>
<td>0.10</td>
<td>0.08</td>
<td>0.06</td>
<td>0.04</td>
<td>0.8</td>
</tr>
<tr>
<td>Palo Alto Park Mutual WC</td>
<td>100%</td>
<td>0.29</td>
<td>0.28</td>
<td>0.25</td>
<td>0.37</td>
<td>0.48</td>
<td>0.57</td>
<td>0.69</td>
<td>0.61</td>
<td>0.60</td>
<td>0.49</td>
<td>0.37</td>
<td>0.27</td>
<td>5.3</td>
</tr>
<tr>
<td>Redwood City MWD</td>
<td>46%</td>
<td>1.22</td>
<td>1.01</td>
<td>1.04</td>
<td>1.67</td>
<td>1.89</td>
<td>2.10</td>
<td>2.26</td>
<td>2.15</td>
<td>2.34</td>
<td>1.93</td>
<td>1.38</td>
<td>1.00</td>
<td>20.0</td>
</tr>
<tr>
<td>Stanford University</td>
<td>100%</td>
<td>2.12</td>
<td>2.13</td>
<td>2.10</td>
<td>2.68</td>
<td>3.43</td>
<td>3.57</td>
<td>3.50</td>
<td>3.45</td>
<td>3.41</td>
<td>3.00</td>
<td>2.22</td>
<td>1.95</td>
<td>33.7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>20.80</td>
<td>21.07</td>
<td>24.80</td>
<td>28.07</td>
<td>37.77</td>
<td>45.46</td>
<td>52.52</td>
<td>50.85</td>
<td>51.63</td>
<td>41.66</td>
<td>26.45</td>
<td>18.30</td>
<td>419.4</td>
</tr>
</tbody>
</table>
3.4.4.3.4 Summary of Dispersed Recharge

The sources of recharge documented in the preceding sections are dispersed, meaning they occur to varying degrees over the entire Study Area. Figure 3-40 shows a map of average annual simulated groundwater recharge during years 1984-2015 for recharge zones in and near the Study Area. Dispersed recharge in the upland tributary watersheds tends to discharge as baseflow into creeks rather than flow laterally into the alluvial subbasins. Some inflow probably does occur from areas immediately adjacent to the southwest edges of the subbasins, but that inflow is treated separately from downward recharge within the subbasins.

Based on the analysis described above, most recharge zones in the Study Area have values between one and six inches per year of dispersed recharge. Variations correlate primarily with land use and to some extent with rainfall and pipe leak rates. Residential areas have intermediate recharge values (3-4 inches per year (in/yr)). Lush residential areas have higher values due to greater deep percolation of applied irrigation water (4-5 in/yr). Large areas of turf have still higher values for the same reason, mostly 5-7 in/yr. Dispersed recharge greater than 9 in/yr occurs in a few zones in the upper watershed area where rainfall is much higher than on the groundwater subbasin area. Rural residential development slightly boosts rainfall recharge and contributes a small amount of irrigation deep percolation. Areas of natural vegetation at lower elevations have low rates of dispersed recharge because plants are efficient at capturing most rainfall infiltration and because urban sources of recharge such as irrigation and pipe leaks are absent in a large part of the confined area, indicating upward flow.

Most previous investigators have considered vertical flow between the shallow and deep aquifers to be very small. This vertical flux is an internal flow not included in the water balance described here. However, the three-dimensional groundwater flow model described in Section 4 simulated vertical flow within the basin, which varied by location, year and management scenario. Those patterns are discussed in Section 4.4.12.

3.4.4.3.5 Streamflow Percolation

Of the various creeks in or near the Study Area, San Francisquito Creek has received the most study in terms of flow gains and losses. Metzger (2002) monitored flow in San Francisquito Creek at 13 locations on five occasions during 1996-1997. Percolation was found to be negligible upstream of the Pulgas Fault, which in this water balance analysis forms the boundary between the Study Area and San Francisquito Creek alluvial deposits located upstream of the fault. The creek consistently lost water to percolation from the Pulgas Fault to Middlefield Road, a distance of 3.3 miles. Below Middlefield Road, percolation alternated between slight gains and slight losses. For the San Mateo Plain groundwater study, flows were measured on June 12, 2017, at three of Metzger’s stations along the reach from the Pulgas Fault to Alma Street in downtown Palo Alto. The flow loss along that reach was very close to the average flow loss measured by Metzger (2.28 cubic feet per second (cfs) versus 2.03 cfs), which suggests that percolation conditions have not substantially changed over the past 20 years. Metzger estimated that average annual groundwater recharge from percolation along San Francisquito Creek was 1,050 AFY, and that value is used in the contemporary water balance for the Study Area.
Although historical flow data are available for several other creeks in or near the Study Area, there was only one gage per creek and in all cases the gage was located upstream of the alluvial subbasin areas. Therefore, the flow data do not provide any indication of flow gains or losses along the reaches that crosses the subbasins. Along all creeks other than San Francisquito Creek, substantial percentages of the channel length have been converted to concrete-lined, engineered channels. The lining greatly restricts flow between the creek and groundwater system. For this study and the San Mateo Plain groundwater study, flows at 21 locations on eight creeks were surveyed on May 5, 2016 and June 12, 2017. Five locations were measured on both dates. The data from the two survey dates are summarized in Tables 3-9 and 3-10.

The field surveys revealed only minor flow gains and losses along the small streams. This was at least partly due to the effect of concrete channel linings along some of the surveyed reaches, but possibly also to relatively high groundwater levels that could have caused stream recharge to be rejected. Groundwater levels in shallow aquifer zones were presumably relatively high because the flow measurements were made shortly after the winter rainy season in two average-to-wet years, and there is little or no groundwater pumping near the creeks. Two unlined creek reaches had flow losses that exceeded the measurement error: a loss of 0.27 cfs along Cordillera Creek (0.23 cfs per mile) and a loss of 0.16 cfs along Matadero Creek (0.10 cfs per mile).

For the contemporary Study Area water balance, average annual percolation recharge from the ten creeks that cross the Study Area was estimated by one of several methods depending on the data available for each stream. The results are shown in Table 3-11. For San Francisquito Creek, the recharge estimate is from Metzger (2002). Stevens Creek annual recharge was taken from the District’s database of “facility recharge”. Percolation from Permanente, Adobe, Hale, Barron and Matadero Creeks was estimated by assuming that daily percolation equaled the smaller of daily stream flow and the percolation capacity. Gaged flows in Matadero Creek during 1991-2015 were used as the flow time series, and channel percolation capacity equaled the estimated percolation capacity per mile multiplied by the miles of unlined channel crossing the Study Area. For these small streams, percolation rates of 0.3 to 0.4 cfs per mile were estimated from older percolation studies (SCVWD, 1977) and percolation rates along nearby creeks where the District releases supplemental water in summer for percolation purposes. For Redwood Creek and Arroyo Ojo de Agua, daily percolation was similarly calculated by capping gaged daily flows in Redwood Creek at a flow equal to the percolation capacity of unlined segments of the creek channels. The result of these tabulations was an overall estimate of groundwater recharge from small stream percolation equal to 4,300 AFY.

The future baseline simulation using the calibrated groundwater model—which represents current land and water use conditions simulated over a 30-year hydrologic period—also estimated average annual percolation from all streams to be 5,400 AFY.

3.4.4.3.6 Subsurface Inflow

Subsurface groundwater inflow is theoretically possible along the northwest, northeast, southeast and southwest sides of the Study Area.
### Table 3-9 Stream Flow Measurements of May 5, 2016

<table>
<thead>
<tr>
<th>Site</th>
<th>Flow (cfs)</th>
<th>Specific Conductance (µS/cm)</th>
<th>Temperature (°C)</th>
<th>Flow Measurement Method</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Mateo Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below Crystal Springs Dam</td>
<td>1.9</td>
<td>--</td>
<td>--</td>
<td>USGS gage</td>
<td>Daily average flow recorded on 5/5/16.</td>
</tr>
<tr>
<td>Crystal Springs Road</td>
<td>1.9</td>
<td>337</td>
<td>13.8</td>
<td>Pygmy meter with top-setting rod.</td>
<td>About 400 ft downstream on El Cerrito Rd from Crystal Springs Road. Low conductivity indicates Hetch Hetchy water from Crystal Springs Reservoir.</td>
</tr>
<tr>
<td>Arroyo Court Park near El Camino</td>
<td>1.6</td>
<td>--</td>
<td>--</td>
<td>Visual from road</td>
<td>At downstream end of park below Mitchell Way. Short run in gravel channel at point bar above property fence.</td>
</tr>
<tr>
<td>Gateway Park at South Humboldt Street</td>
<td>1.65</td>
<td>680</td>
<td>14.8</td>
<td>Pygmy meter with top-setting rod.</td>
<td>Gravel bed at D/S end of box culvert under Humboldt and East 3rd Avenue, below Gateway Park.</td>
</tr>
<tr>
<td>Laurel Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fernwood Street</td>
<td>0.13</td>
<td>1,293</td>
<td>14.2</td>
<td>Bucket and stopwatch</td>
<td>Caught flow falling off concrete bridge apron. 10-quart bucket filled in average of 2.53 seconds.</td>
</tr>
<tr>
<td>Otay Avenue</td>
<td>0.67</td>
<td>1,056</td>
<td>15.2</td>
<td>Pygmy meter with top-setting rod.</td>
<td>50 ft upstream of bridge on Otay cul-de-sac. Shifted gravels and removed filamentous algae to create better measurement conditions.</td>
</tr>
<tr>
<td>Belmont Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twin Pines Park</td>
<td>0.19</td>
<td>1,401</td>
<td>--</td>
<td>Salt dilution</td>
<td>10-foot run in gravel channel.</td>
</tr>
<tr>
<td>Arroyo Ojo de Agua</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stulsaft Park</td>
<td>0.32</td>
<td>1,051</td>
<td>15.9</td>
<td>Pygmy meter with top-setting rod.</td>
<td>At downstream end of park below Mitchell Way. Short run in gravel channel at point bar above property fence.</td>
</tr>
<tr>
<td>King Street (at Vera St)</td>
<td>Similar</td>
<td></td>
<td></td>
<td>Visual from road</td>
<td>Concrete trapezoidal channel below box culvert under Red Morton Park. Flow is &lt;=1 inch deep and 4-6 ft wide on flat cement bottom. Much filamentous algae. Tightly fenced to prevent access. No good way to measure this type of flow. Made visual observation through fence.</td>
</tr>
<tr>
<td>Hudson Street</td>
<td>Similar</td>
<td></td>
<td></td>
<td>Visual from road</td>
<td>Cement trapezoidal channel. Did not enter.</td>
</tr>
<tr>
<td>Clinton Street</td>
<td>Similar</td>
<td></td>
<td></td>
<td>Visual from road</td>
<td>Cement trapezoidal transitions to rectangular channel. Bottom 10 ft wide, fully covered by flow perhaps 0.3 ft deep, moving slowly. Algae focuses flow into narrow area.</td>
</tr>
<tr>
<td>Redwood Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arroyo de las Pulgas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Natural channel in Menlo Country Club. Chain link and barbed wire fence. Channel pooled upstream of road culvert so could not estimate velocity or flow through fence. Site of former USGS gage.</td>
</tr>
<tr>
<td>Kentfield Avenue</td>
<td>0.8</td>
<td>--</td>
<td>--</td>
<td>Visual from road plus floating wings for velocity.</td>
<td>Trapezoidal concrete channel, tightly fenced. Bottom 7 ft wide, fully wetted. Algae focuses perhaps 80% of flow into 1.5 ft wide x 0.5 ft deep x 1.04 ft/s = 0.78 cfs.</td>
</tr>
<tr>
<td>El Camino Real</td>
<td>Similar</td>
<td>--</td>
<td>--</td>
<td>Visual from road</td>
<td>El Camino to Maple Street concrete channel 10 ft wide on bottom, fully wetted, much algae focusing flow into narrow runs. Below Maple Street is backwater condition.</td>
</tr>
</tbody>
</table>

**Notes:**
- cfs - cubic feet per second
- °C - degrees Celsius
- V - velocity (feet per second)
- µS/cm - microsiemens per centimeter
- ft - feet
- W - flow top width (feet)
- USGS - U.S. Geological Survey
- similar - visual from road
### Table 3-10 Stream Flow Measurements of June 12, 2017

<table>
<thead>
<tr>
<th>Site</th>
<th>Flow (cfs)</th>
<th>Specific Conductance (µS/cm)</th>
<th>Temperature (°C)</th>
<th>Flow Measurement Method</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Mateo Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below Crystal Springs Dam</td>
<td>3.69</td>
<td>--</td>
<td>--</td>
<td>USGS gage</td>
<td>Daily average flow recorded on 6/12/17.</td>
</tr>
<tr>
<td>Crystal Springs Road</td>
<td>3.84</td>
<td>283</td>
<td>14.2</td>
<td>Pygmy meter with top-setting rod.</td>
<td>About 400 ft downstream on El Cerrito Rd from Crystal Springs Road. Low conductivity indicates Hetch Hetchy water from Crystal Springs Reservoir.</td>
</tr>
<tr>
<td>Arroyo Court Park near El Camino</td>
<td>3.56</td>
<td>311</td>
<td>14.2</td>
<td>Pygmy meter with top-setting rod.</td>
<td>Run between pools upstream of large storm drain.</td>
</tr>
<tr>
<td>Gateway Park at South Humboldt Street</td>
<td>3.68</td>
<td>318</td>
<td>14.8</td>
<td>Pygmy meter with top-setting rod.</td>
<td>Gravel bed at downstream end of box culvert under Humboldt and East 3rd Avenue, below Gateway Park.</td>
</tr>
<tr>
<td>Cordilleras Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edgewood Road</td>
<td>0.29</td>
<td>991</td>
<td>14.9</td>
<td>Visual from road: 1 ft wide x 0.08 ft deep x 0.3 ft/s</td>
<td>80 ft upstream of Edgewood Road. Bedrock in channel.</td>
</tr>
<tr>
<td>Warwick</td>
<td>0.024</td>
<td>1,065</td>
<td>15.4</td>
<td>Pygmy meter with top-setting rod.</td>
<td>Box culvert. Approx. 1,000 ft upstream of El Camino Real. Water sample collected from bridge by bucket and string.</td>
</tr>
<tr>
<td>Redwood Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alameda de las Pulgas</td>
<td>0.25</td>
<td>1,152</td>
<td>16</td>
<td>Pygmy meter with top-setting rod.</td>
<td>Natural channel in Menlo Country Club. Chain link and barbed wire fence. Channel pooled upstream of road culvert so could not estimate velocity or flow through fence. Site of former USGS gage.</td>
</tr>
<tr>
<td>El Camino Real</td>
<td>0.4</td>
<td>1,437</td>
<td>21.3</td>
<td>Visual from road: 2 ft wide x 0.2 ft deep x 1 ft/s</td>
<td>Trapezoidal concrete culvert downstream of El Camino. Flow estimate was 100 ft upstream of Lathrop Street. Water quality sample obtained from bridge by bucket and string.</td>
</tr>
<tr>
<td>San Francisquito Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand Hill Road</td>
<td>4.37</td>
<td>922</td>
<td>17.7</td>
<td>Pygmy meter with top-setting rod.</td>
<td>Metzger site 4. Boulder and cattail riffle between pools 200 ft upstream of bike bridge.</td>
</tr>
<tr>
<td>San Mateo Drive bike bridge</td>
<td>3.63</td>
<td>937</td>
<td>19</td>
<td>Pygmy meter with top-setting rod.</td>
<td>Metzger site 5. Run by gravel bar 200 ft upstream of bike bridge.</td>
</tr>
<tr>
<td>Alma Street</td>
<td>2.09</td>
<td>937</td>
<td>18.6</td>
<td>Pygmy meter with top-setting rod.</td>
<td>Metzger site 6. Run by gravel bar under railroad bridge.</td>
</tr>
<tr>
<td>Matadero Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foothill Expressway</td>
<td>0.16</td>
<td>2,084</td>
<td>15.4</td>
<td>Pygmy meter with top-setting rod. Floating-stick velocity for part of section.</td>
<td>Short run by gravel bar 300 ft upstream of road. Cleared algae and focused flow.</td>
</tr>
<tr>
<td>Matadero Road</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>Visual from road.</td>
<td>At Josina Avenue, about 800 ft upstream of El Camino Real. Nearly continuous pools but no surface flow.</td>
</tr>
</tbody>
</table>

- cfs - cubic feet per second
- D - flow depth (feet)
- ft - feet
- V - velocity (feet per second)
- W - flow top width (feet)
- USGS - U.S. Geological Survey
- µS/cm - microsiemens per centimeter

*Groundwater Assessment, and Indirect Potable Reuse Feasibility Evaluation and Implementation Strategy*
### Table 3-11 Groundwater Recharge from Stream Percolation

<table>
<thead>
<tr>
<th>Creek</th>
<th>Unlined Channel Length (mi)</th>
<th>Percolation Rate (cfs/mi)</th>
<th>Average Annual Percolation (AFY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arroyo Ojo de Agua</td>
<td>0.4</td>
<td>0.40</td>
<td>62</td>
</tr>
<tr>
<td>Redwood Creek</td>
<td>0.2</td>
<td>0.40</td>
<td>44</td>
</tr>
<tr>
<td>Atherton Flood Channel</td>
<td>0.0</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>San Francisquito Creek</td>
<td>5.7</td>
<td>0.61-1.80</td>
<td>1,050</td>
</tr>
<tr>
<td>Matadero Creek</td>
<td>2.0</td>
<td>0.40</td>
<td>330</td>
</tr>
<tr>
<td>Barron Creek</td>
<td>2.3</td>
<td>0.30</td>
<td>297</td>
</tr>
<tr>
<td>Adobe Creek</td>
<td>4.2</td>
<td>0.40</td>
<td>517</td>
</tr>
<tr>
<td>Hale Creek</td>
<td>1.4</td>
<td>0.30</td>
<td>211</td>
</tr>
<tr>
<td>Permanente Creek</td>
<td>2.3</td>
<td>0.40</td>
<td>358</td>
</tr>
<tr>
<td>Stevens Creek</td>
<td>5.0</td>
<td>0.52</td>
<td>1,421</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>4,290</strong></td>
</tr>
</tbody>
</table>

mi - miles  
cfs - cubic feet per second  
AFY - acre-feet per year

a - Measured losses for San Francisquito Creek reaches from Metzger (2002). Values calculated from the
b - Annual percolation volumes for Arroyo Ojo de Agua and Redwood Creek estimated from gaged flows
in Redwood Creek during water years 1985-1997 after capping daily flows at a maximum equal to the
unlined channel percolation capacity. The Matadero Creek percolation volume was similarly estimated,
c - 2.6 miles of Stevens Creek follow the IPR study area boundary. Only half of the percolation along that
reach is credited to the study area water balance.

### Northwest Boundary

Contours of fall 2010 groundwater elevations in shallow and deep wells in Redwood City at the
northwest Study Area boundary indicate groundwater flow toward the Bay, parallel to the
boundary (EKI et al., 2017). This means there is little or no flow across the boundary into or out
of the Study Area.

### Southeast Boundary

Recent groundwater elevation contours show groundwater gradients parallel to the southeast
Study Area boundary, toward San Francisco Bay. In fall 2016 and spring 2017, for example, the
indicated flow direction was either parallel to the boundary or slightly inward near the inland
dge of the boundary (see Figures 3-25 through 3-28). The slight inward flow appears to be
emanating from the upper end of Stevens Creek and is probably associated with recharge from
stream percolation, which is already included in the water balance table. Thus, it is reasonable
to assume that flow across the southeast Study Area boundary is close to zero.
Flow across the southeast boundary would change if pumping on either side increased or decreased. The primary reason the Study Area was extended this far south was to minimize the effect of pumping in Palo Alto on the boundary flow by placing the boundary far from the potential pumping.

The future baseline simulation using the groundwater model estimated that average annual groundwater inflow from Santa Clara Plain to the Study Area was about 2,300 AFY.

**Northeast Boundary**

The northeast boundary of the Study Area water balance area is in San Francisco Bay. Shallow and deep groundwater level contours (see Figures 3-25 through 3-28) and the water balance analysis indicate that flow is presently from the Study Area to the Bay. However, increased groundwater pumping could reverse the direction of flow across this boundary. Because flow is presently toward the Bay, this boundary is discussed in greater detail in Section 3.4.4.4.

**Southwest Boundary**

The southwest boundary of the Study Area is the contact between the unconsolidated alluvial deposits or semi-consolidated Santa Clara Formation and bedrock units (Figure 3-6). Inflow to the groundwater subbasins through bedrock fractures is possible, and two methods were used to roughly estimate the magnitude of that flow. The first method evaluated base flow in creeks that drain the upland bedrock area. If the volume and duration of base flow in a stream are high, it can be inferred that the bedrock in the watershed is highly fractured with substantial storage and permeability. Those same characteristics would promote subsurface inflow to the adjacent groundwater subbasins. Conversely, low base flow volume and persistence indicate low storativity and permeability, and hence relatively low bedrock inflow to the subbasins. The USGS operated stream gages at various times on four local creeks whose watersheds drain only bedrock areas east of the San Andreas Fault: Redwood Creek, Sharon Creek (a tributary to Atherton Channel), Los Trancos Creek (a tributary to San Francisquito Creek) and Matadero Creek. Hydrographs showing daily flows for five-year periods for each of those gages are shown in Figure 3-41. The scale is cropped to show only flows less than 14 cfs. In all four watersheds, there is little base flow. Sustained flows greater than 1 cfs occur only during wet-weather periods and probably result from shallow subsurface flow through soils and weathered bedrock rather than flow through deep bedrock fractures. All of the creeks dry up fairly quickly after the rainy season ends. These base flow patterns indicate low bedrock storativity and permeability and imply that subsurface inflow to the groundwater subbasins from bedrock uplands is small.

The second approach was to tabulate recharge over upland areas immediately adjacent to the subbasins where groundwater gradients in the soil and weathered bedrock zone were estimated to be directly toward the subbasins rather than toward a creek channel in the uplands. Recharge zones fitting this description with a combined area of 3,657 acres were identified. Simulated average annual groundwater recharge in those zones was about 900 AFY. This corresponds to about 5% of total Study Area recharge and is consistent with the baseflow data and associated inference that bedrock inflow is relatively small.
3.4.4.4 Outflows

3.4.4.4.1 Groundwater Supply Pumping

Estimates of groundwater pumping for water supply are listed in Table 3-12. In the Santa Clara Subbasin, all groundwater pumpers are required to report their pumping amounts to the District (or pumping is estimated by the District for small users), whereas no such reporting or monitoring occurs in the San Mateo Plain Subbasin. Different approaches were used to tabulate pumping in the two parts of the Study Area, and the results were combined in the water balance table.

Use of groundwater for public supply in the San Mateo Plain part of the Study Area is limited to Palo Alto Park Mutual Water Company and O’Connor Tract Cooperative Water Company, which are two adjoining small community water systems near the border between Menlo Park and East Palo Alto (see Figure 3-37). Also listed in Table 3-12 are individual large institutions whose use of groundwater for irrigation was confirmed by telephone or assumed to be ongoing. These users were identified in previous studies (Wood, 1975; Metzger and Fio, 1997; Todd et al., 2012), but the water use estimates were revised for the San Mateo Plain groundwater study based on irrigated area measured from high-resolution aerial photographs and simulated annual applied irrigation water (EKI et al., 2017).

The lower half of the table includes estimates of groundwater use for several groups of users, mostly private irrigation wells in Atherton and nearby areas. Except for wells drilled since 1995, the estimated combined production for these users was taken from previous studies (Metzger and Fio, 1997; HydroFocus, 2011).

The lower half of the table includes all water supply pumping in the Santa Clara Plain part of the Study Area, subtotaled for three user categories: agricultural (AG), domestic (DO) and municipal/Industrial (MI). Average annual pumping for 2005-2014 is shown in the table, and the locations and amounts of pumping are shown in Figure 3-42. Overall, groundwater use for water supply totals an estimated 5,500 AFY under current land use and water supply conditions.

3.4.4.4.2 Groundwater Remediation System Pumping

Groundwater remediation often involves pumping contaminated groundwater, removing the contaminants and discharging the treated water to a storm drain. For the San Mateo Plain Subbasin part of the Study Area, the amount of remediation pumping was estimated from information on discharge permits. The SFRWQCB issues permits to discharge treated groundwater that is pumped from groundwater contamination sites pursuant to the National Pollution Discharge Elimination System (NPDES). In 2016, the SFRWQCB conducted a search of its groundwater cleanup permit databases for NPDES/waiver permitted pump-and-treat discharges. The search found six permitted remediation sites within the San Mateo Plain portion of the Study Area. Total pumping at those sites during 2014 to mid-2016 was 231 AF, or 92 AFY.
### Table 3-12 Groundwater Pumping for Water Supply

<table>
<thead>
<tr>
<th>Well Number</th>
<th>Well Name</th>
<th>Owner</th>
<th>Type of Use</th>
<th>Average Annual Production (AF)</th>
<th>Method of Estimate</th>
<th>Sources of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>05S03W33D002 and 33D001</td>
<td>No. 3 and 4</td>
<td>Menlo School and College</td>
<td>Irrigation of lawns and athletic fields</td>
<td>80</td>
<td>Lot area and percent irrigated estimated from high-resolution aerial photographs. Irrigated area multiplied by 33.4 in/yr applied water. Potable use assumed to have been discontinued since the early 1970s.</td>
<td>This study and OF-75-43</td>
</tr>
<tr>
<td>05S03W26D002</td>
<td>U.S. Veterans Administration hospital</td>
<td></td>
<td></td>
<td>64</td>
<td>Lot area and percent irrigated estimated from high-resolution aerial photographs. Irrigated area multiplied by 33.4 in/yr applied water.</td>
<td>This study</td>
</tr>
<tr>
<td>05S03W15D002</td>
<td>St. Patrick’s Seminary</td>
<td></td>
<td>Swimming pool and landscape irrigation</td>
<td>19</td>
<td>Lot area and percent irrigated estimated from high-resolution aerial photographs. Irrigated area multiplied by 33.4 in/yr applied water.</td>
<td>This study</td>
</tr>
<tr>
<td>--</td>
<td>U.S. Geological Survey</td>
<td></td>
<td>Assumed landscape irrigation</td>
<td>11</td>
<td>Lot area and percent irrigated estimated from high-resolution aerial photographs. Irrigated area multiplied by 33.4 in/yr applied water.</td>
<td>This study</td>
</tr>
</tbody>
</table>

#### User Groups

| -- | 298 active or potentially active residential wells | Private homeowners in Atherton | Landscape irrigation | 545 | 32 wells metered during 1993-1995 extrapolated to 269 wells in WRIR 97-4033. 11 "irrigation" and 18 "domestic" wells drilled since 1995 and 35 AFY of irrigation use added by this study. | WRIR 97-4033, drillers logs and this study |
| -- | 100 residential irrigation wells in San Francisco Outer Area outside Atherton | Residents near Atherton | Irrigation | 190 | 1.9 AFY per well, copying estimate from Metzger and Fio (1997) for Atherton residential irrigation wells. | Todd Engineers and others (2012) |
| -- | 9 institutional wells in Atherton | Institutions in Atherton | Irrigate landscaping and athletic fields | 120 | USGS-reported 1993-1995 production minus the estimate for Menlo College (which is listed separately above); 4 of the 9 wells were metered in 1993-1995 | WRIR 97-4033 |
| -- | 19 wells in Santa Clara County | Cities or individuals | Irrigation | 739 | "AG" wells with non-zero pumping in SCVWD database. Average annual production during 2005-2014. | SCVWD groundwater production database |
| -- | 191 wells in Santa Clara County | Homeowners | Domestic uses (probably irrigation) | 176 | "DO" wells with non-zero pumping in SCVWD database. Average annual production during 2005-2014. | SCVWD groundwater production database |

**TOTAL** | 5,507 | | | | | |

AFY - acre-feet per year  
in/yr - inches per year  
WRIR - Water Resources Investigations Report  
OF - Open-File Report  
SCVWD - Santa Clara Valley Water District  
AG - agricultural  
MI - municipal/industrial

**References Cited**


For the Santa Clara Subbasin part of the Study Area, remediation pumping is included in the District’s production database located within the Study Area. Remediation pumping is included in the “MI” category along with municipal and industrial pumping. Some MI wells in the Study Area are further identified by an industrial user code, and one code is for remediation pumping. Average annual remediation pumping by wells in the Study Area was 1,027 AFY.

### 3.4.4.4.3 Dewatering Pumping

Groundwater pumping for dewatering purposes is permitted by various local agencies. The City of Palo Alto issues permits for temporary and long-term (greater than 1 year) dewatering. In 2016, eight permits were issued for residential construction dewatering. The typical duration of pumping at a site was about 10 weeks. The dewatering discharge was metered at the sites, and pumping rates ranged from 67-235 gpm (average of 149 gpm). The total volume pumped over the year was 416 AF. This is greater than the average estimate of 180 AFY presented in a staff report to the Palo Alto city council in June 2008 based on assumptions that included longer pumping durations but much smaller pumping rates (Morris et al., 2008). In 2016, Palo Alto had 28 active permits for long-term dewatering at industrial sites on file, for which pumping totaled 205 AFY. Long-term pumping appears to be for removing seepage into underground structures. Also, the Oregon Expressway underpass has a dewatering pump that discharges an average of 161 AFY. The locations and amounts of dewatering pumping in Palo Alto in 2016 are shown in Figure 3-43, and they totaled 782 AF. Detailed data were not available for other years.

The City of Mountain View estimated that dewatering pumping in 2016 was 5 AFY, which excludes brackish water pumped to dewater a landfill near the Bay. The number is only an estimate because some sites were not metered and, in some cases, stormwater and construction water comingle with groundwater (Sandahl, 2017).

Records of dewatering pumping are less complete in the San Mateo Subbasin part of the Study Area. The SFRWQCB issues NPDES permits for discharges of clean groundwater pumped for dewatering of construction sites or underground structures. Only discharges greater than 10,000 gallons per day (11.2 AFY) require a permit. When records were requested in 2016 for the San Mateo Plain groundwater study, SFRWQCB staff found no active permits in their database for this type of discharge in the San Mateo Plain Subbasin.

In some cases, dewatering water is discharged to the sanitary sewer system, and in San Mateo County this requires a County permit. A search of records for 2011-2016 found six permits. The total reported discharge of groundwater was 1.2 AF, corresponding to an average annual rate of 0.3 AFY. This amount appears far too small in comparison to reported amounts of dewatering pumping in the Santa Clara Subbasin part of the Study Area.

The discrepancy among the dewatering pumping estimates is notable. Palo Alto, Mountain View and San Mateo County each occupy about one-third of the length of the Study Area. Shallow groundwater—and hence the need for dewatering—occurs primarily in a band of low topographic elevation roughly parallel to the Bay shoreline. It would be reasonable to expect the amount of dewatering pumping to be similar for the three areas. But the reported amount of dewatering pumping in Palo Alto is over one hundred times greater than in the other areas. Documentation of dewatering appears to be more systematic and quantitative in Palo Alto than
in the other areas, suggesting that dewatering is underreported in those areas. For planning purposes, the amounts of dewatering pumping in the San Mateo County and Mountain View parts of the Study area were each assumed to equal half the amount reported in Palo Alto. Thus, total dewatering pumping for the Study Area was estimated to equal 1,600 AFY.

3.4.4.4 Use of Groundwater by Riparian and Wetland Vegetation
Some natural stream channels in the Study Area have a corridor of large trees along both banks. Where the water table is within 10 to 15 feet of the ground surface, some trees (phreatophytes) can grow roots to the water table and use groundwater directly. Where the water table is too deep to reach but the stream has flow during the dry season, the trees can intercept stream percolation that would otherwise become groundwater recharge, with the same effect on the water balance as extracting water from the water table. Use of groundwater by riparian trees was estimated by measuring the area of tree canopy and estimating the amount of transpiration that is supplied by groundwater rather than rainfall. Table 3-13 lists the length and average canopy width of corridors of trees along stream channels that cross the Study Area, as identified on recent aerial photographs. There is a total of 240 acres of riparian tree canopy in the Study Area.

Consumptive use of groundwater was estimated by simulating a hypothetical riparian forest zone using the recharge simulation model. The zone was simulated as completely non-irrigated during 1984-2015 then re-simulated as completely irrigated. The difference in simulated actual evapotranspiration equals the amount of groundwater consumed (the water table serving as the source of "irrigation" in the simulation). Consumptive use of groundwater by this method averaged 24.6 in/yr, or 500 AFY over the entire area of riparian vegetation.

This estimate is probably high because some of the riparian trees probably do not receive all of the water they could use, either because the water table is too deep or stream flow and percolation taper off too much during the dry season. Also, some stream flow in summer derives from irrigation overspray and other human activities in the surrounding urban areas that result in potable supply water flowing to storm drains. To the extent the trees are using this source of water, their use of groundwater is overestimated. However, any error would be small in the context of the overall Study Area water balance.

The only wetlands of significant size in the Study Area are the tidal wetlands along the Bay shore. The evapotranspiration needs of tidal marsh vegetation are assumed to be met by Bay water or by subsurface groundwater discharge to the Bay, which is accounted for separately in the water balance.
### Table 3-13 Groundwater Use by Riparian Vegetation

<table>
<thead>
<tr>
<th>Creek</th>
<th>Length (ft)</th>
<th>Average Width (ft)</th>
<th>Area (acres)</th>
<th>Consumptive Use of Groundwater (AFY)(^a)</th>
<th>Reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redwood/Arroyo Ojo de Agua</td>
<td>2,184</td>
<td>70</td>
<td>3.5</td>
<td>7.2</td>
<td>Basin boundary to Connecticut Drive</td>
</tr>
<tr>
<td>San Francisquito</td>
<td>28,982</td>
<td>120</td>
<td>79.8</td>
<td>163.5</td>
<td>Junipero Serra Road to Hwy. 101</td>
</tr>
<tr>
<td>Matadero</td>
<td>9,247</td>
<td>80</td>
<td>17.0</td>
<td>34.8</td>
<td>Page Mill Rd. to El Camino Real</td>
</tr>
<tr>
<td>Deer</td>
<td>4,924</td>
<td>70</td>
<td>7.9</td>
<td>16.2</td>
<td>Arastradero Rd. to Foothill Expwy.</td>
</tr>
<tr>
<td>Barron</td>
<td>10,373</td>
<td>100</td>
<td>23.8</td>
<td>48.8</td>
<td>Ortega Dr. to Laguna Way</td>
</tr>
<tr>
<td>Adobe &amp; Purissima</td>
<td>31,177</td>
<td>90</td>
<td>64.4</td>
<td>131.9</td>
<td>Elena Rd. to El Camino Real</td>
</tr>
<tr>
<td>Hale</td>
<td>7,945</td>
<td>100</td>
<td>18.2</td>
<td>37.4</td>
<td>I-280 to Rose Ave.</td>
</tr>
<tr>
<td>Permanente</td>
<td>12,025</td>
<td>105</td>
<td>29.0</td>
<td>59.4</td>
<td>I-280 to El Camino Real (with gaps)</td>
</tr>
<tr>
<td>Stevens</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Along Study Area boundary</td>
<td>13,756</td>
<td>140</td>
<td>44.2</td>
<td>90.6</td>
<td>I-280 to Heatherstone Way</td>
</tr>
<tr>
<td>Within Study Area</td>
<td>12,811</td>
<td>130</td>
<td>38.2</td>
<td>78.3</td>
<td>Heatherstone Way to Moffet Blvd.</td>
</tr>
</tbody>
</table>

| TOTAL                         | 106,857     | --                 | 243.7        | 499.2                                       |                                            |

\(^a\) Based on average annual consumptive use of groundwater of 24.6 in/yr derived from comparison of riparian forest under

\(^b\) Only riparian vegetation along the north bank of the creek is included, consistent with the treatment of stream percolation.
3.4.4.4.5  Groundwater Discharge to Surface Waters

Groundwater in the Study Area generally flows towards the Bay, and the water table becomes increasingly shallow along that flow path. Near the Bay, the water table can be higher than the invert elevations of creek channels, sewers and storm drains, which allows groundwater to seep into those waterways. Of these outflow pathways, groundwater infiltration into sanitary sewers can most readily be estimated from available data. Inflows to wastewater treatment plants are metered, and in the case of the Silicon Valley Clean Water (SVCW) treatment plant, flow data are available for subregions within the overall sewer service area. Groundwater infiltration has a seasonal pattern that is distinct from other sources of infiltration, which is a gradual decline during the summer dry season. This stems from the natural decline in water table elevation during the dry season. Tidal infiltration fluctuates hourly but is otherwise constant throughout the year. Wet weather infiltration occurs only during and following winter storm events. Infiltration related to water use also would not logically decline steadily during the dry season.

Several years of daily flow data were obtained for the SVCW, Palo Alto, Sunnyvale and San Jose/Santa Clara wastewater treatment plants (see Figure 3-38 for the locations of the plants and contributing sewer areas). Evidence of groundwater infiltration was detected in the flow hydrographs for the SVCW Redwood City pump station and the Palo Alto and Sunnyvale wastewater treatment plants, as shown in Figure 3-44. A steady declining trend during the dry season is evident in all three hydrographs. 2014 was one of the driest years on record, and the declining trend continued through the winter that year. All of the hydrographs include frequent spikes in daily flow that cannot logically be attributed to groundwater. A computer program designed to separate stream base flow from storm-event runoff (Arnold et al., 1995; Arnold and Allen, 1999) was applied to the daily sewer flow time series to extract the “base flow” that consists of normal discharges from sewer users and groundwater infiltration. The volume of dry-season groundwater infiltration was calculated by subtracting the average flow in November from each daily base flow during April-November. Total infiltration was then prorated to the Study Area based on the percentage of each sewer service area located within the Study Area. These calculations are documented at the bottom of the figure and produced a total dry-season infiltration volume of 1,500 AFY. In winter, the groundwater infiltration component of flow is difficult to detect because of larger, sporadic inflows of stormwater. Because groundwater levels change relatively gradually, it was simply assumed that average groundwater infiltration during the wet season was the same as the average during the dry season. Thus, the water balance table shows a total of 2,000 AFY.

Few data are available to quantify groundwater discharges to creeks, storm drains and tidal wetlands. There are few stream gages near the Bay in either the San Mateo Plain or Santa Clara Subbasin, partly due to the difficulty of measuring flow where creek stage can be influenced by tides. However, the District operates gages close to the Bay on Coyote Creek and the Guadalupe River elsewhere in the Santa Clara Subbasin. Dry season base flow at those locations are about 3 cfs and 10 cfs higher, respectively, than base flow at upstream gages in the mid-basin area. Some of that increase undoubtedly derives from groundwater remediation and dewatering discharges, but the overall magnitude of groundwater discharge is on the order of 10,000 AFY. The creeks and watersheds in the Study Area are much smaller, and smaller amounts of groundwater discharge would be expected. Groundwater discharges to tidal
wetlands or by subsurface flow beneath the Bay toward Niles Cone are probably smaller than
the discharge to creeks and storm drains because the flow paths are much longer and/or less
permeable. For the water balance table, groundwater outflow to creeks, storm drains, tidal
wetlands and subsurface flow toward Niles Cone were collectively estimated as the residual in
the water balance. Two-thirds of the estimate was assigned to discharge to creeks and storm
drains, with the remaining third assigned to tidal wetlands and Niles Cone. This roughly equals
the proportions of outflow simulated by the preliminary groundwater flow model developed
for the San Mateo Plain groundwater study (EKI et al., 2017).

3.4.4.6 Subsurface Outflow

As described in Section 3.4.4.3, shallow and deep groundwater flow gradients along the
northwest and southeast boundaries of the Study Area are parallel to the boundaries.
Therefore, little or no subsurface inflow or outflow presently occurs across those boundaries.
Those flows could change in the future if pumping increases or decreases on either side of
those boundary segments.

There is no groundwater outflow across the southwest Study Area boundary because water
level gradients are from the bedrock uplands toward the groundwater subbasin.

Subsurface outflow probably occurs northeastward toward the tidal marshes, San Francisco Bay
and Niles Cone. This outflow was assigned one-third of the residual in the contemporary water
balance (2,200 AFY), while the remainder was assigned to groundwater discharge into creeks
and storm drains. Some of the subsurface outflow probably discharges into the tidal wetlands,
some might discharge into the open-water part of San Francisco Bay, and some might remain in
confined aquifers until it reaches wells in the Niles Cone area. The proportions of these specific
outflows are unknown.

3.4.4.5 Change in Storage

Average annual storage change is assumed to be zero in the contemporary water balance
because groundwater levels in the Study Area have not exhibited long-term upward or
downward trends in the past 20 years. Pumping has been small compared to historical
pumping, and the groundwater levels have remained high during that time. Many wells with
long-term records show fairly flat long-term trends (see Figures 3-32 through 3-34).

Groundwater storage fluctuates seasonally, even if long-term trends are level. In terms of
volume, seasonal fluctuations in storage are greatest near the water table, where pores
between grains of sediment fill and drain as water levels rise and fall. Based on a comparison of
total groundwater pumping and water-level change in the San Francisquito Cone area,
Killingsworth and Hyde estimated an average specific yield of 0.0564 (dimensionless). A
seasonal water-table fluctuation of two feet over the 47,340-acre onshore part of the Study
Area would correspond to a seasonal storage fluctuation of +/- 5,400 acre-feet.

3.4.4.6 Water Balance Summary, Uncertainty and Variability

The contemporary water balance is shown in the block diagram in Figure 3-45. The major
sources of recharge are dispersed recharge from rainfall and irrigation (55%), percolation from
creeks (25%), and pipe leaks (13%). The major outflows are pumping at wells (47%), seepage
into creeks and storm drains (26%), subsurface flow to San Francisco Bay and Niles Cone (13%) and seepage into sanitary sewers (11%). The magnitudes of the budget items can be compared visually in the bar chart shown in Figure 3-46.

There is substantial uncertainty in the estimates for almost all of the water budget items. Table entries are rounded to the nearest 100 AFY, but in most cases the estimated value may have an uncertainty as large as +/- 50 percent. A range of plausible values for each budget item is included in Table 3-5. For entries linked more directly to measured data, the range was decreased relative to the less certain items. The estimated uncertainty in the overall water balance stems from the magnitude of imbalance deemed likely to cause noticeable upward or downward long-term water-level trends.

The contemporary water balance represents annual flows under land and water use conditions of the past decade and averaged over a series of years when average rainfall equaled the long-term average. Some water balance items remain relatively constant from year to year, including pipe leaks, deep percolation of applied irrigation water, subsurface inflow from bedrock uplands, groundwater pumping, and evapotranspiration by riparian vegetation. Other items depend on current-year rainfall and vary substantially from year to year, including rainfall recharge, percolation from streams, and subsurface outflow to creeks and the Bay. In dry years, rainfall recharge can be close to zero; all infiltrated rainfall is retained in the root zone and later transpired by plants. The duration of stream flow is also much less in dry years, reducing the opportunity for percolation. For planning purposes, it would be reasonable to assume that in a dry year rainfall recharge is zero and percolation from streams is only 25% of the average annual value. This would reduce total inflow to about 9,800 AFY.

The decrease in inflow during a dry year is balanced by temporary decreases in subsurface outflow and groundwater storage. The amount by which each of those items responds to the decrease in inflow depends partly on hydrogeology and the location of decreased inflow. For planning purposes, it is reasonable to assume that half of the decrease in inflow would be absorbed by a decrease in storage and the other half would be absorbed by decreases in groundwater outflow (by a uniform percentage for all outflows). Thus, groundwater storage might decrease by 3,500 AFY, and subsurface outflows to sewers, creeks and storm drains, and wetlands and San Francisco Bay might decrease by 900 AFY, 1,700 AFY and 870 AFY, respectively.

During wet periods, rainfall recharge and stream percolation would be above average, which would replenish the temporary decrease in groundwater storage and restore subsurface outflows to their former values. A sequence of wet years would temporarily boost all of those items to above-average values.

Assessment of increased City pumping based on the contemporary water balance is discussed in Section 3.6.1.
3.5 Groundwater Quality

3.5.1 Ambient Groundwater Quality Data Sources

This section discusses ambient water quality conditions in the Study Area. Environmental site releases associated with point sources are discussed in the Section 3.5.3.

3.5.1.1 Santa Clara Valley Water District

The District actively manages groundwater through implementation of its Groundwater Management Plan (GWMP) (SCVWD, 2016c). The District monitors selected wells and compiles water quality data from other sources such as the State Water Resources Control Board (SWRCB), Division of Drinking Water (DDW), Groundwater Ambient Monitoring and Assessment Program (GAMA), USGS special studies, and other studies. The District reports on water quality in annual reports.

The District, in coordination with the United States Geologic Survey (Newhouse et al., 2004) installed several multiple-completion monitoring wells in the Santa Clara Subbasin and one in the local Study Area (ELNR) with one screen in the shallow aquifer and three screens in the deep aquifer. This well provides useful information on differences in water quality (and water levels) with depth.

The District has also developed a Salt and Nutrient Management Plan (SNMP) for the Santa Clara Subbasin as required by the SWRQB’s 2009 Recycled Water Policy. The purpose of these SNMPs is to address current and future regional salt and nutrient loading to groundwater from all sources. The groundwater quality section discusses trends in salts and nutrients including total dissolved solids (TDS) and nitrate from 1998 to 2012 and predicts future trends (SCVWD, 2014).

3.5.1.2 State Water Resources Control Board, Division of Drinking Water

DDW regulates public drinking water systems to ensure the delivery of safe drinking water to the public. A public drinking water system is defined as a system for the provision of water for human consumption through pipes or other constructed conveyances that has 15 or more service connections or regularly serves at least 25 individuals daily at least 60 days out of the year. Private domestic wells are not regulated by the DDW. DDW requires regular monitoring and reporting by water purveyors with active drinking water wells with constituents monitored and frequency of monitoring established by DDW. These data are compiled by the District in their water quality database.

3.5.1.3 City of Palo Alto

The City has collected groundwater quality data for its emergency supply wells. Some data have been reported to DDW and are in the District water quality database. Other data available in laboratory reports was entered into the project water quality database.

3.5.1.4 San Mateo Plain Study

Water quality data from the San Mateo Plain Study (EKI et al., 2017) for the local Study Area was incorporated into the database used for this study. Because the San Mateo Plain is not
actively managed and there are few public supply wells, data from multiple sources were compiled. The San Mateo Plain water quality data set incorporated water quality data from DDW and San Francisco Regional Water Quality Control Board (SFRWQCB) online databases (e.g., Geotracker), San Mateo County records, and previous studies.

3.5.2 Overview of Historic and Recent Ambient Groundwater Quality

Natural groundwater quality in the Study Area varies spatially and with depth. Shallow groundwater tends to be similar in composition to recharge water (surface water, precipitation, imported water). Deeper groundwater varies in composition as a result of contact and residence time with formation sediments (Metzger, 2002). In general, groundwater tends to be somewhat hard (i.e., high in calcium carbonate) with levels of chloride, iron, manganese, and total dissolved solids (TDS) that can exceed secondary maximum contaminant levels in some wells. Generally, groundwater in the area is acceptable for both potable and irrigation uses; however, some consumers may find untreated/unblended groundwater to be less desirable when compared with Hetch-Hetchy water.

3.5.2.1 General Mineral Characteristics

General minerals include the major cations (e.g., calcium, magnesium, and sodium) and major anions (bicarbonate, chloride, sulfate). These ions are typically used to identify water types (e.g., calcium-bicarbonate type, etc.) but more importantly calcium and magnesium are used to determine water hardness for which there are no regulatory levels. Hardness is a condition by which the calcium and magnesium ions form insoluble residues with soap. Therefore, hardness is determined by the range of calcium carbonate (CaCO₃) in water in milligrams per liter (mg/L) or parts per million (ppm) which is known as calcium hardness or the range of magnesium expressed as CaCO₃ (magnesium hardness) (Hounslow, 1995). Water with hardness of less than 75 mg/L is considered as soft (Todd, 1980). However, hardness in water, used for ordinary domestic purposes, does not become particularly objectionable until it reaches a hardness level of about 100 mg/L (Hem, 1989).

The Study Area groundwater is hard with hardness concentrations in the Palo Alto area ranging from 36 mg/L to 370 mg/L (Oliver, 1990; Metzger, 2002) and in the Stanford University wells ranging from 260 to 361 mg/L (Geomatrix, 1992). Groundwater from wells operated by the O’Connor Tract Cooperative Water Company in Menlo Park and the Palo Alto Mutual Park Water Company in East Palo Alto meets all primary drinking water quality standards without additional treatment. However, many residences served by these private companies have in-home water softeners to mitigate water hardness (Todd, 2005). Water quality from the most recent sampling event in each of the City’s emergency supply wells is presented in Table 3-14. Total hardness ranges from 100 mg/L in the Fernando well to 270 mg/L in the Rinconada well indicating generally hard water. Note that general mineral analyses including hardness have not been conducted for the Eleanor Pardee and Main Library wells.
### Table 3-14 City of Palo Alto Emergency Supply Well Water Quality

<table>
<thead>
<tr>
<th>Analyte</th>
<th>MCL/SMCL</th>
<th>Units</th>
<th>El Camino Park</th>
<th>Eleanor Pardee</th>
<th>Fernando Hale</th>
<th>Matadero Peers Park</th>
<th>Rinconada Main Library</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>mg/L</td>
<td>75</td>
<td>NT</td>
<td>32</td>
<td>56</td>
<td>64</td>
<td>86</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg/L</td>
<td>17</td>
<td>NT</td>
<td>11</td>
<td>18</td>
<td>9.4</td>
<td>10</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg/L</td>
<td>1.8</td>
<td>NT</td>
<td>1.3</td>
<td>1.9</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/L</td>
<td>71</td>
<td>NT</td>
<td>140</td>
<td>200</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td><strong>Total Hardness (as CaCO₃)</strong></td>
<td>mg/L</td>
<td>260</td>
<td>NT</td>
<td>120</td>
<td>210</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td><strong>Anions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Alkalinity (as CaCO₃)</strong></td>
<td>mg/L</td>
<td>220</td>
<td>NT</td>
<td>240</td>
<td>180</td>
<td>220</td>
<td>200</td>
</tr>
<tr>
<td><strong>Carbonate Alkalinity (as CO₃)</strong></td>
<td>mg/L</td>
<td>&lt;5</td>
<td>NT</td>
<td>&lt;2.4</td>
<td>&lt;2.4</td>
<td>&lt;10</td>
<td>&lt;2.4</td>
</tr>
<tr>
<td><strong>Bicarbonate Alkalinity (as HCO₃)</strong></td>
<td>mg/L</td>
<td>220</td>
<td>NT</td>
<td>290</td>
<td>220</td>
<td>260</td>
<td>240</td>
</tr>
<tr>
<td>Chloride</td>
<td>250 mg/L</td>
<td>54</td>
<td>47</td>
<td>130</td>
<td>610</td>
<td>110</td>
<td>150</td>
</tr>
<tr>
<td>Fluoride</td>
<td>2 mg/L</td>
<td>0.2</td>
<td>0.26</td>
<td>0.12</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Nitrate (as Nitrate)</td>
<td>45 mg/L</td>
<td>10</td>
<td>6.2</td>
<td>&lt;0.5</td>
<td>&lt;1</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Nitrate + Nitrite (as Nitrogen)</td>
<td>10 mg/L</td>
<td>2.3</td>
<td>1.4</td>
<td>NT</td>
<td>0.67</td>
<td>NT</td>
<td>NT</td>
</tr>
<tr>
<td>Nitrite (as Nitrogen)</td>
<td>1 mg/L</td>
<td>&lt;0.1</td>
<td>&lt;0.15</td>
<td>&lt;0.2</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>Sulfate</td>
<td>500 mg/L</td>
<td>83</td>
<td>38</td>
<td>14</td>
<td>23</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td><strong>Inorganics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Aluminum</strong></td>
<td>1000 ug/L</td>
<td>&lt;50</td>
<td>13</td>
<td>500</td>
<td>&lt;50</td>
<td>NT</td>
<td>NT</td>
</tr>
<tr>
<td>Antimony</td>
<td>6 mg/L</td>
<td>&lt;6</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Arsenic</td>
<td>10 ug/L</td>
<td>&lt;2</td>
<td>&lt;1</td>
<td>1.9</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Barium</td>
<td>1000 ug/L</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>86</td>
<td>260</td>
<td>80</td>
<td>9</td>
</tr>
<tr>
<td>Beryllium</td>
<td>4 ug/L</td>
<td>&lt;1</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Boron</td>
<td>200 mg/L</td>
<td>NT</td>
<td>200</td>
<td>NT</td>
<td>480</td>
<td>480</td>
<td>220</td>
</tr>
<tr>
<td>Cadmium</td>
<td>5 ug/L</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Total Chromium</td>
<td>50 ug/L</td>
<td>&lt;10</td>
<td>&lt;2</td>
<td>2.1</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Hexavalent Chromium</td>
<td>10 ug/L</td>
<td>NT</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Copper</td>
<td>1300 ug/L</td>
<td>&lt;50</td>
<td>4.1</td>
<td>16</td>
<td>&lt;50</td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td>Iron</td>
<td>300 ug/L</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>120</td>
<td>1100</td>
<td>690</td>
<td>140</td>
</tr>
<tr>
<td>Lead</td>
<td>15 ug/L</td>
<td>&lt;5</td>
<td>0.12</td>
<td>&lt;1</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>NT</td>
</tr>
<tr>
<td>Manganese</td>
<td>50 ug/L</td>
<td>&lt;20</td>
<td>36</td>
<td>180</td>
<td>125</td>
<td>140</td>
<td>230</td>
</tr>
<tr>
<td>Mercury</td>
<td>2 ug/L</td>
<td>&lt;1</td>
<td>&lt;0.2</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Nickel</td>
<td>100 ug/L</td>
<td>&lt;10</td>
<td>&lt;2.0</td>
<td>&lt;10</td>
<td>&lt;2.0</td>
<td>&lt;2.0</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>Selenium</td>
<td>50 ug/L</td>
<td>&lt;5</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Thallium</td>
<td>2 ug/L</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Zinc</td>
<td>5000 ug/L</td>
<td>&lt;50</td>
<td>&lt;20</td>
<td>&lt;20</td>
<td>&lt;20</td>
<td>&lt;20</td>
<td>&lt;20</td>
</tr>
<tr>
<td><strong>Physical Parameters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methyl Blue Active Substances</td>
<td>500 mg/L</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td><strong>Total Dissolved Solids</strong></td>
<td>500/1000 mg/L</td>
<td>430</td>
<td>450</td>
<td>470</td>
<td>1400</td>
<td>450</td>
<td>500</td>
</tr>
<tr>
<td><strong>Radioactive Analyses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross Alpha</td>
<td>15 Pci/L</td>
<td>3.51</td>
<td>1.7</td>
<td>&lt;3</td>
<td>&lt;3</td>
<td>&lt;3</td>
<td>&lt;3</td>
</tr>
<tr>
<td>Gross Beta</td>
<td>50 Pci/L</td>
<td>NT</td>
<td>1.3</td>
<td>&lt;4</td>
<td>&lt;4</td>
<td>&lt;4</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Radium (226)</td>
<td>5 Pci/L</td>
<td>0.05</td>
<td>0.044</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Radium (228)</td>
<td>5 Pci/L</td>
<td>0.081</td>
<td>0.14</td>
<td>&lt;0.67</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Uranium</td>
<td>20 Pci/L</td>
<td>0.803</td>
<td>1.1</td>
<td>&lt;1</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td><strong>Other Analyses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatile Organic Compounds</td>
<td>* ug/L</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Semi-Volatile Organic Compounds</td>
<td>* ug/L</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Pesticides and PCBs</td>
<td>* ug/L</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Perchlorate</td>
<td>4 ug/L</td>
<td>ND</td>
<td>&lt;4</td>
<td>&lt;4</td>
<td>&lt;4</td>
<td>&lt;4</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Trihalomethanes</td>
<td>1 ug/L</td>
<td>ND</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>NT</td>
<td>NT</td>
<td>NT</td>
</tr>
</tbody>
</table>

**ND** - not detected above MRL  
**MRL** - Method Reporting Limit  
**µmoles/cm** - micromhos per centimeter  
**TOC** - total dissolved solids  
**MCL** - maximum contaminant level  
**mg/L** - milligrams per liter  
**NT** - not tested  
**SM** - Standard Method  
**Pci/L** - picocuries per liter  

*a* - Variable MCLs based on constituent  
*b* - Reported as tested but not included in report by Bonkowski, 2010
3.5.2.2 Total Dissolved Solids (TDS)

Total salinity is commonly expressed in terms of total dissolved solids (TDS) in mg/L. The transport and fate of salinity in infiltrating water and groundwater is largely governed by the amount of TDS.

As established by DDW, the recommended Secondary Maximum Contaminant Level (SMCL) for TDS is 500 mg/L, with an upper limit of 1,000 mg/L and a short-term limit of 1,500 mg/L. A SMCL is a water quality standard established by DDW to manage drinking water for aesthetic considerations, such as taste, color, and odor. Contaminants with only SMCLs are not considered to pose a risk to human health.

While TDS can be an indicator of anthropogenic impacts, there are also natural background TDS levels in groundwater. The background TDS concentrations in groundwater can vary considerably based on purity and crystal size of the minerals in the aquifer, rock texture and porosity, the regional structure, origin of sediments, the age of the groundwater, and many other factors (Hem, 1989).

The areal distribution for TDS in deep wells (screened at depths greater than 200 feet), the District multi-completion well (ELNR), and one shallow/deep well pair located in the Baylands is shown on Figure 3-47. The figure shows the most recent available concentration and also shows time concentration plots for selected wells. Time/concentration plots for the older City wells (Matadero, Fernando, Peers Park, Rinconada, and Hale) with a longer record of water quality are shown. The newly installed City wells (Main Library, Eleanor Pardee, and El Camino Park only have one water quality data point. Note that all of the City wells are actually screened in both the shallow and deep aquifer (Table 3-1).

TDS is generally detected below the upper SMCL of 1,000 mg/L in deep wells (i.e., ambient groundwater) in the Study Area. A few wells in San Mateo County located near the Bay show concentrations above 1,000 mg/L as does the Hale well for the most recent sample. City wells Rinconada and Hale show frequent TDS detection above 500 mg/L, while Peers Park, Fernando, and Matadero, El Camino Park, Eleanor Pardee, and the Main Library well show TDS concentrations closer to 500 mg/L. The Hale and Rinconada wells have been exhibiting an increase trend in TDS concentrations since the 1980s. The reason for the increase is not known.

One of the relatively deep screened intervals (720-740 ft-bgs) in the ELNR multi-completion well shows high TDS concentrations near or above 2,500 mg/L, with the other intervals having TDS concentrations below 1,000 mg/L. Another shallow/deep well pair is located in Palo Alto in the Baylands. The shallow well shows extremely high TDS, above 50,000 mg/L, while the deep well shows concentrations typically below 400 mg/L.

Figure 3-48 shows TDS in shallow groundwater, with much higher TDS in the shallow wells, particularly nearer to the Bay.

Elevated TDS and chloride can be indicators of saline water intrusion. The source of the elevated TDS in both the shallow and deep aquifer wells, located inland from the Baylands, is believed to be the result of leaching of chloride-rich marine deposits, rather than recent saline intrusion (Metzger and Fio, 1997; Metzger, 2002) (see additional discussion in Section 3.5.2.3).
The Santa Clara Valley SNMP (District, 2014) documented that most wells in the Study Area showed no trends (either upward or downward) for TDS between 1998 and 2012 in either the shallow or deep aquifer.

Table 3-14 shows the most recent detection of TDS and other constituent the City wells. TDS in the City wells ranges from 430 mg/L in the El Camino Park well to 1,400 mg/L in the Hale well.

### 3.5.2.3 Chloride and Saline Water Intrusion

Chloride is an inorganic salt that is naturally occurring in groundwater and is commonly expressed in terms of mg/L. High concentrations of chloride in shallow groundwater near the Bay have historically been attributed to Bay water intrusion. However, more recent work attributes high chloride in shallow groundwater to the influence of saline marine deposits and hypersaline marsh water. High chloride in deep groundwater is also attributed to connate water influenced by chloride-rich marine deposits.

As established by DDW, the recommended SMCL for chloride is 250 mg/L, with an upper limit of 500 mg/L and a short-term limit of 600 mg/L.

Similar to TDS, elevated chloride concentrations are undesirable for aesthetic reasons related to taste, odor, or appearance of the water, and not for health reasons; however, elevated chloride concentrations in water can damage crops, affect plant growth, and damage municipal and industrial equipment. Chloride is conservative and mobile in the environment. Conservative, in this context, means a constituent that does not interact with subsurface media (vadose zone and saturated zone) and therefore, is not readily attenuated in the subsurface.

While chloride can be an indicator of anthropogenic impacts, there are also natural background chloride levels in groundwater.

The areal distribution for chloride in deep wells (screened at depths greater than 200 feet), the District multi-completion well (ELNR), and one shallow/deep well pair located in the Baylands is shown on Figure 3-49. The figure shows the most recent available concentration and also shows time concentration plots for selected wells.

While most deep wells in the Study Area have chloride concentrations below the SMCL of 250 mg/L, concentrations above 250 mg/L do occur. The City’s Hale and Rinconada wells are currently showing chloride concentrations above 250 mg/L. While chloride concentrations are variable, both wells appear to show long-term increasing trends. The reason for the increasing trends is uncertain. Comparing the chloride trends with groundwater elevations shown in Figure 3-30 shows that chloride concentrations were below the 250 mg/L MCLSMCL during the period of significant groundwater use prior to 1962 and generally increasing trends as groundwater levels have risen and stabilized. If saline water were intruding from the Bay, one would expect higher concentrations during periods of significant drawdown and lowered concentrations during water level recovery. It is unclear why chloride concentrations are increasing in these wells. One of the relatively deep screened intervals (720-740 ft-bgs) in the ELNR well shows high chloride concentrations above 1,000 mg/L, with the other intervals having chloride concentrations below 1,000 mg/L. The source of the elevated chloride in this deep interval is characterized as resulting from leaching of chloride-rich marine deposits, rather
than recent saline intrusion (Metzger and Fio, 1997; Metzger, 2002). Through use of various geochemical analyses such as isotopic data and constituent ratios, Metzger (2002) demonstrated that the high chloride (and associated TDS) concentrations in shallow and deep groundwater in the area are not associated with Bay water intrusion, but rather, are the result of water moving through the aquifers coming into contact with chloride-rich marine deposits including both undifferentiated clay deposits and consolidated to unconsolidated bedrock assemblages underlying the alluvial aquifer. Undifferentiated clay deposits overlay the shallow aquifer and separate the shallow and deep aquifers throughout most of the Study Area, particularly proximate to the Bay. In the Palo Alto Baylands, the source of elevated chloride (and associated TDS) is different. Very high chloride, TDS and other constituents in shallow Baylands groundwater is the result of evaporative concentration and percolation in the salt marshes, resulting in hypersaline brine in shallow groundwater near Bay (Hamlin, 1983 and 1985). These hypersaline conditions are observed in the shalower of the shallow/deep well pair in the Baylands area shown on Figure 3-49.

Another shallow/deep well pair is located in Palo Alto in the Baylands. The shallow well shows extremely high chloride above 20,000 mg/L, while the deep well shows concentrations typically below 200 mg/L. Very high chloride concentrations in the Baylands area are the result of evaporative concentration and percolation in the salt marshes, resulting in hypersaline brine in shallow groundwater near Bay (Hamlin, 1983).

Table 3-14 shows the most recent detection of chloride and other constituent the City wells. Recent chloride concentrations in the City wells range from 47 mg/L in the El Camino Park well to 610 mg/L in the Hale well.

Figure 3-50 shows chloride in shallow groundwater showing much higher chloride concentrations in the shallow wells near to the Bay. Figure 3-51 shows the historical inland extent of chloride concentrations above 100 mg/L in the shallow aquifer from the District’s 2016 Groundwater Management Plan.

**3.5.2.4 Iron and Manganese**

Iron and manganese are inorganic groundwater constituents generally derived from geologic sources. They are commonly considered or grouped together because of similar geochemical characteristics and occurrences in groundwater. Iron in groundwater may be attributed to iron oxyhydroxides or ferrous oxide coatings on sand and gravel and with iron-containing (ferruginous) clays (Parsons, et al., 2012). Elevated manganese and iron can also occur when wells are screened in clay horizons (Todd, 1980). Moreover, elevated concentrations can result in problems such as bacterial clogging of well screens and staining of plumbing and laundry.

The current SMCL for iron is 300 micrograms per liter (µg/L) and for manganese is 50 µg/L. Figures 3-51 and 3-52 show iron concentrations in the deep and shallow aquifers, respectively. Figures 3-53 and 3-54 show manganese in the deep and shallow aquifers, respectively. Iron is frequently detected above 300 µg/L in deep groundwater wells. It is only detected above the SMCL in shallow wells near the Bay. The ELNR multi-completion well shows iron concentrations typically below the SMCL in all screened intervals.
Manganese is frequently detected above the SMCL in deep and shallow aquifer wells in the Study Area. Concentrations appear to be lower and typically below the SMCL in the southeastern portion of the Study Area in the vicinity of Mountain View and Los Altos. The ELNR multi-completion wells show the lowest manganese concentrations in the shallow aquifer (180 – 200 ft-bgs), although the concentrations are typically above 50 µg/L. The deeper intervals screened in the deep aquifer are all above the SMCL.

**Table 3-14** shows the most recent detections of iron and manganese and other constituents the City wells. Iron in the City wells ranges from 80 µg/L in the Main Library well to 1,100 µg/L in the Fernando well. Recent manganese concentrations in the City wells range from less than 20 µg/L in El Camino Park to 230 µg/L in Peers Park.

### 3.5.2.5 Nitrate

Nutrients, such as nitrate (NO$_3$) and nitrite (NO$_2$), can be present naturally at low concentrations in groundwater but elevated (high and moderate) concentrations are commonly derived from anthropogenic (human) activities. In urban areas, sources include fertilizer application to landscaping and wastewater sources such as septic systems and leaking sewage lines (Parsons, et al., 2012). Legacy nitrate from historical agricultural land use in Santa Clara Valley is also a source of nitrate loading to groundwater (SCVWD, 2014). It is sometimes difficult to link high nitrate concentrations in groundwater directly to overlying nitrogen inputs. Natural nitrate (as NO$_3$) background concentrations are generally considered to be 10 mg/L or less (Todd, 1980). The current primary MCL for nitrate (as NO$_3$) is 45 mg/L. Nitrate is a health concern due to methemoglobinemia, or “blue baby syndrome,” which affects infants. Elevated levels may also be unhealthy for pregnant women (SWRCB, 2016).

**Figures 3-56 and 5-57** show nitrate (as NO$_3$) in the deep and shallow aquifers, respectively. Nitrate is not detected in recent data in deep or shallow groundwater above the MCL in the Study Area, with the exception of one well located in San Mateo County. Some wells show concentrations above 10 mg/L, indicating potential impacts from anthropogenic sources. The ELNR multi-completion well and the shallow/deep well pair located in the Baylands all show low concentrations of nitrate less than 10 mg/L.

The Santa Clara Subbasin SNMP (District, 2014) indicated that most wells in the Study Area showed no statistically significant trends (either upward or downward) for nitrate between 1998 and 2012 in either the shallow or deep aquifer.

**Table 3-14** shows the most recent results for nitrate and other constituent the City wells. Nitrate in the City wells ranges from below the detection limit in most wells to 10 mg/L in the El Camino Park well.

### 3.5.3 Point-Source Contamination

In addition to ambient groundwater quality, anthropogenic chemicals may also be present in groundwater, and need to be considered for the City’s IPR recharge and production well planning. Several groundwater contaminant plumes are present within the City (typically at depths above 125 ft-bgs) and pose potential threats to future IPR and groundwater production operations. If contaminants are drawn into City supply wells, expensive wellhead treatment...
may be required in order to meet drinking water standards. Operation of production wells and future IPR recharge facilities also could potentially exacerbate plume migration and spreading, which could result in additional hydraulic control or treatment facilities in order to meet regulatory requirements and cleanup goals.

In order to evaluate these potential risks, the locations, distributions, and current containment status of known contaminant plumes within the city of Palo Alto were evaluated relative to potential future IPR recharge and groundwater production operations.

Federal, state, and local laws regulate the handling and storage of chemicals and are intended to prevent contamination of the environment and groundwater resources. However, historical business and manufacturing practices have in some cases resulted in the release of various contaminants into the soil and groundwater. In Palo Alto, the most common sources of soil and groundwater contamination are 1) current or former gasoline service stations with leaking underground storage tanks (LUSTs) that resulted in discharge of hydrocarbon fuels, and 2) industrial facilities including technology companies that discharged volatile organic compounds (VOCs) often associated with leaking underground storage tanks (USTs), piping, and/or subsurface sumps.

Numerous contamination sites have been identified in Palo Alto based on reports of releases and site investigations required by State and Federal environmental policies and regulations, or during due diligence investigations for real estate property transactions. Many of these sites have been investigated through installation and sampling of monitoring wells, and some sites have been partially or completely remediated, while others remain contaminated. Investigation and remediation are typically conducted by the responsible party or property owner under the supervision of the regulating agency or agencies.

At sites with groundwater contamination, downward gravity-driven migration through the vadose zone causes contaminants to enter the saturated groundwater zone, where they flow via advection in groundwater, spread laterally and vertically due to dispersion and molecular diffusion, and depending on chemical type, can adsorb onto the solid aquifer matrix and/or degrade into other compounds. The extents of chemical plumes in groundwater are controlled by chemical properties and site-specific hydrogeologic conditions (e.g., groundwater flow rates and directions (lateral and vertical), and the presence of fine- and coarse-grained layers that could impede or allow migration, as well as the size, duration, and timing of the release.

Typically, following initial discovery at most contaminated sites, soil and groundwater investigations are conducted to assess the nature and extent of the impact, and to inform the development and implementation of remediation plans, if needed. Investigations often entail installation of soil borings, monitoring points/wells, measurement of groundwater levels, estimation of flow directions and rates, collection and analysis of soil, groundwater, and/or soil vapor samples, and hydrogeologic evaluations to develop a conceptual model of the particular site and contamination. Remedial efforts at sites in the City have included excavation of contaminated soil, extraction and treatment of contaminants using groundwater and/or soil vapor extraction (SVE) wells, and injection of remediation compounds to degrade contaminants into less harmful substances. Additionally, engineering and/or institutional land use controls have been implemented at some sites to protect site occupants or workers from exposure to
contaminants. A few sites have been adequately remediated to the point where they no longer pose a threat to public health or the beneficial use(s) of the groundwater resource; these have been "closed" by the oversight agency either with or without ongoing land use controls.

### 3.5.3.1 Regulatory Oversight

Regulatory agencies responsible for oversight of contaminated sites in Palo Alto include the United States Environmental Protection Agency (USEPA), SFRWQCB, California Department of Toxic Substances Control (DTSC), and the Santa Clara County Environmental Health Services Department under its Hazardous Materials and Underground Storage Tanks Site Mitigation Programs (County DEH). Typically, the DTSC and SFRWQCB oversee the chlorinated solvent site cleanups (under the SFRWQCB “Site Cleanup Program”) while the County oversees the petroleum hydrocarbon LUST sites. The USEPA provides additional oversite on cleanups of (primarily chlorinated solvent) sites listed under the National Priorities List (NPL) “Superfund” program.

The LUST Cleanup Sites, which involve hydrocarbon contamination, are generally easier to remediate, because the hydrocarbons tend to biodegrade and naturally attenuate. However, the drinking water MCL for benzene, a component of gasoline, is 0.5 µg/L, a very low concentration. Methyl tertiary butyl ether (MTBE), also present in groundwater at some sites, is a gasoline additive historically added to gasoline, that is less degradable than petroleum hydrocarbons. MTBE has a primary MCL of 13 µg/L.

It should be noted that many of the regulatory cleanup requirements for sites in the City were established by the different regulatory agencies based on the assumption that groundwater was not used for municipal drinking water supply. Although this was generally true in previous years, implementation of municipal production by the City will change that condition. In some cases, contaminant plumes have been allowed to be only partially remediated, under the assumption that contaminants will eventually “naturally attenuate” through chemical reactions, biodegradation, and dilution.

Initiation of IPR and municipal groundwater production by the City may necessitate discussions with the regulatory agencies about residual contamination and natural attenuation remedies. Changes in cleanup orders may be required in order to ensure that City IPR and groundwater production operations are not impacted by residual contaminants.

### 3.5.3.2 Characteristics and Status of Known Contamination Sites

The known regulated open and closed contaminated sites within the City and nearby area are shown on Figure 3-58 along with the locations of the City’s emergency supply wells. The open and closed sites were identified in the SWRCB’s Geotracker system, the DTSC’s Envirostor database, and the USEPA CERCLA list. Of these, 40 sites in Palo Alto are currently open (meaning active remediation or monitoring is still occurring).

Due to the persistence of chlorinated hydrocarbons in the subsurface and relatively low MCLs, the Cleanup Program Sites have been relatively difficult to remediate, even after decades of active remedial measures. The primary chlorinated hydrocarbons present at Cleanup Program Sites in the City include tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene
(cis-1,2-DCE), 1,1-dichloroethene (1,1-DCE), and vinyl chloride (VC). These five chlorinated solvents have primary MCLs ranging from 0.5 to 6 µg/L. 1,1,1-trichloroethane (1,1,1-TCA) and other solvent compounds are also present at some of the contaminated sites. 1,1,1-TCA has an MCL of 200 µg/L.

Figure 3-59 shows the extent of several large contaminant plumes located in the southwest area of the City. Three of the City wells (Fernando, Matadero, and Peers Park) are located proximate to the COE plume. Other City wells, Main Library, Rinconada, and Eleanor Pardee are located generally downgradient from the COE plume. The depths of the plumes are indicated by the color of the plume and vary from less than 50 feet to greater than 100 feet. Contaminant plumes emanating from these sites may pose a risk to the quality of groundwater produced by the City wells if chemicals from these sites flow to the wells. Contamination sites, both those with mapped plumes and soil contamination only, limit where surface spreading IPR facilities may be located due to the potential to mobilize contamination. Potential areas for surface spreading include the alluvial and Santa Clara Formation recharge areas, where several large contamination plumes are located.

To assess threats to City wells and potential limits on IPR facility siting, available information on the open sites was obtained and reviewed. Site investigation and monitoring reports were obtained from the SFRWQCB Geotracker and DTSC Envirostor online databases, and the types, amounts, and distributions of contaminant plumes within the City were identified. Particular attention was paid to the lateral and vertical distributions of chlorinated hydrocarbon plumes, because these are some of the most persistent and toxic chemical contaminants in groundwater.

3.5.3.2.1 SFRWQCB Chlorinated Solvent Cleanup Program Sites

Figure 3-59 shows the locations and recent extent (greater than 5 µg/L) of VOC contaminant plumes in the City. Several of the contaminant plumes are located upgradient (south) of or in the vicinity of City emergency supply wells. Five mapped plumes are located in the Santa Clara Formation recharge area. Siting surface spreading IPR facilities near or directly upgradient of these plumes could result in mobilization of contaminants. Contaminant plumes emanating from these sites may pose a risk to the quality of groundwater produced by the City wells if chemicals from these sites flow to the wells.

The conditions and status of major solvent Cleanup Program Sites in the City are presented below. The site locations are shown on Figure 3-59 and are described below based on their location from north to south.

California-Olive-Emerson Study Area
The California-Olive-Emerson (COE) Study Area comprises three large adjacent contaminated sites, along with several smaller sites, with co-mingled chlorinated hydrocarbon plumes. The three large sites are the Hewlett-Packard (HP) facility at 640 Page Mill Road, the HP facility at 395 Page Mill Road, and the Varian Medical Systems site at 601 California Road. HP and predecessor occupants began electronic equipment manufacturing operations at the 395 and 640 Page Mill sites in the 1940s and 1950s, respectively. The 601 California site was originally leased to Varian and other electronics manufacturing companies beginning in the 1950s. As a
part of the manufacturing processes, numerous VOCs and inorganic chemicals were stored and used at the sites.

HP and Varian began conducting soil and groundwater investigations at their respective sites in the early 1980s. Source area investigation and soil remediation were addressed separately at each site under SFRWQCB oversight. HP and Varian worked cooperatively under SFRWQCB oversight to investigate and remediate groundwater impacts in the downgradient (north) offsite area. Investigation findings were presented in the Study Area Remedial Investigation Report (Environ, 1993). These investigations determined that contamination resulted from historical chemical releases at the sites as well as other sources upgradient of the sites. The primary chemicals of concern are PCE, TCE, and 1,1,1-TCA.

The SFRWQCB issued Revised Site Cleanup Requirements, Order No. 94-130 on September 21, 1994, requiring remediation of VOC-impacted soil and groundwater. In accordance with the Order, remedial measures undertaken since the 1980s include soil excavation, SVE, in-situ chemical treatment, and groundwater extraction and treatment. Current remediation systems include onsite pumping and/or in-situ chemical treatment at each of the three sites, and offsite plume control via the Oregon Expressway Underpass (OEU) dewatering system, where the Oregon Expressway passes beneath Alma Street.

Based on recent (2014) groundwater sampling results (Stantec, 2015a), there are still very high VOC concentrations present in groundwater, particularly in onsite areas. TCE concentrations exceeding 10,000 µg/L are present in several onsite subareas of the greater COE site.

Figure 3-59 shows the current recent (2014) lateral extent of the COE VOC plume, which extends from upgradient of the three larger sites, described above, to just beyond the containment system. VOCs are detected at low concentrations in monitoring wells downgradient (north) of Alma Street, indicating that the onsite and offsite groundwater extraction systems may not be completely effective in containing downgradient plume migration. Contamination currently extends to the B1 zone, to a depth of approximately 100 ft-bgs.

Figures 3-60B and 3-60C illustrate the extent and depth of the COE plume in cross section and the well completions for City wells located close to the plume and downgradient of the plume. The City’s Matadero and Fernando wells are located just south (approximately 1,000 feet) and east (approximately 630 feet), respectively, of the COE plume and do not intersect the plume (see Figure 3-59). The Peers Park well is located approximately 2,000 feet northwest of the plume. Groundwater samples from the Matadero, Fernando, and Peers Park wells were last tested for VOCs in November 2013 and no VOCs were detected above the laboratory reporting limits. The Matadero and Fernando well surface seals extend to 60 and 91 ft-bgs, respectively, and the wells are gravel packed below those depths for the entire well depth from 60 to 1,066 and 91 to 1,020, respectively. The Matadero well is screened continuously from 142 to 1,066 and the screened interval of the Fernando well is unknown, but presumed to be similar to the Matadero well (see Table 3-1). Thus, these wells are screened and gravel packed in both the shallow and deep aquifers and at depths were COE site contamination is found. Potential future pumping of these wells will lower groundwater levels in the vicinity and for some distance around the wells resulting in a pumping cone of depression and a downward vertical hydraulic
gradient. It is possible that VOCs could be drawn into the wells under sustained pumping conditions. The Peers Park well is located at greater distance and is gravel packed and screened at greater depths than the Matadero and Fernando wells and thus is less vulnerable to contamination impacts. Figure 3-60C shows the Rinconada, Main Library, and Eleanor Pardee wells located at distances greater than one mile downgradient from the COE plume. Given the distance and deeper surface seals, these wells are not thought to be at high risk from contamination from the COE plume.

Groundwater modeling, to be conducted in subsequent phases of this project, can better estimate groundwater level and vertical gradient changes associated with different pumping scenarios for these wells. It is recommended that routine monitoring of these wells for VOCs be conducted if the wells are used for ongoing supply. In addition, a video log should be conducted of the Fernando well to determine the screened interval(s). Both wells were drilled in the 1950s and the City may want to consider replacing them with new wells in a different area of the City. Finally, comprehensive Drinking Water Source Assessment Program (DWSAP) reports should be prepared for these and all City wells. The DWSAP is a DDW program whereby every water supply well undergoes an assessment to predicted groundwater vulnerability to contamination based on intrinsic hydrogeology parameters and a comprehensive inventory and ranking of nearby potentially contaminating activities within the capture zone of the well. A capture zone refers to the three-dimensional region that contributes the groundwater extracted by one or more wells.

**Hewlett-Packard 1501 Page Mill Road Site**

The Hewlett-Packard 1501 Page Mill Road site covers approximately 36 acres and is located within the Stanford Research Park. The site was initially developed in the 1950s, and underground chemical storage tanks were installed in the 1960s and 1970s and used for storage of VOCs and fuels. Groundwater investigations began in the early 1980s. Historical VOC concentrations in monitoring wells exceeded 40,000 µg/L. Chemicals present in groundwater include TCE, 1,1,1-TCA, benzene, ethylene dibromide (EDB) and other chlorinated solvents and aromatics.

Site remediation began in 1987 and included contaminated soil excavation, soil vapor extraction, and groundwater extraction and treatment. Currently remediation activities consist of groundwater extraction in selected areas. An enhanced in-situ bioremediation pilot study also has been initiated. Consistent with SFRWQCB approvals, the groundwater extraction system currently extracts groundwater from six wells completed in four different hydrostratigraphic depth zones (referred to as Surficial, Gamma 1, Gamma 2, and Gamma 4).

Figure 3-59 shows the approximate current (2016) lateral extent of the plume associated with this site. Current VOC concentrations remain well above MCLs. The maximum TCE concentration in 2016 was 3,400 µg/L (Stantec, 2016a). Although groundwater extraction continues at the site, certain portions of the plume downgradient of the extraction system remain above MCLs indicating the potential for further plume migration. Contamination at site may extend to depths greater than 200 feet. The Matadero, Fernando, and Peers Park wells are located about 3,150, 4,200, and 6,300 feet downgradient of the Hewlett-Packard plume, respectively, as shown on Figure 3-59. Given the distances, these wells are not at high risk of
contamination from the Hewlett-Packard plume; however, regular monitoring of the wells for VOCs and review of ongoing monitoring and remedial activities at the Hewlett-Packard site are recommended.

The depths of the plume (approximately 200 ft-bgs) provides an indication of the permeability of the Santa Clara Formation and the potential suitability of the formation for IPR surface recharge facilities. While IPR facilities are not recommended in close proximity or directly upgradient of known contamination sites, elsewhere in the Santa Clara Formation recharge area may be considered.

**Hillview-Porter Study Area**

The Hillview Porter study area occupies about 320 acres and includes nine sites within the Stanford Research Park, portions of the Veterans Administration Hospital property, Matadero Creek, and the Barron Park neighborhood. Numerous technology and manufacturing companies including Coherent, General Instrument, Gould, HP, Lockheed, Monsanto, Quality Technologies, SmithKline, Syntax, Teledyne-MEC, Teledyne-Singer, and Watkins-Johnson occupied adjacent properties on Hillview Avenue, Porter Drive, and Page Mill Road (ENSR, 1989). Numerous USTs were installed at the sites beginning in 1960. Numerous VOCs and other chemicals leaked into the subsurface, commingled, and subsequently emerged into Matadero Creek. Historical TCE concentrations in shallow groundwater were as high as 340,000 µg/L and water samples from Matadero Creek contained TCE at concentrations of up to 160 µg/L. Initial investigations and remedial actions were conducted under former California Department of Health Services Remedial Action Order No 88/89-016 dated December 9, 1988. The SFRWQCB adopted Site Cleanup Requirements Order No. 93-092 (amending previous Orders). Regulatory oversight of the individual sites subsequently transferred to the DTSC.

Remedial actions including soil excavation, SVE, and groundwater extraction and treatment began in the late 1980s. Both vertical and horizontal extraction wells/drains have been installed and operated, and in-situ reactive zone technologies were also installed at portions of the site in the 2000s.

The lateral and vertical extent of the plume has been characterized based on onsite and offsite shallow and deeper monitoring wells, completed in various aquifer sub-units referred to alternatively as the A1, A2, and B zones; the Alluvium, S Zone, and Gamma 1-4 Zones; and most recently, as the A, B, C, D, E, F, G, and H depth zones (Stantec, 2012, 2016b). Figure 3-59 shows the recent (November 2015) lateral extent of the site VOC plume greater than 5 µg/L. The plume extends from multiple individual source areas and crosses Matadero Creek. Recent (November 2015) TCE concentrations remain as high as 18,000 µg/L in onsite shallow wells and currently exceed 100 µg/L in the deepest aquifer zones monitored, around 100 ft-bgs. Other VOCs and chromium-VI are also present at concentrations exceeding MCLs. Offsite monitoring wells in the downgradient Barron Park Neighborhood (beyond the 5 µg/L area) contain lower concentrations, but still exceed MCLs.

Figure 3-60A illustrates the depth of the Hillview Porter site plume in cross section. VOCs extend to a depth greater than 125 ft-bgs. The Matadero and Fernando wells are located about 4,200 and 5,700 feet downgradient form the Hillview Porter plume, respectively, as shown on...
Figure 3-59. Given the distances, these wells are not at high risk of contamination from the Hillview Porter plume; however, regular monitoring of the wells for VOCs and review of ongoing monitoring and remedial activities at the Hillview Porter site are recommended.

The depths of the plume (greater than 125 feet) provides an indication of the permeability of the Santa Clara Formation and the potential suitability of the formation for IPR surface recharge facilities. While IPR facilities are not recommended in close proximity or directly upgradient of known contamination sites, elsewhere in the Santa Clara Formation recharge area may be considered.

Former Fairchild Semiconductor 4001 Miranda Avenue Site
Fairchild Semiconductor Corporation leased the site from 1963 through 1987 and conducted research, design, and support activities related to the manufacture of semiconductor devices. Chemicals used and released at the site included VOCs, acids, and bases. The chlorinated solvents TCE and cis-1,2-DCE are the primary contaminants of concern at the site. Groundwater extraction and treatment began in 1985 and continued until 2003. Ongoing groundwater monitoring indicated that at most locations sampled, contaminant levels have reached asymptotic levels. Several rounds of in-situ chemical oxidation have been conducted at and in the vicinity of the former source area since 2000.

Figure 3-59 shows the approximate current (2015) extent of the VOC plume (Langan Treadwell Rollo, 2016). TCE and cis-1,2-DCE concentrations near the “dry well” source area are as high as 1,000 and 690 µg/L, respectively. TCE and cis-1,2-DCE concentrations in downgradient wells also remain well above MCLs. The current (2015) depth of contamination is limited to the upper 200 feet of alluvium. However, because the site is in the “unconfined” recharge area of the groundwater subbasin, contaminants may continue to migrate downward and to the north toward the Fernando and Matadero wells. Accordingly, regular monitoring of the wells for VOCs and review of ongoing monitoring and remedial activities at the Former Fairchild Semiconductor site are recommended. IPR surface spreading facilities are not recommended in the vicinity of this site.

3.5.3.2 DTSC Chlorinated Solvent Sites

Palo Alto Town & Country Village 855 El Camino Real
The Palo Alto Town & Country Village site is a retail shopping center comprising six buildings on approximately 13 acres. Several dry-cleaning businesses have operated at the site since 1958. Dry cleaners use PCE and other solvents in their cleaning processes, and sometimes discharge chemicals to leaky sewers, where they can migrate into soil and groundwater. Groundwater, soil, and soil vapor have been sampled at the site to characterize the extent of VOC contamination. Currently, six shallow (40 feet deep) monitoring wells have been installed, and the wells are sampled quarterly. During March 2017, PCE was detected in two of the wells at concentrations of 27 and 43 µg/L (IRC Environmental Consulting, 2017). Because the most downgradient well (MW-2) had 25 µg/L PCE and because the wells are all shallow, the lateral and vertical extent of the plume have not been delineated.

Because of its upgradient location and because the extent of the plume has not been delineated, there is a possibility that VOCs could impact City wells. Accordingly, regular
groundwater quality at the City wells.

3.5.3.2 Petroleum Hydrocarbon LUST Sites

There are numerous LUST sites throughout the City. Many of these sites were investigated, some were remediated, while others had identified releases to soil and groundwater but were “closed” (meaning no additional investigation or remediation was required by regulatory agencies), based on the assumptions that there are no nearby groundwater users and that the hydrocarbons will naturally attenuate. However, there have been cases where “closed” sites remain contaminated and are ongoing sources of groundwater contamination.

There are only two “open” LUST sites in the City. One is a small UST discovered at a private residence at the corner of North California Avenue and South Court. The UST was removed during site redevelopment and high concentrations of petroleum hydrocarbons in soil beneath the tank were reported by the DEH. The County requires additional assessment of soil and groundwater prior to evaluating case for closure. However, the property owner has not responded to DEH directive letters and is currently out of compliance.

The other open LUST Site is the Chevron Station located at 2799 Middlefield Road (Chevron Station 90339). Thirteen monitoring wells have been installed at the station, and remedial activities have been conducted. As of 2015, petroleum hydrocarbons including benzene were still present in groundwater at the site (Stantec, 2015b). However, due to its location relative to City wells, it is not considered a threat to groundwater quality at the City wells.

3.6 Groundwater Use Assessment Findings

This section presents a preliminary assessment of potential impacts of increased City pumping. Increased groundwater pumping and implementation of IPR projects was further evaluated with groundwater modeling as presented in Section 4.

3.6.1 Assessment of Increased Pumping by City of Palo Alto

The City owns eight emergency water supply wells including Hale, Rinconada, Peers Park, Fernando, Matadero, Eleanor Pardee, Main Library, and El Camino Park. Five are older wells constructed in the 1950s and three are newer wells constructed between 2009 and 2013. Table 3-1 provides the well construction and performance information. All of the wells are screened in both the shallow aquifer (less than 200 ft-bgs) and deep aquifer (greater than 200 ft-bgs). The well capacities vary from 600 to 3,300 gpm, which is consistent with observed variability in aquifer properties in the Study Area. The total capacity of all the wells is estimated at 11,300 gpm or 18,227 AFY based on pumping tests, which is more than the total City water demand projection for 2020 of 12,000 AF. The City’s demand projections decrease after 2020 to 11,000 AF in 2040 (SCVWD, 2015a). This groundwater use assessment addresses the Study Area’s ability to sustain potential future City groundwater pumping at various levels up to the City’s 2020 demand of 12,000 AFY. Groundwater modeling presented in Section 4.4 was used to refine City pumping and IPR recharge scenarios and assess their feasibility.
The estimated capacity of the City wells may be less than predicted by the pumping tests due to well interference if all wells or multiple wells are pumped at the same time. Several of the City wells are located in close proximity to each other and well interference between wells is expected based on the large area of observed drawdown documented in the Stanford pumping test in Well 4R (see Section 3.2.8). The City may want to consider additional pumping tests with observation wells to better define potential well interference and yields.

The groundwater yield available to the City of Palo Alto can be estimated from the water balance information in two ways. The practical rate of withdrawal method compares the pumping and storage change over a number of years. The capturable outflow method estimates the fraction of groundwater outflow that could be captured by increased pumping. These two approaches are described below. For comparison, a third approach is to use a groundwater model. The model simulation of City pumping without accompanying IPR described in Section 4 produced a yield estimate of 3,000 AFY.

### 3.6.1.1 Practical Rate of Withdrawal Method

The practical rate of withdrawal method compares annual pumping and annual storage change for historical periods with a range of pumping amounts. The historical water balances described in Sections 3.4.2 and 3.4.3 were incomplete in the sense that the authors did not quantify all inflows and outflows and the ones that were quantified did not total up to a balanced budget. However, the early 1930s and early 1960s water balances both included estimates of pumping and storage change. Average annual pumping and storage change in the San Francisquito Cone area were tabulated and plotted for four historical periods. In the 1920’s (Clark, 1924) and again in the 1950s (Sokol, 1964), groundwater pumping was large and storage was decreasing. Beginning in the mid-1960s, groundwater pumping was small and storage was increasing. Finally, in the contemporary water balance (2010s) pumping is small for the San Francisquito Cone and storage is approximately stable. Figure 3-61 shows data points for those four periods plotted on a graph of storage change versus annual pumping. A preliminary estimate of potential available yield can be obtained by plotting a regression line through the data points. The amount of pumping corresponding to the point where the regression line crosses the zero-storage-change level on the Y axis is the estimate of operable yield. The estimate of 4,000 AFY indicated by the graph is very approximate because of the large scatter in the data points. Note that this yield estimate is for the San Francisquito Cone area, not the entire Study Area.

### 3.6.1.2 Capturable Outflow Method

Pumping by City Palo Alto wells could potentially capture recharge from a larger area than the San Francisquito Cone, which is why the Study Area boundaries were placed some distance northwest and southeast of the Cone. A preliminary estimate of potential yield roughly equals groundwater outflows to sewers, creeks, storm drains, tidal marshes, San Francisco Bay and Niles Cone minus the amounts of outflows needed to protect other users and prevent undesirable results. Those outflows totaled 8,700 AFY in the contemporary water balance. Subtractions from that amount should include the following.

First, other pumpers within the Study Area might also want to make use of some of the available yield as discussed in Section 3.6.2. Second, wells in Palo Alto might not efficiently
capture recharge from creeks in the southeastern part of the Study Area. Third, some outflow to creeks and the Bay is likely needed to maintain aquatic habitat and prevent subsidence. For preliminary planning purposes, it might be reasonable to assume that one-third of those current outflows are needed to prevent undesirable results, or 2,900 AFY. Subtracting that from the preliminary estimate produces an adjusted yield estimate available to the City of about 5,800 AFY. Groundwater use by other water purveyors in the Study Area has varied historically and plans for future use continue to evolve. For rough planning purposes, it might be reasonable to assume that half of the Study Area yield should be reserved for those areas (Menlo Park, East Palo Alto, Los Altos and Mountain View). This would leave 2,900 AFY of yield available for use by Palo Alto, which is slightly less than the 4,000 AFY estimate obtained from the practical rate of withdrawal method. This amount of groundwater equals roughly one-fourth of Palo Alto’s current annual water use or about 24% of the projected 2020 demand.

Groundwater flow modeling described in Section 4.4 included a simulation of 3,000 AFY of Palo Alto pumping (with no IPR), which appeared to be the maximum rate that could be sustained without creating an elevated risk of saline water intrusion during droughts at existing public supply wells in Menlo Park. Implementation of IPR facilities would augment recharge and increase the potential yield available to the City, and the groundwater modeling included scenarios with various combinations of IPR recharge and City pumping.

3.6.1.3 Yield Estimate from 1988 Drawdown Data

A third estimate of groundwater yield available to the City of Palo Alto was developed by Carollo Engineers (2003) using a completely different approach. They documented that 1,500 AF of pumping by City wells over 5 months in 1988 produced an average of 24 feet of water-level decline at the pumping wells, and that water levels fully recovered within 18 months after pumping stopped. No adverse effects related to the temporary water-level declines were reported, and Carollo concluded that the amount of pumping in 1988 was therefore a reasonable estimate of yield for an isolated year of pumping (reduced to 500 AFY for consecutive pumping years). The Carollo yield estimate is smaller than the yield estimate presented in this report primarily because it is based on analysis of a relatively brief stress in a small geographic area. The water-level declines measured in the pumping wells probably represented localized cones of depression, not a broader lowering of the water-level surface. Also, a longer duration of pumping would have accessed groundwater storage at the water table (specific yield), which is much larger that the short-term storage response in semi-confined aquifers. Furthermore, if the City had pumped 2,900 AFY over a full year and the water levels had fully recovered over the subsequent two years, the Carollo method would have produced a yield estimate 2,900 AFY. Finally, the Study Area for the present report is six times larger than the area evaluated by Carollo, and some of the recharge from the additional land area is presumed to be available to support pumping by Palo Alto.

3.6.2 Potential Increased Pumping by Others in Study Area

The District maintains a database of historical pumping within established groundwater charge zones in Santa Clara County, which includes municipal, domestic, irrigation, industrial and remedial uses. Dewatering operations for high shallow groundwater is not monitored or tracked by the District. The District predicts future groundwater pumping with its regional
Groundwater Assessment, and Indirect Potable Reuse Feasibility Evaluation and Implementation Strategy

Water supply planning and operations model (WEAP model) based on hydrologic conditions observed from 1922 to 2015. Water purveyors and the District also project future groundwater pumping in their UWMPs and the Bay Area Water Supply and Conservation Agency (BAWSCA) Annual Survey included pumping forecasts. Table 3-15 shows projections of groundwater pumping in the Study Area based on UWMPs and the BAWSCA Annual Survey. The Palo Alto projections are listed as zero for 2020, 2025, 2030, and 2040; however; various pumping (and IPR) scenarios were evaluated with groundwater flow modeling (Section 4.4).

Mountain View (2016) projects a modest increase in pumping from 566 to 621 AFY between 2020 and 2040. The BAWSCA Annual Survey for fiscal year 2014-15 shows increased pumping for Stanford from 616 to 840 AFY between 2020 and 2040. Stanford has indicated that their existing irrigation wells could be used for emergency potable supply. The California Water Service Los Altos Suburban District (2016) projects decreasing groundwater use from 3,824 to 3,552 AFY between 2020 and 2040. There are also a large number of relatively low yielding private irrigation wells, particularly in Palo Alto and Los Altos. The future use of groundwater by private well owners for irrigation should remain relatively stable, unless a significant number of new wells are drilled as has happened in the past during extended droughts when irrigation usage is restricted.

Unlike Santa Clara County, there is currently no regional groundwater management agency that meters or tracks groundwater pumping in San Mateo County. Menlo Park is currently pursuing a program of drilling three new wells for emergency supply; however, their UWMP (EKI, 2016a) projects no groundwater use as a supplemental potable water supply source through 2040. The projected short-term capacity of the Menlo Park emergency supply wells is 3,000 gpm. Assuming this capacity of pumping for three months during an emergency would yield about 1,200 AFY. East Palo Alto is developing wells for ongoing potable supply and projects use of 1,200 AFY of groundwater from 2020 through 2040 (EKI, 2016b). This projected use of groundwater may be reduced by diversion of SFPUC allocations from other local entities. The City of Mountain View has agreed to transfer one million gallons per day of its SFPUC allocation to East Palo Alto for a one-time payment of $5 million (Mountain View Voice, 2017). This is an increase in demand relative to current conditions. The California Water Service Bear Gulch District (2016), which serves Atherton, Portola Valley, Woodside, and portions of Menlo Park and Redwood City projects stable groundwater use of 1,535 AFY of groundwater between 2020 and 2040. Redwood City (EKI, 2016c) does not currently use groundwater and projects no use of groundwater between 2020 and 2040. As in Santa Clara County, private irrigation wells are used in the San Mateo County portion of the Study Area, particularly in the Atherton area.

Overall, with the exception of new groundwater development by East Palo Alto, it appears that groundwater use by other pumpers in the Study Area will be relatively stable for the next 20 years based on planning documents. However, if Stanford and/or Menlo Park were to begin use of their irrigation wells and emergency supply wells for emergency supply, this could increase short-term pumping in the region.
## Table 3-15 Retailer Groundwater Demand Projections (in AFY)

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<td>0</td>
<td>EKI, 2016c, UWMP</td>
</tr>
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</table>

a - Short-term capacity of emergency supply wells is 3,000 gallons per minute

UWMP - Urban Water Management Plan   AFY - acre-feet per year
3.6.3 Land Subsidence

The land subsidence between 1934 and 1967 occurred when San Francisquito Cone pumping was as high as 7,500 AFY (Sokol, 1964) and historical groundwater elevations were below sea level (up to -140 feet NGVD 29 at the Hale Well in Palo Alto). Although no significant additional land subsidence has occurred in the Study Area since 1970, the potential exists for up to an additional 8.5 feet of land subsidence in the Study Area (Geoscience, 1991, SCVWD, 2016b). Therefore, maintaining groundwater levels in the Study Area above historical lows or other defined subsidence thresholds is key to avoiding future land subsidence issues.

Several on-going land subsidence monitoring programs are currently underway in the Santa Clara Valley. The District has established a tolerable continuing rate of subsidence of 0.01 feet per year (SCVWD, 2016a and 2016b). Currently, the District conducts an ongoing monitoring program across the Santa Clara Valley, including parts of the Study Area, that involves the following:

- Two 1,000-foot deep extensometers directly measure aquifer compaction. One extensometer is located adjacent to the Study Area in Sunnyvale near Moffett Field (Figure 3-36). It has data loggers to provide hourly readings of aquifer compaction and water level (SCVWD, 2016b).
- A benchmark leveling program that consists of annual surveys along three cross valley level circuits across the Santa Clara Valley. In 2015, the District analyzed land surface elevation data from 145 benchmarks to evaluate the spatial variability of land subsidence. One of the level circuits goes through the Study Area and includes about 30 benchmarks in Mountain View, Palo Alto and Los Altos.
- Regular groundwater level measurements at ten subsidence index wells. The District has established subsidence thresholds, or groundwater elevations, where subsidence greater than 0.01 feet per year may occur (Geoscience, 1991, SCVWD, 2016b). If water levels drop below subsidence thresholds for extended periods, permanent land subsidence may resume. Two of these wells are in or adjacent to the Study Area (Figure 3-36), and the subsidence thresholds for these wells are -26 and -30 feet NGVD 29 at Sunnyvale and Mountain View (Geoscience, 1991, SCVWD, 2016b), respectively, which is about 60 to 75 feet above the historic low to reflect the influence of time lag in the compaction of thick clays in the area.

Additional benchmarks are monitored by several municipalities and other agencies within the Study Area. East Palo Alto installed five permanent survey benchmarks in 2014 and is surveying them bi-annually to monitor for land subsidence as part of the implementation of its recently-adopted Groundwater Management Plan (Todd, 2015).

Because of the potential economic cost of additional land subsidence, land subsidence monitoring should be a part of any future plans for increased pumping by the City. Specifically, Todd Groundwater recommends the following:

- The existing District municipal survey benchmarks should be monitored for changes in land surface elevations on a regular basis.
• Identify an existing or install a new monitoring well that could be added to the District subsidence index wells in the Palo Alto area. The well would need to be completed below the primary clays layers and located close to a well with a sufficiently long groundwater level history. An analysis would be required to define a subsidence threshold for the well comparable to the Geoscience (1991) Study.

• The use of InSAR to monitor land subsidence in the Study Area could be used in conjunction with an agency, such as the USGS (under their Local Agency Partnership program), that has experience with this method of monitoring.

A mitigation plan would need to be developed to determine what action would be required to mitigate potential subsidence should any of the thresholds be exceeded. These monitoring activities would need to be coordinated with the District and other local agencies.

Potential subsidence under different City pumping and IPR is discussed further in Section 4.4 based on groundwater flow modeling.

3.6.4 Saline Water Intrusion

Due to high groundwater pumping and land subsidence, particularly in the years following World War II, saline water intrusion was observed in the shallow aquifer of the Santa Clara Plain (SCVWD, 2016a). The Palo Alto Baylands contains a zone of hyper saline water adjacent to and sub-parallel to the Bay as a result of evaporative concentration and percolation from salt marshes (Hamlin, 1985). This hyper-saline water can migrate inland in the shallow aquifer if significant pumping from the shallow aquifer causes inland flow. The deep aquifer is not directly connected to the Bay and elevated chloride levels in the deep aquifer and some shallow aquifer wells are thought to be the result of dissolution of salts from marine deposits (Metzger, 2002).

To assess saline water intrusion, the District monitors groundwater quality in a network of wells near San Francisco Bay in Santa Clara County. In addition, East Palo Alto has initiated a groundwater monitoring program that involves regular groundwater quality sampling to establish the current distribution and to track future water quality trends of selected chemicals of concern, including indicators of saline water intrusion from the Bay (Todd, 2015).

The Groundwater Management Plan (GWMP) for East Palo Alto (Todd, 2015) expressed specific concern regarding saline water intrusion via the Ravenswood wells located near the Bay. These wells were not properly abandoned and could create a conduit for flow of saline water from the Bay into the deep aquifer.

Because the City wells are screened in both the shallow and deep aquifer, wells located near the Bay and San Francisquito Creek (Hale, Eleanor Pardee, Main Library, and Rinconada) may be vulnerable to shallow aquifer saline water intrusion from the Baylands or tidal influences in the creek if the groundwater levels are lowered significantly. In addition, sea water level rise could increase the inland extent tidal influences in San Francisquito Creek.

The City may want to consider increased monitoring for TDS and chloride in the City emergency supply wells nearest to the Bay.
The potential for saline water intrusion is discussed further in Section 4.4 based on groundwater flow modeling.

### 3.6.5 Impacts to Interconnected Surface Water

Groundwater and surface water are hydraulically coupled only where the water table next to the creek is at or above the elevation of the creek bed. At lower water table elevations, stream percolation occurs at a rate that is independent of the groundwater level. Where the groundwater and creek are hydraulically connected, the rate of stream flow depletion caused by a well depends on its screen depth and proximity to the creek. For a shallow well close to a creek, nearly all of the pumped water is supplied by induced percolation from the creek. In alluvial basins with numerous or thick fine-grained layers, a deep well at the same location induces downward leakage from shallower aquifer units over a broad area, and much of the pumped water typically derives from other sources of recharge, such as rainfall, irrigation and pipe leaks.

Based on water quality testing, Metzger (2002) concluded that surface water and shallow groundwater and the upper deep aquifer near the San Francisquito Creek have similar water quality characteristics indicating recharge from creek.

San Francisquito Creek supports riparian vegetation and fauna, including threatened species such as the red-legged frog and western pond turtle. It is the only free-flowing urban creek on the south Peninsula (USGS, 2015) and the most viable remaining native steelhead population in South San Francisco Bay. Citing concern for steelhead, the creek has been included in the 303(d) listing by the SFRWQCB as impaired for sediment (California Coastal Commission, 2006). A habitat assessment in the upland watershed (Jones & Stokes, 2006) concluded that a lack of suitable habitat (e.g., deep pools) is the key factor limiting smolt production and juvenile rearing, while steelhead outmigration is limited by seasonal drying of the channel (a natural phenomenon) and exacerbated by passage impediments. Given its environmental significance, San Francisquito Creek has been the subject of numerous studies (e.g., Jones & Stokes, 2006; USGS, 2015), restoration plans focused on bank stabilization and re-vegetation, and active restoration, education and outreach efforts (Acterra, 2015).

A detailed study of groundwater-surface water interaction along San Francisquito Creek was undertaken by the USGS in 1996-1997 (Metzger, 2002). The creek consistently lost water to percolation from below the Pulgas Fault near the subbasins boundary to Middlefield Road (half of the total distance to San Francisco Bay). However, groundwater levels at the time of the study were more than 20 feet below the creek bed, and percolation consequently was interpreted to be independent of the groundwater level. Increased groundwater pumping in that area would not have increased percolation losses.

Downstream of Middlefield Road, the study found alternating gaining and losing reaches, suggesting that the creek and water table had similar elevations and were hydraulically coupled. Pumping from shallow wells within 1,000 feet of the creek along that reach could potentially induce additional stream percolation. Accordingly, it is possible that increased pumping from City wells screened in both the shallow and deep aquifer located near the lower stretches of the creek (Hale and Eleanor Pardee) may induce some loss from the creek.
Potential impacts to creeks under different City pumping and IPR scenarios is discussed further in Section 4.4.

### 3.6.6 Mobilization of Environmental Release Site Contamination Due to Increased Pumping

As discussed above in Section 3.5.3, point source contamination sites pose a potential risk to underlying groundwater. The degree of risk depends on the toxicity and concentrations of the contaminants and the potential for complete exposure pathways to sensitive receptors, including humans and biota. Exposure pathways include ingestion if the groundwater is a source of drinking water supply, inhalation of contaminants in indoor air as a result of vapor intrusion of volatile contaminants from contaminated soil and/or groundwater, and contact with contaminated media during construction or non-construction activities. The regulatory framework for point source contamination sites that have been identified and are under active oversight aims to provide protection of sensitive receptors through enforcement actions that may include engineering and/or administrative controls.

The risks as related to future City IPR projects and the groundwater production wells fall into two main categories:

- Risk of contaminant transport to City production wells and production of contaminated water exceeding drinking water health standards, and
- Risk of contaminant plume spreading and loss of remediation system containment due to recharge facility or production well operations changing established flow directions.

Both natural and anthropogenic factors affect the fate of contaminants in groundwater and their potential impacts to City recharge facilities and production wells. Natural factors include recharge rates, horizontal and vertical permeability of the aquifers, horizontal and vertical hydraulic gradients (both magnitude and direction), presence of fine-grained layers that may impede advection but may also result in back-diffusion of contaminants to "cleaned-up" permeable zones, and biogeochemical conditions which can influence contamination degradation processes. Anthropogenic factors include future recharge operations that could exacerbate spreading of contaminants, groundwater pumping and other changes to the natural fluxes and gradients, the presence of artificial subsurface conduits (e.g., horizontal pipelines and the backfill surrounding them, and vertical wells with perforations and/or gravel-packed intervals spanning multiple depth zones), and intentional remediation efforts to remove, degrade, or limit the spread of contaminant mass.

As discussed above, the hydrogeology of the subbasins consists of alluvial fan and alluvial/fluvial plain sediments that exhibit patterns of alternating fine- and coarse-grained deposits, with the presence of thicker confining units in the northern area near the Bay and absence of or less extensive confining units in the southwestern recharge areas near the foothills. The more permeable coarse-grained deposits tend to transmit water horizontally under the regional hydraulic gradients, while the less permeable fine-grained deposits tend to inhibit vertical groundwater flow. This anisotropy in aquifers in the northeastern portion of the subbasin generally causes contaminant plumes to favor horizontal rather than vertical migration. In this area, point source contamination originating at or near the land surface is
generally limited in vertical extent to the uppermost coarse-grained layers in the vicinity of the release site, rarely penetrating below depths of approximately 100 ft-bgs. However, in the recharge area, contaminant plumes have migrated to greater depths, due to the relative absence of fine-grained impedance layers along with local downward gradients.

Although most of the contaminant plumes within the City appear to be partially or totally contained by remedial barriers and pump-and-treat extraction systems, the extent of containment is difficult to establish, due to uncertainties in subsurface conditions and aquifer hydraulic properties. For these reasons, it is recommended that potential recharge project locations avoid known contaminant plume areas. In addition, groundwater production from wells near the known plumes (especially wells Matadero, Fernando, and Peers) should be regularly monitored, to ensure contaminants are not drawn into the wells.

### 3.6.7 Cross-Contamination Between Shallow and Deep Aquifers

In the Study Area, alluvial fan and intra-fan depositional processes have resulted in a highly anisotropic geologic setting, with sub-horizontal interbeds of coarse and fine layers that generally make vertical migration of groundwater much harder than horizontal migration. The deep aquifer in the confined portions of the subbasins, particularly closer to the Bay where clay units become thicker and more extensive, has more hydraulic separation from the shallow aquifer than in the recharge zone and the confined zone near the foothills. Nonetheless, inter-aquifer flow through water supply wells screened across multiple aquifers is recognized as an important component to the flow of groundwater (Hansen, 2015). All of the City wells are screened in both the shallow and deep aquifers and therefore may pull in shallow aquifer groundwater and provide conduits for movement of water between the two aquifers.

Migration of contaminants from shallow to deep aquifers is largely controlled by vertical gradients, which change in response to pumping. Vertical gradients between the shallow and deep aquifer affect the natural movement of water between the aquifers and potentially within wells screened in multiple aquifers or in unknown improperly abandoned wells that may provide conduits for flow between the aquifers. As described in Section 3.2.9, Figure 3-32 shows how the vertical gradient between the shallow and deep aquifers change with groundwater pumping. Historically, vertical gradients were downward during periods of significant groundwater pumping in the Palo Alto and Stanford Area. As pumping declined after importation of Hetch-Hetchy water, groundwater gradients reversed and there is now an upward vertical gradient from the deep to shallow aquifer in the confined zone. The District’s Eleanor multi-completion monitoring well clearly shows an upward vertical gradient from the shallow to deep aquifer since it was installed (2003).

Ambient shallow groundwater quality in the Palo Alto area is not significantly poorer than deep groundwater except in and near the Baylands where hypersaline water occurs and can flow inland, if inland pumping is significant. Shallow groundwater is also subject to contamination from environmental release sites and these sites can pose a threat to deep well water quality.

If the City develops significant groundwater supplies, the vertical gradient will likely switch back to downward, resulting in more potential for downward movement of shallow groundwater, and potentially downward movement of shallow contaminated groundwater.
The groundwater model developed for evaluating IPR scenarios in Section 4 was also used to evaluate vertical fluxes of water between shallow and deep aquifers in the Study Area. That evaluation is described in Section 4.4.12.

Cross contamination from shallow to deep aquifers can be mitigated by closely monitoring the relationship between deep aquifer pumping and water levels in the shallow and deep zones. Minimizing the downward vertical gradients by limiting pumping and/or augmenting groundwater with IPR water will help limit the migration of contaminants from the shallow to the deep aquifer.

### 3.6.8 Potential Impacts of Sea Level Rise

Climate change has led to global increases in temperature, polar ice cap melting, and global sea level rise. In the past century, global mean sea level has increased by approximately eight inches. However, the rate of sea level rise is increasing, and much greater rates of rise are predicted for the 21st century. In March 2013, the State provided updated guidance and sea level rise projections ranging from 10 to 17 inches by 2050, 17 to 32 inches by 2070, and 31 to 69 inches by 2100 (California Climate Action Team, 2013). These estimates were developed by the National Research Council in 2012 for San Francisco. In 2016, the Palo Alto City Manager provided information to the City Council on potential impacts of sea level rise in South San Francisco Bay on Palo Alto resources and infrastructure and adopted these projections. The City has since revised its sea level rise projections to numbers developed by the California Natural Resources Agency and Ocean Protection Council – Sea Level Rise Guidance 2018 Update. Over the modeling simulation period, the two projections are close. Among the potential impacts are:

- Shoreline inundation;
- Increased flooding along San Francisquito Creek; and
- Flooding of City infrastructure, including roads, hospitals, schools, emergency facilities, and water supply facilities.

Several local and State-level programs are underway to identify and implement protection projects in order to minimize flooding and damage to infrastructure. Most of these projects involve levee construction and rehabilitation in order to minimize inundation and flooding risks. However, in addition to surface inundation and flooding impacts, potential subsurface impacts to groundwater levels, flow, and quality may also occur. These potential impacts include:

- Increased groundwater elevations, artesian conditions, and decreased depths to water; and
- Increased intrusion of saline water into the aquifers bordering the Bay.

As Bay levels rise, groundwater levels in the shallow aquifer likely will increase in response, with the largest rises occurring close to the Bay. Because some deep aquifer wells in the confined zone exhibit artesian conditions, increased artesian pressure may occur, especially in the absence of groundwater pumping. Shallow groundwater levels and extent may increase, potentially causing seepage and foundation flooding from shallow groundwater. Rising
groundwater levels may incrementally reduce the recharge capacity of vadose zone IPR injection wells or surface recharge facilities, as less vadose zone capacity may be available.

The second potential impact of sea level rise is increased saline water intrusion from the Bay. The freshwater-saline water interface, currently located near the Bay Shoreline, may migrate landward in response to the increased hydraulic head of the Bay. This could potentially impact produced water quality at shallow wells in the northeastern portions of the City.

Groundwater monitoring is recommended to track water levels and inorganic water quality in City wells. Future operation of recharge and groundwater production facilities may need to account for higher groundwater levels and changing water quality conditions.
4 INDIRECT POTABLE REUSE FEASIBILITY EVALUATION AND IMPLEMENTATION STRATEGY

This indirect potable reuse feasibility evaluation describes several City pumping and IPR scenarios, applies groundwater flow modeling to assess potential impacts of those scenarios on groundwater levels and creek flow, and carries one scenario into development of an implementation strategy. Modeling was used to assess subsurface purified recycled water travel times between injection wells and potable supply wells for the selected scenario for compliance with recycled water recharge regulations. The implementation strategy identifies permitting, CEQA, and regulatory compliance requirements and presents costs for the selected scenario.

4.1 Identified Areas for IPR

Preliminary general areas where IPR surface spreading or injection could occur in the Palo Alto area were identified based on hydrogeologic and regulatory criteria. While the original scope of work for the project called for identification of specific IPR recharge facility parcels, based on the preliminary planning nature of this study, the scope was changed to identify general areas where publicly-owned parcels are available within an appropriate distance from the generally identified potential IPR sites. Also, while initially, general areas where identified for both surface spreading and injection wells, after estimating the relatively large size of parcels needed for surface spreading and considering the limited availability of large parcels in the surface spreading area, surface spreading projects were deemed infeasible and only injection wells were carried forward in the analysis.

4.1.1 Hydrogeologic and Other Consideration for IPR Siting

Preliminary, planning-level IPR siting criteria were developed based on the hydrogeology of the Palo Alto area and the range of goals for IPR recharge and pumping. The preliminary evaluation of locations where surface spreading and injection wells could be sited and the total area of spreading and number of injection wells needed were informed by various factors including:

- Surface spreading:
  - Located in unconfined recharge areas in the City downgradient of Pulgas Fault
  - Proximate to and upgradient of City production wells
  - Adequate distance from production wells to meet State Water Resources Control Board, Division of Drinking Water (DDW) requirements for response retention time (RRT)
  - Minimum potential for mobilization of known contamination plumes
  - Size of recharge area required is based on estimated infiltration rate
  - Adequate storage capacity is available in the vadose zone or can be made available through increased pumping to accommodate recharge

- Injection wells:
  - Located in unconfined recharge areas or confined zone in the City
  - Proximate to and upgradient of City production wells
  - Adequate distance from production wells to meet DDW requirements for RRT
- Minimum potential for mobilization of known contaminant plumes
- Number of injection wells is based on expected injection rates assuming 50% to 80% of average production well yields
- Provide separation between injection wells to reduce well interference
- Adequate storage capacity is available in aquifer or can be made available through increased pumping to accommodate recharge

The Groundwater Use Assessment presented in Section 3 provides much of the information needed to identify preliminary general IPR siting areas. Figure 4-1 shows preliminary general IPR recharge facility siting areas for surface spreading and injection wells. The City’s production wells are shown with buffer zones around the wells. Potable supply wells or wells that might be used for potable supply in an emergency (i.e., Stanford irrigation wells) are also shown with encircling buffer zones. Other pumping wells near the potential IPR recharge areas are also shown. These wells are mostly used for irrigation and remedial extraction at contamination sites; although, some could also be used for domestic supply based on the designated use listed on the driller’s logs and District databases. However, while driller’s logs may identify a well’s use as domestic implying use for drinking water, the provision by the City of higher quality imported water for supply makes it unlikely that private domestic wells are being used for drinking water. Pumping well locations in San Mateo County, with the exception of potable supply wells, are approximate and generally located to model pumping. Buffer zones were generated based on the Darcy’s Law equation calculation of 6 months subsurface travel around each well and a DDW-required correction.

DDW has developed Groundwater Replenishment with Recycled Water regulations (GWR regulations) (DDW, 2014). Among other requirements, the GWR regulations include provisions for determination of a RRT, which is the time recycled water must be retained underground between recharge and extraction to allow a Project Sponsor ample time to identify potential treatment failures and implement appropriate actions to protect public health from inadequately treated recycled water. The minimum RRT allowed is 2 months and the proposed RRT must be approved by DDW.

The needed travel time underground to achieve the required RRT is specific to each project and can be estimated by analytical methods (such as Darcy’s Law flow calculations) or groundwater modeling, but ultimately must be validated by an added or intrinsic tracer test approved by DDW after startup of the project. Todd Groundwater and Woodard and Curran (Todd/WC) propose that the RRT be set at 6 months for planning purposes. RRTs at other active IPR projects in California range from about 2.75 to 7 months.

Darcy’s Law was used to estimate groundwater velocity and travel time buffers around the City’s wells and other potable or potentially potable supply wells in the local area to help define preliminary IPR recharge facility siting areas. Darcy’s Law is the basic equation that describes fluid flow through porous media represented by the following:

\[ v = K(\Delta h/\Delta l)/n \]
where \( v \) = average linear groundwater velocity in feet per day, \( K \) = hydraulic conductivity in feet per day, \( \Delta h/\Delta l \) = groundwater hydraulic gradient in foot per foot (\( h \) = head and \( l \) = distance), and \( n \) = effective porosity in percent.

Deep zone groundwater elevation contour maps (Figures 3-26 and 3-28) indicate a hydraulic gradient of about 0.004 foot per foot in the Palo Alto area. Horizontal hydraulic conductivity in the deep aquifer layers in the District model developed for their ongoing IPR studies (IMOD model) in the Palo Alto area is 70 ft/day. Effective porosity is assumed to be 0.20, typical of fine sand (USEPA, 1986). Based on these parameters, the estimated groundwater velocity is 1.4 ft/day. Based on an assumed RRT of 6 months, the buffer distance around each well is 255 feet. However, because of uncertainties associated with the Darcy equation and parameters used, DDW requires the application of a safety factor of four to travel time estimates developed using such analytical methods. Multiplying 255 times 4 yields a buffer area of 1,022 feet around each well (rounded to 1,000 feet). It is noted that this buffer area is used for preliminary planning and that groundwater flow modeling was conducted for the selected IPR injection/pumping scenario to verify that adequate underground residence time is available to meet the proposed RRT (see Section 4.4.15).

Figure 4-1 shows general groundwater flow directions based on deep zone groundwater elevation contour maps (Figures 3-26 and 3-28). Note that the groundwater elevation contours will change if City wells are put into operation and IPR recharge is implemented. Simulation of groundwater flow and elevations was modeled as discussed in Section 4.4.15. The surface spreading IPR area is located in the recharge area in Palo Alto downgradient of the Pulgas Fault, which is thought to be a potential barrier to groundwater flow and a couple thousand feet upgradient of the City’s Fernando and Matadero wells, about 4,000 feet upgradient of the Peers Park Well and more than 10,000 feet upgradient of the City’s Main Library, Rinconada, and Eleanor Pardee wells. Areas of groundwater contamination (COE Site, Hillview Porter Site, Hewlett-Packard Site, and former Fairchild Semiconductor Site) are shown in Figure 4-1 located in the vicinity of the potential surface spreading area. One site (Town and County Village Site) is located in the general injection well area. These sites are discussed in more detail in Section 3.5.3.

Figure 4-1 also shows the general injection well IPR recharge facility siting area. The area is hydraulically upgradient of the City’s Hale, Eleanor Pardee, Main Library, Rinconada, Peers Park, and El Camino Park wells.

The preliminary purified water design flow allocated to Palo Alto is 5 million gallons per day (mgd) or 5,600 AFY of advanced-treated water. This preliminary design flow was used to identify the total area required for surface spreading and number of injection wells. Lower and higher levels of IPR recharge were included in the five modeled scenarios discussed in Section 4.3. Table 4-1 summarizes the District’s reported infiltration rates for their recharge ponds based on “potential recharge rates” presented in a District Groundwater Recharge Facilities report (1977) and “recharge capacity rates” presented in the 2016 Groundwater Management Plan (SCVWD, 2016b). In SCVWD (1977), the potential recharge rate includes the assumption of unlimited “clean” water supply with and an expanded operations and maintenance program and indicates a minimum infiltration rate of 0.3 ft/day, maximum rate of 7.1 ft/day and average
rate of 2.0 ft/day. SCVWD (2016b) assumes that recharge water is available all year and that ponds are in normal operating condition and indicates a minimum infiltration rate of 0.02 ft/day, maximum rate of 0.5 ft/day and average rate of 0.1 ft/day. The infiltration rate for Lake Lagunita located on the Stanford Campus was estimated to be 0.2 ft/day. However, it is noted that Stanford had reported past attempts to clay line the lake to reduce the infiltration rate to reduce losses. The assumed infiltration rate has a significant impact on the calculation of the area needed for surface recharge. For planning purposes, a recharge rate of 0.3 ft/day was assumed, which results in a required total surface spreading area of 50 acres, assuming the need to recharge all the design flow of 5,600 AFY. The total potential surface spreading area is 290 acres, so 50 acres represents almost 20% of the total area. Based on this analysis, the City determined that due to the large area required, surface spreading is not feasible and no further surface spreading facility siting or analysis were conducted.

Table 4-1  District Recharge Pond Infiltration Rates

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<th>Potential Recharge Ratea (AF/day)</th>
<th>Recharge Capacityb (AF/day)</th>
<th>Infiltration Ratea (ft/day)</th>
<th>Infiltration Rateb (ft/day)</th>
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a - Source: SCVWD, December 1977, District Groundwater Recharge Facilities. The potential recharge rate assumes an unlimited "clean" water supply with an expanded operations and maintenance program.

b - Source: SCVWD, November 2016, 2016 Groundwater Management Plan, Appendix D - District Managed Recharge Facilities. The recharge capacity assumes water is available all year and that ponds are in normal operating condition.

AF/day - acre-feet per day  
ft/day - feet per day  
NR - not reported  
SCVWD - Santa Clara Valley Water District
City pumping test data were used to estimate the potential injection rate and number of injection wells needed to accommodate the purified recycled water design flow. Table 4-2 provides pumping test data for City production wells (both current emergency supply wells and older wells). Pumping rates from initial specific capacity testing and more formal pumping tests vary considerably. Specific capacity testing pumping rates range from 490 gpm to 1,850 gpm, with an average of 1,007 gpm. Pumping tests show a range from 173 gpm to 1,864 gpm with an average of 773 gpm. For planning purposes, the lower end of the average is assumed. Typically, injection wells are assumed to deliver between 50% and 80% of production well yields. For planning purposes, an injection rate of 400 gpm was assumed. To recharge 5 mgd of purified recycled water at this assumed injection rate would require 9 wells. For design purposes, one additional well was assumed for backup to account for wells being out of service due to maintenance, for a total of 10 wells.

4.1.2 Injection Well Siting

Figure 4-2 shows the general IPR injection well area, 1,000 feet by 1,000 feet groundwater flow model grid cells and City production wells. The target IPR injection well area encompasses 750 acres of which 23 acres are City-owned with an additional 143 acres of other public facilities. Possible injection well locations were identified within the general IPR injection well area considering proximity to City-owned properties and parcels designated as public facilities and open spaces. Parcel size and a preliminary review of existing land use were also considered. In selecting proposed injection well locations for modeling, preference was given to proximity to City-owned properties (which includes locations B4, B5, C4, C5, D5, G5 and E8) followed by other public facilities and open spaces (which includes locations F4, D7 and D8). The ability to group wells, thereby reducing distribution pipeline construction costs and proximity to existing City production wells were also considered.

Figure 4-2 shows 17 possible injection well locations centered within the associated model grid cell. To provide the recommended 1,000 feet well separation, only one injection well is located in a model grid cell.

4.2 IPR Water Quality and Potential Impacts

4.2.1 Purified Water Quality

DDW has developed GWR regulations that require specific water quality standards for purified recycled water used for injection. Purified recycled water produced at the RWQCP will meet or exceed these standards. Demonstration testing and monitoring of the finished facility will provide documentation that the actual purified recycled water quality meets required standards.
### Table 4-2  Aquifer Testing and Pumping Rates for City of Palo Alto Wells

| Owner          | Owner Well Name | Use       | Date Drilled | Well or Boring Depth (ft) | Casing Diameter (in) | Screen Interval (ft) | Screen Length (ft) | Depth to Bedrock (feet) | Pumping Rate (gpm) | Drawdown (ft) | Time (hours) | Specific Capacity (gpm/ft) | Specific Capacity Transmissivity (ft2/d) | Specific Capacity Hydraulic Conductivity (ft/d) | Pumping Test Pumping Rate (gpm) | Pumping Test Transmissivity (ft2/d) | Pumping Test Hydraulic Conductivity (ft/d) | Pumping Test Storage Coefficient | Source                             |
|----------------|-----------------|-----------|--------------|---------------------------|---------------------|---------------------|-------------------|-----------------------|-------------------|----------------|--------------|---------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|---------------------|
| City of Palo Alto | Library         | Municipal | Oct-09       | 185-285                  | 120                  | 530                 | 600               | 277                   | 24                | 2.2           | 579                      | 5                              | 600                                     | 2.2                                      | 579                                       | 5                             | 600                                     | 2.2                                      | Bonkowski 2010            |
| City of Palo Alto | Eleanor Pardee  | Municipal | Dec-09       | 160-280                  | 120                  | 1,000               | 159               | 10                    | 6.3               | 1,682         | 14                       | 1,000                         | 3,000                                   | 296                                      | 0.00295                                  | 9                             | 0.00295                                 | City (newer)                            | Bonkowski 2010            |
| City of Palo Alto | Rinconada       | Municipal | May-54       | 156-900                  | 744                  | >1082               | 1,820             | 35                    | 100               | 52.0          | 13,903                   | 19                            | 920                                     | 4,597                                    | 7                                           |                               | 4,597                                   | CH2M/HILL 1992 (older)                     |
| City of Palo Alto | Middlefield     | Municipal | Apr-05       | 165-592                 |                      |                    |                   |                        |                   |               |                           |                               |                                         | 505                                      | 42,130                                    | 86                          | L&S, undated; analysis by Todd                         |
| City of Palo Alto | Seale           | Municipal | Apr-05       | 160-280                  | 744                  | 1,000               | 159               | 10                    | 6.3               | 1,682         | 14                       | 1,000                         | 3,000                                   | 296                                      | 0.00295                                  | 9                             | 0.00295                                 | CH2M 1992                              |
| City of Palo Alto | El Camino Park  | Municipal | Feb-13       | 152-204                 | 98                   | 1,850               | 34                | 8                     | 54.4             | 14,548        | 149                      | 1,864                         | 42,130                                  | 86                                       |                               |                               | 42,130                                   | L&S, undated; analysis by Todd                         |
| City of Palo Alto | Park            | Municipal | Apr-05       | 165-522                 | 155                  | 522                 |                   |                        |                   |               |                           |                               |                                         | 173                                      | 2,640                                    | 58                          | CH2M 1992                              |
| City of Palo Alto | Peers Park      | Municipal | Mar-58       | 150-850                 | 700                  | 1,000               | 138               | 36                    | 7.2              | 1,937         | 3                        |                               |                                         | 807                                     | 1                                        |                               | 807                                      | DWR log; City of PA                         |
| City of Palo Alto | Fernando        | Municipal | Oct-54       | 1022                    | 816                  | 1,178               | 700               | 232                   | 202               | 3.0           | 807                      |                               |                                         | 1,248                                   | 1                                        |                               | 1,248                                   | DWR log; City of PA                         |
| City of Palo Alto | Maladera        | Municipal | Oct-56       | 1186                    | 146-1066              | 924                 | 490               | 105                   | 92                | 4.7           | 1,248                    |                               |                                         | 2                                       |                               | 1                                        | City of PA                                 |
| City of Palo Alto | Hale            | Municipal | Sep-55       | 108-829                 | 720                  | 927                 | 1,000              | 211                   | 4.7              | 1,267         | 2                        |                               |                                         | 7,716                                  | 86                                       | 1,864                                    | L&S, undated; analysis by Todd                         |
| City of Palo Alto | Sauzanne        | Municipal | Oct-56       | 1054                    | 146-1066              | 912                 | 605               | 152                   | 86                | 4.0           | 1,064                    |                               |                                         | 42,130                                  | 86                                       | 1,864                                    | L&S, undated; analysis by Todd                         |

<table>
<thead>
<tr>
<th>MIN</th>
<th>MAX</th>
<th>AVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>490</td>
<td>1,850</td>
<td>1,007</td>
</tr>
<tr>
<td>2.2</td>
<td>5.79</td>
<td>15.4</td>
</tr>
<tr>
<td>1.0</td>
<td>1.73</td>
<td>4,115</td>
</tr>
<tr>
<td>296</td>
<td>1,864</td>
<td>7,716</td>
</tr>
<tr>
<td>0.82</td>
<td>42,130</td>
<td>0.19500</td>
</tr>
</tbody>
</table>

ft - feet
in - inches
ft/d - feet per day
gpm/ft - gallons per minute per foot of drawdown
ft²/d - square feet per day
DWR - California Department of Water Resources
L&S - Luhdorf and Scalmanini
4.2.2 Dissolution of Naturally-Occurring Constituents

When water types with different water chemistries (such as purified recycled water and groundwater) interact with subsurface sediments, the compatibility of such waters with unsaturated/vadose zone and aquifer materials requires examination because of the potential for adverse chemical reactions (e.g. leaching of naturally-occurring but potentially toxic metals). Adding purified water to the unsaturated zone and aquifers may cause naturally-occurring toxic trace elements such as arsenic, chromium, lead, and mercury to desorb and dissolve from mineral surfaces. A secondary concern when introducing a different water type is the potential for reduction in aquifer permeability resulting from cation exchange and changes in the mineral structures of clay sediments or from precipitation of calcite. Because the dissolved mineral content of purified water is very low, neither structural changes to aquifer solids nor precipitation of solutes is a concern.

Typically, the IPR Project Proponent will conduct dissolution studies using the purified recycled water being produced and soil samples collected from the proposed IPR area to evaluate the potential for mobilization of naturally-occurring constituents and aquifer clogging and report the results in the Engineering Report prepared for the project, which is reviewed by the regulatory agencies. Negative impacts of recharge of purified water can be mitigated by buffering the purified recycled water, typically by lowering the pH.

Nonetheless, in general, mixing of native groundwater with purified recycled water results in an improvement in groundwater quality due to the extremely low mineral content of purified water. Over time it is anticipated that IPR in Palo Alto would lower levels of chloride, iron, manganese, and TDS, which result in relatively hard water and associated aesthetic issues.

4.2.3 Mobilization of Environmental Release Site Contamination Due to IPR Operations

Environmental contamination and potential mobilization of environmental contamination was discussed previously in Sections 3.5.3. Potential negative impacts to environmental release site contamination plumes or remedial systems due to increased groundwater pumping by the City was discussed in Section 3.6.6. Several groundwater contamination plumes have been identified in the Palo Alto area. Two city wells, Fernando and Matadero, are located near the COE site plume (Figure 3-59). As discussed in Section 3.6.6, if these wells are pumped, regular monitoring is recommended for environmental contaminants. It is noted that only one of the pumping/injection scenarios discussed in the following section includes pumping of these two wells.

As shown in Figure 4-1, four contaminant plumes (COE, Hewlett-Packard, Hillview Porter, and Former Fairchild Semiconductor sites) are located near the IPR surface spreading area, which was dropped from further consideration due to the large spreading area need. Because no surface spreading IPR projects are currently under consideration, these plumes will not be impacted by potential IPR activities.

One plume, associated with the Town and Country Village Site is located in the general IPR injection well area (Figure 4-1), however, the depth of contamination is characterized as less
than 50 ft-bgs. The injection wells will be designed to inject into the confined zone at depths below 200 ft-bgs, so the IPR injection is not likely to mobilize contamination from this site. Typically, environmental groundwater contamination does not occur in the confined aquifers, due to the protection afforded by the confining layer.

### 4.3 IPR Scenarios

Five preliminary IPR injection/City pumping scenarios and a baseline “no project” scenario were initially developed. The baseline scenario assumes no IPR injection and no pumping by the City and was used for comparison to assess impacts of pumping/injection scenarios. The initial scenario goals were:

- **Scenario 1** – Refined operable yield estimate with no IPR: Determine the City operable yield that is feasible with no IPR
- **Scenario 2** – Operable yield with IPR: Determine the City operable yield with the preliminary maximum City recycled water design flow allocation of 5,600 AFY of purified recycled water for injection
- **Scenario 3** – Realistic near-term scenario: Pump the El Camino Park Well at 80% of its capacity (2,400 AFY), determine if IPR is needed to support pumping
- **Scenario 4** – Operable yield with reduced IPR: Inject 50% of the preliminary maximum City recycled water design flow allocation or 2,800 AFY of purified recycled water and determine the City operable yield that could be supported by this level of IPR (half of preliminary purified water design flow)
- **Scenario 5** – 100% demand: City pumping at 12,000 AFY (100% of 2020 demand) and determine IPR needed to support this level of pumping

The terms operable yield and feasible mean the level of City pumping that would not result in undesirable impacts such as excessive drawdown, subsidence, saline water intrusion, or impacts to streams. Criteria used to assess these impacts are discussed in Section 4.4.13. Initial estimates of pumping and injection were made and then modeling was used to test and refine the estimates to identify the pumping rates and locations and injection rates and locations that maximized City yield for each scenario. The final specifications for each scenario are described below and listed in Table 4-3.

- Scenario 1 assumed no IPR and that all City wells are available for pumping. Pumping was distributed among the wells to minimize simulated drawdown and saline water intrusion risk at municipal wells near the Bay, including ones in San Mateo County. That risk turned out to be the constraint on available yield. Adjusting the pumping locations allowed operable pumping at 3,000 AFY. All remaining scenarios assumed no pumping by the Matadero and Fernando wells because these two wells are located near contamination plumes, the wells are located a considerable distance upgradient of injection wells, and the remaining City wells have adequate capacity to achieve the desired pumping volume.
# Table 4-3 Pumping/Injection Scenarios

<table>
<thead>
<tr>
<th>Scenario No.</th>
<th>Description</th>
<th>Scenario Well Production - City Wells (AFY)</th>
<th>Injection Wells Utilized</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>City Pumping Volume (AFY)</td>
<td>Percentage of City Projected 2020 Water Demand</td>
</tr>
<tr>
<td>0</td>
<td>Baseline scenario. Goal is to model effects to the aquifer over the 30 year period from 2015-2044 at District-projected levels of pumping and recharge.</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>1</td>
<td>Preliminary yield estimate. Goal is to determine operable City pumping over 30 years without IPR. This scenario is meant to refine the preliminary operable yield estimate of 2,900 AFY determined in the groundwater assessment.</td>
<td>3,000</td>
<td>25%</td>
</tr>
<tr>
<td>2</td>
<td>Determine maximum operable yield with injection. Goal is to model groundwater augmentation with maximum potentially available purified water based on Palo Alto's existing recycled water allocation. This scenario will use 60% of the City's total projected 2020 water demand for the initial model run.</td>
<td>7,200</td>
<td>60%</td>
</tr>
<tr>
<td>3</td>
<td>Realistic near-term scenario. Goal is to model using El Camino Park Well only to supply 20% of the City's projected 2020 water demand, and determine if IPR is needed to support this scenario. El Camino Park Well is technically the most feasible location for long-term groundwater production due to available storage, blending facilities, and space for treatment.</td>
<td>2,400</td>
<td>20%</td>
</tr>
<tr>
<td>4</td>
<td>Reduced IPR. Goal is to model injection at a reduced level and at fewer locations to determine the operable pumping level with 2,800 AFY injection. This scenario will use 40% of the City's projected 2020 water demand for the initial model run.</td>
<td>5,900</td>
<td>49%</td>
</tr>
<tr>
<td>5</td>
<td>100% Demand. Goal is to model complete City dependence on groundwater and to determine the IPR volume needed to support this scenario. Pumping is set at 100% of the City's projected 2020 demand.</td>
<td>12,000</td>
<td>100%</td>
</tr>
</tbody>
</table>

AFY - Acre-Feet per year
a. Pumping volumes are in addition to the study area outputs determined in the Groundwater Assessment, such as groundwater supply pumping and construction dewatering
b. Total projected 2020 water demand for Palo Alto is 12,000 acre feet based on the City's Urban Water Master Plan
c. IPR - Indirect potable reuse; groundwater augmentation with purified water (highly treated wastewater) via injection wells

* Matadero and Fernando wells are not considered in Scenarios 2 through 5 due to their proximity to known groundwater contamination, distance from injection wells, and ability of remaining wells to provide needed capacity.
Scenario 2 assumed 5,600 AFY of injection. By trial and error, a concurrent maximum City pumping rate of 7,200 AFY was identified.

Scenario 3 assumed only the El Camino Park well pumping at 2,400 AFY. Modeling indicated that this pumping would be feasible without IPR.

Scenario 4 assumed a reduced level of injection of 2,800 AFY. By trial and error, a concurrent maximum City pumping rate of 5,900 AFY was identified.

Scenario 5 assumed that 100% of the City’s total 2020 water demand of 12,000 AFY is provided by groundwater. An initial test of 8,400 AFY of concurrent IPR proved to be infeasible. This exceeds the planned IPR capacity, so this scenario was deemed infeasible without further testing.

The findings of the modeling and scenario feasibility are presented in Section 4.4.14.

4.4 Groundwater Modeling

4.4.1 Overview of Groundwater Model Development

A numerical groundwater flow model (IMOD) of the Santa Clara Subbasin (excluding the Coyote Valley Region) was developed for the District to evaluate proposed spreading and injection of purified recycled water in the subbasin (Todd, 2017a and 2017b). This original model is referred to as the IMOD model. The IMOD model was modified and recalibrated for application to the Northwest County Recycled Water Strategic Plan project and is referred to as the PMOD model. A general model overview, modification, calibration, and application for this study are presented herein. The reader is referred to the District IPR reports (Todd, 2017a and 2017b) for more detailed information on the IMOD model as a basis for the PMOD model.

To simulate groundwater flow, both models use MODFLOW-2005, the current version of the MODFLOW finite-difference computer program developed by the USGS (Harbaugh, 2005). To expedite preparing and checking model input and processing model output, the MODFLOW program was operated from within Groundwater Vistas v.6.1, which is a widely-used graphical user interface program developed by and available from Environmental Simulations, Inc.

Additional steps in data preparation and model post-processing were completed using Microsoft Excel spreadsheets and custom Fortran utility programs developed by Todd Groundwater. Processing of variables with geographic distributions were completed using ArcGIS 10 software available from the ESRI company.

The District’s IMOD model simulates three-dimensional groundwater flow Santa Clara Plain groundwater management area (Santa Clara Subbasin less the Coyote Valley area). It was developed during 2015-2017 by combining and enhancing features of two prior models (GMOD and XMOD) (Todd, 2017a). The PMOD model area includes the northwestern portion of the District’s IMOD model domain and extends further into San Mateo County. Information from concurrent development and calibration of the San Mateo Plain groundwater model—which overlaps the PMOD model—was incorporated.

The following sections focus on changes that were made to the District’s IMOD model for this study.
4.4.2 Active Flow Area and Model Grid

The PMOD model domain is shown in Figure 4-3. The model domain encompasses the Santa Clara Plain and extends to Redwood City in the north. Because the boundary between Santa Clara and San Mateo counties is a political boundary and does not represent a hydrologic boundary, there is potential for groundwater to flow back and forth across the boundary depending on pumping and recharge conditions. Because increased City pumping and IPR in Palo Alto can influence flow patterns in both counties, the model was extended further into San Mateo County. Both the IMOD and PMOD models include the Santa Clara Formation on the southwest side of the Study Area in the active flow domain. This area is included in the DWR-defined Santa Clara Subbasin extent.

The PMOD model grid is the same as the uniform-grid version of the IMOD model, but by converting inactive cells to active cells, the area of simulation was extended farther into San Mateo County to include the entire Study Area.

A project-specific version of IMOD with variable grid spacing was developed for the District IPR study in 2016-2017. Examination of simulated water-level gradients and particle tracking in the fine-grid regions of that model indicated that results would have been essentially the same had the uniform-grid version of IMOD been used. That is, the curvature of particle paths and the simulated travel times to downgradient locations did not appear to be affected by grid cells spacing. Accordingly, the uniform-grid (1,000 x 1,000-foot cells) version was selected for the Palo Alto IPR study.

4.4.3 Model Layers

The PMOD model layers were modified slightly from the IMOD model based on local available information. Both models have six layers. In the IMOD model, Layer 2 (second from top) represents a regional clay confining layer that extends inland from beneath San Francisco Bay. The cross sections prepared for this study do not support layer 2 as a prominent confining layer, rather, thin, discontinuous fine and coarse-grained deposits are observed throughout the basin with the amount of fine-grained deposits increasing near the Bay.

The bedrock surface representing the base of the model was updated in PMOD to reflect the refined bedrock surface generated with ArcHydro tool discussed in Section 3.2.7.1.

Layer elevations were also revised to match screen depths opposite coarse-grained deposits at the Eleanor Pardee multi-completion well. Based on the hydrogeologic cross sections presented in Section 3.2.7.1, there are no clear aquifer depth zones (i.e., shallow and deep aquifers and confining layer), so layer depths were not tied to specific geologic horizons. Model layer elevations along grid row 53 and grid column 45 in the Palo Alto area are shown in Figure 4-3 (section locations are shown in Figure 4-4).

4.4.4 Hydrogeologic Properties

The hydraulic conductivity and storativity (K and S, respectively) zone boundaries were reconfigured in the Study Area to test alternative conceptual patterns of geologic deposition and associated aquifer characteristics. These patterns included bands of uniform K and S...
parallel to the western boundary of the Study Area between the hills and the Bay, and an alternative pattern with relatively high hydraulic conductivity in a band along the current alignment of San Francisquito Creek. Calibration results were not strongly affected by changes in zonal patterns. The three-band pattern and calibrated K and S values shown in Figure 4-5 produced results that were marginally better than the alternatives tested. In contrast to the expected transition from higher horizontal K (Kh) near the foothills—where coarse sediments are present near the apex of San Francisquito Cone—to lower Kh near San Francisco Bay, the pattern selected by calibration had the opposite relative values. The aquifer property zones shown in the figure have the same footprint in all model layers, although the extent of active cells becomes progressively smaller from layer 1 to layer 6. The aquifer properties for the three zones in the Palo Alto area are the same in all model layers. The properties in the southern part of the Study Area were not changed from the IMOD model and vary by layer.

The calibrated vertical hydraulic conductivity (Kz) pattern was more consistent with the hydrogeologic conceptual model, which includes increasing degree of confinement and thus decreasing values of Kz from the foothills to the Bay. The same Kz value was assigned to all layers, and the value near the Bay was calibrated to match the observed water-level differences between well screens of different depths at the Eleanor Pardee multi-completion monitoring in Palo Alto.

Specific storativity (So) and specific yield (Sy) values were uniform with depth, and Sy progressed from larger to smaller values between the foothills and the Bay. This horizontal transition is similar to the pattern in the original IMOD model, but the vertical distribution is more uniform. The calibrated K and S values differ somewhat from those in the San Mateo Plain Groundwater Model (SMPGWM), which encompasses the Study Area and was recently completed by another firm (EKI, HydroFocus and Todd, 2018). Aquifer characteristics in that model were texture-based and varied over small distances. The Kh values in PMOD were within the range of values in the corresponding region of SMPGWM except for the upper part of the San Francisquito Cone, where SMPGWM had much higher values. Kz was within the range of values in the SMPGWM model. Therefore, values in PMOD were mostly about an order of magnitude greater than in SMPGWM.

4.4.5 Calibration and Future Simulated Time Periods

The calibration period and the future simulated time periods are the same in both the IMOD and PMOD models. The future model simulations (2015 to 2044) consisted of 360 monthly stress periods that used actual 1985-2014 hydrology (calibration period) for natural rainfall, ET₀, and stream flow recharge, which includes normal, wet and dry periods. The monthly stress periods are the increments of time for which input data are specified. The model simulated 30 years of future hydrogeologic conditions (2015 to 2044) to evaluate the long-term movement of purified recycled water underground and of increased City pumping under normal, drought and wet conditions.

The simulation periods and stress periods were selected on the basis of several criteria:
• Land and water use conditions from 1985-2014 are similar to current conditions. Calibrating the model to conditions during 1985-2014 provided a more reliable basis for simulating future scenarios than calibrating to an older historical period.
• Thirty years is sufficient to simulate long-term responses to changes in recharge and pumping. It is relatively easy to switch the 30-year simulation from historical (1985-2014) to future simulation period (2015-2044), whereas changing the duration of the simulation requires more comprehensive modification of model pre-processing and post-processing files.
• Climatic conditions during 1985-2014 reflect the average for the historical period of record and include multi-year wet and dry periods.
• Monthly stress periods offer a reasonable compromise between accurately simulating short-term non-linear hydrologic processes (such as recharge from large stream flow events) and simulating long-term changes in groundwater conditions with manageable data file sizes and model run times.

4.4.6 Pumping

For the 1985-2014 calibration period, the District’s pumping database was used to represent pumping in Santa Clara County. Pumping in San Mateo County was estimated in collaboration with the ongoing San Mateo Plain modeling work. Dewatering pumping in the Study Area was estimated from municipal records. Pumping assumptions are described in more detail in the Water Balance Section 3.4.

A baseline and five scenarios were simulated for the future simulation period. All assumptions for the baseline and scenarios were the same except that City pumping and IPR recharge were added in differing amounts and locations for each of the scenarios, while the baseline assumed no increased pumping by the City and no IPR in the Palo Alto area.

The future simulation period also included estimates of changes in future pumping by parties other than the City. The District’s WEAP model was used to predict future pumping and managed aquifer recharge (including IPR projects) for the Santa Clara Subbasin portion of the Study Area, except for the City pumping, which was simulated at various volumes depending on the scenario being modeled. All totalizer pumping (i.e., multiple wells totaled as one value) was simulated as the 2010 to 2014 average. The District uses the WEAP model to evaluate conjunctive use of groundwater, local surface water, imported water and recycled water under different future conditions. The WEAP model was updated for the Palo Alto IPR model simulations (file used: “2040 Trending Demand WEAP Simulations_Results_for_Palo_Alto_IPR_Simulation.xlsx”). For the San Mateo Plain Subbasin portion of the Study Area, available literature including 2015 Urban Water Management Plans (UWMPs) prepared by water purveyors as well as pumping information from the San Mateo Plain Groundwater Model was used to predict future pumping.

4.4.7 Other Factors

For the calibration period, new recharge zones for the local Study Area and parameters were developed as discussed in Section 3.4. A pre-processing program was used to estimate
dispersed recharge from rainfall, irrigation deep percolation and pipe leaks. Subsurface inflow from bedrock hills and other model boundaries were simulated as general-head boundaries, where the amount and direction of flow depends on concurrent simulated water levels. Subsurface flow to or from San Francisco Bay was simulated in the same manner. Flow between the groundwater system and overlying hydraulically coupled streams was dynamically simulated based on concurrent water levels. The model simulates stream flow as well as groundwater flow, with mass conserved in both domains. Stream flow included unregulated natural rainfall runoff, local reservoir releases, and releases of imported water into creek channels for supplemental percolation.

For the future simulation, climate and natural stream flow for 2015-2044 were the same as for the 1985-2014-time series, except for the five streams most affected by updated WEAP values (including Calabazas, Los Gatos, Penetencia, Ross/Lone Hill, and Saratoga). Urban development factors (irrigation, irrigation efficiency, pipe leaks, impervious area, etc.) were held constant at 2014 values for the future simulation period.

4.4.8 Bay Water Level Rise

Potential impacts of sea water level rise (and associated Bay rise) were discussed in Section 3.6.8. Opinions vary on the forecasted amount of sea level rise, but there is little argument that the rising trend will continue. Rising Bay levels affect the groundwater flow simulations by increasing groundwater outflow to creeks and storm drains and potentially altering groundwater gradients from bay ward to inland. At the time the modeling was being planned, the City had adopted a sea level rise estimate of a minimum of 55 inches by year 2100 based on the San Francisco Bay Conservation and Development Commission projections for capital projects (City, 2016). For modeling scenarios, a 30-year future simulation period was projected from 2015 to 2044 as discussed above. Based on a linear interpolation of the 2100 projection, the projected rise in sea level is 18.8 inches in 2044. The model uses the NGVD 1929 vertical datum. The 2044 sea level elevation is 2.8 feet above that datum. The City has since revised its sea level rise projections to numbers developed by the California Natural Resources Agency and Ocean Protection Council – Sea Level Rise Guidance 2018 Update. Over the model simulation period, the two projections are close. For all scenarios including the baseline, the model simulated increased San Francisco Bay water levels of 18 inches for the entire projection period from 2015 to 2044. This approach was used rather than a gradually increasing trend so that higher sea levels could be simulated for all hydrologic conditions. The 2040 sea level was included in the future baseline scenario and thus its effects are included in all of the other scenarios.

4.4.9 Initial Groundwater Levels

Initial water levels for future scenario simulations were set equal to the simulated December 2011 water levels from the calibration simulation. This represents recent groundwater levels without the temporary effects of the 2012-2017 drought.
4.4.10  Model Calibration

The PMOD model was calibrated to reflect changes from the IMOD model. These included the larger simulated flow domain, revised estimates of pumping, revised layer elevations, and revised estimates of dispersed recharge. Because the Study Area occupies only a small part of the total model domain, calibration focused on results in that area. Other parts of the flow domain were not modified for the Palo Alto IPR study, and the IMOD calibration for those areas was assumed to remain adequate.

Twenty-four additional wells in the Study Area with good water levels records were added to the original IMOD model calibration data set. Monthly simulated water levels were compared to measured water levels at 28 well locations in or near the Study Area, including one multi-completion monitoring well with 4 separate well screen depths (Eleanor Pardee monitoring well). The calibration wells are all in the Santa Clara County part of the Study Area because water levels in San Mateo County are not routinely monitored. Groundwater elevation contour maps developed for this study and San Mateo County studies were also considered in the calibration process.

The primary variables adjusted during model calibration were the zonal patterns and values of horizontal and vertical hydraulic conductivity (permeability) and aquifer storativity. The calibrated values are discussed in Section 4.4.4. In addition, stream bed permeability and drain conductance values were adjusted so that simulated recharge from streams and discharge to drains (representing discharge to sanitary sewers, storm drains and tidal wetlands) were similar in magnitude to independently derived estimates presented in Section 3.4. Outside the Study Area, model parameters were not changed from the values obtained during the original District IPR study IMOD model calibration.

After calibration, simulated water levels matched hydrographs of measured water levels at most locations reasonably well.

Figures 4-5a through 4-5g show hydrographs of water levels for the 28 calibration wells in the Study Area. The location of each well is shown to the upper right of the hydrograph.

4.4.10.1  Residual Statistics

Various statistical metrics are commonly used to quantify model performance. The differences between each measured water level and the corresponding simulated water level is the residual. The model calibration guidelines presented in ASTM D-5490-93 (2014) recommend that these statistical summaries be calculated. Residuals statistics are not a completely objective measure of model performance because the process of selecting and evaluating measured data is subjective, as follows:

- Often, some wells are excluded from the calibration data set because they are geographically clustered, have too few data points to be useful, or have erratic or apparently abnormal water levels. In this case, the 28 wells were somewhat clustered. A smooth, convex envelope drawn around the wells on a map had an area equal to 47 percent of the total non-tidal, onshore part of the Study Area.
Some water-level measurements were omitted based on a subjective conclusion that they are not representative of ambient groundwater conditions (such as a measurement made while the well pump was operating). In other cases, the frequency of measured data points was thinned to approximately monthly to achieve a more uniform frequency of measurements among wells and throughout the 1985-2014 calibration period. The green ovals in the hydrographs on Figures 4-6a through 4-6g encompass data points that were omitted from the statistical analysis of residuals.

Deciding whether model performance is adequate based on residuals statistics is subjective. A common rule of thumb is that model performance can be considered acceptable if the root-mean-squared residual is less than 10% of the total range of measured water levels (Environmental Simulations, Inc., 2011). In this case, calibration was halted when most hydrographs exhibited a subjectively good fit between measured and simulated water levels and when further adjustments to model inputs yielded little additional improvement.

A scatterplot of the 3,378 pairs of measured and simulated water levels is shown in Figure 4-7, and the summary statistics are displayed on the graph. The mean residual is -0.3 feet, which indicates that there is no overall bias toward high or low water levels. Looking at the scatterplot, there are outlying points in layer 4 where measured water levels are 15-50 feet below sea level and the corresponding simulated water levels are as much as 60 feet higher. Those measured values were likely collected while the well pump was on or shortly after it shut off, and the measured values reflect localized drawdown at the well. Those points could reasonably have been removed from the statistical data set along with the many other data points that appeared to be influenced by pumping.

Another notable residuals pattern is the large amount of scatter in layer 3 residuals. The scatter spreads equally above and below the 1:1 “perfect fit” line. Almost all of the scatter derives from four wells. Wells 06S02W19M001 and 05S02W35R001 account for 77 of the 90 largest negative residuals (observed level lower than simulated level), and wells 06S02W24C008 and 06S02W20N001 account for 72 of the 90 largest positive residuals. Thus, the large amount of scatter does not indicate widespread inaccuracy in model results. Inspection of the hydrographs for these wells (Figures 4-6e, 4-6a, 4-6f and 4-6e for 06S02W19M001, 05S02W35R001, 06S02W24C008 and 06S02W20N001, respectively) provides a clearer picture of how their simulated water levels deviate systematically from measured water levels.

The standard deviation of the residuals provides a quantitative measure of goodness-of-fit between simulated and measured water levels per industry standard ASTM D-5490-93 (2014). For the PMOD model all measured values were assigned the same weight, so no adjustments related to weighting were necessary. The standard deviation of the residuals was 11.8 ft. The standard deviation is commonly divided by the overall range in measured water levels to obtain a dimensionless metric known as the normalized standard deviation. In this case, the range of water levels was 129 feet, and the normalized standard deviation was 9.2%.
4.4.11 Model Advantages and Limitations

The advantages and limitations of the District’s IMOD model relative to its predecessors GMOD and XMOD have been previously documented (Todd, 2017a). The same general advantages and limitations apply to the PMOD model. Relative to IMOD, PMOD offers the following advantages for some model uses:

- The calibration focuses on the Santa Clara County part of the Study Area, with improved results and more apparent accuracy in that region than the IMOD model.
- The PMOD domain extends farther into San Mateo County and has more accurate estimates of pumping locations and rates. This adds accuracy to the calibration and to simulated alternatives in that part of the model domain relative to IMOD.

Despite the above improvements, PMOD is still a simplified representation of the physical groundwater system. Its ability to simulate all details of groundwater flow and levels is limited, and those limitations should be considered when applying the model to address groundwater management questions. Limitations of the PMOD model include the following:

- The lack of production wells with long-term hydrographs in the San Mateo County portion of the Study Area results in a poorer calibration in this area.
- Model results are more accurate at the regional scale than at local scales. This is partly due to the high degree of horizontal and vertical spatial variability in groundwater conditions evident in measured water level data. The model provides a good estimate of the “average” groundwater conditions at any location in the model area, but the actual conditions encountered if a well were drilled at that location could differ from the average.
- Accurate simulation of local groundwater conditions is also limited by the grid cell spacing. The simulated water level in each model cell represents the average water level over the 1,000 x 1,000-foot cell. The actual water level at a pumping well within the cell would be lower than the average. Thus, the model is not an appropriate tool for evaluating available drawdown or well screen dewatering in wells or the drawdown caused by a pumping well at another well located less than 1,000 feet away.
- The limitations on spatial accuracy of model results apply to vertical as well as horizontal accuracy. The complex distribution of individual lenses of alluvial materials with different textures is represented crudely in the model. Vertical water-level gradients should be viewed as averages over areas encompassing several square miles. Actual gradients at specific locations are highly influenced by the screen depths at nearby production wells.
- The model is not capable of accurately simulating hydrologic processes over time intervals less than one month, which is the stress period duration used for transient simulations. This includes drawdown during pumping cycles shorter than one month and the effects of brief stream flow peaks on groundwater recharge.
- The PMOD model does not simulate subsidence. Consequently, results might not be accurate for scenarios in which groundwater levels approach or drop below the minimum water levels reached in the 1960s.
4.4.12 Flow Between Shallow and Deep Aquifers and Lateral Flow Across Study Area Boundaries

The groundwater model was used to evaluate vertical flows of water between shallow and deep aquifers in the Study Area and to compare those fluxes with the amount of net inflow from Subbasin areas outside the Study Area. The vertical fluxes and the lateral boundary fluxes vary by location and over time, but the net flux is of greatest importance from the standpoint of water supply. For the vertical flux evaluation, model layers 1 and 2 were grouped as a shallow zone and layers 3-6 as a deep zone. For recent historical conditions (calendar years 2005-2014), average annual water balances were subtotaled for the shallow and deep regions within the Study Area. Flows were substantial in both direction across the boundaries between shallow and deep, shallow and external, and deep and external. For the shallow zone in the Study Area, there was a net groundwater inflow from areas outside the Study Area of 1,420 AFY and a net downward flow to the deep zone of 2,450 AFY. The only two sources of recharge to the deep zone were the downward flux and 1,300 AFY of net inflow from areas outside the Study Area. Together, these inflows exactly balanced the amount of pumping. Thus, net lateral inflow to the deep zone supplied 37% of the pumping, with downward flux from the shallow zone accounting for the remainder. In the shallow zone, net lateral inflow was only 12% of total inflows and hence contributed 12% of the water extracted by wells.

Most of the time, simulated vertical gradients in recent years between the shallow and deep zones were downward in inland areas and upward near the Bay. The net downward flux of 2,450 AFY was the difference between 6,370 AFY of downward flux and 3,930 AFY of upward flux. Vertical flow gradients between the shallow and deep aquifers can change based on hydrologic and pumping conditions as groundwater levels in the two aquifers change relative to each other.

4.4.13 Impacts Assessment Criteria

Quantitative criteria were developed for evaluating saline water intrusion, subsidence, creek depletion, and impacts to nearby supply wells associated with model-simulated future groundwater elevations. The criteria were used to assess negative impacts of the five scenarios and their feasibility. A summary of the criteria is provided below.

1. **Saline Intrusion -- Criteria 1) Water levels at a potentially affected well**
   Duration of water levels below sea level does not exceed 12 years and the 12-year running average does not exceed 10 feet below sea level during that time (depth-duration limit equal to 1/5 the historical depth-duration combination).
2. **Saline Intrusion -- Criteria 2) Water levels between well and Bay**
   Water levels in wells of similar screened interval and located between the pumping well and San Francisco Bay remain above sea level throughout the period when water levels at the pumping well are below sea level.

3. **Subsidence -- Criteria 3) Subsidence threshold**
   Sustained (12-year moving average) groundwater levels remain above -40 ft-msl. During future periods of significant City pumping, water levels in a threshold well in the Palo Alto area should be monitored.

4. **Impacts to Creeks -- Criteria 4) Streamflow depletion**
   The range of acceptable streamflow depletion is up to 1 cubic feet per second (cfs) if it does not reduce steelhead passage opportunity by more than 10% in any 3-year period.

5. **Impacts to Nearby Wells -- Criteria 5) Reduced water levels**
   Increased City pumping does not cause groundwater levels to drop to more than 70 ft-bgs (median depth to top of screen in local area domestic and irrigation wells) for more than three consecutive years to prevent potential screen corrosion.

4.4.13.1 Saline Intrusion

Efforts in California to identify protective groundwater elevations that will avoid seawater intrusion typically assume a relatively unlayered aquifer system and focus on the density difference between seawater and freshwater (HydroMetrics, 2012; Geoscience, 2013). Because of the density difference, seawater can theoretically extend inland at the base of an aquifer beneath an overlying freshwater zone even if water levels in wells are slightly above sea level. The density relationship is described by the Ghyben-Herzberg equation. While theoretically correct, the equation assumes hydrogeologic conditions completely unlike conditions along the San Francisco Bay shoreline in the Study Area. The equation applies to a single layer of sand in connection with the ocean in which fresh groundwater flows to the sea over a basal wedge of saltwater. In the Study Area, the Santa Clara and San Mateo Plain subbasins consist of numerous thin and primarily fine-grained layers of alluvial materials with sufficient lateral continuity to create strong groundwater confinement except near the foothills where unconfined recharge areas occur. Historically, confined conditions created a band of flowing wells along the Bay margin and even today, many wells in the area, including some located well inland, currently show artesian conditions. The monitoring well cluster at Eleanor Pardee Park currently exhibits an upward groundwater gradient with the water levels in the deep well completions above the ground surface.

The connection between the shallow groundwater system and the Bay occurs where there is permeability across the fine-grained confining layers. Previous studies have concluded that some cross-cutting permeability occurs where major streams—such as San Francisquito Creek and the Guadalupe River—have cut through fine-grained layers, and more importantly, where wells penetrate across the layers and provide conduits for vertical groundwater flow within the groundwater basin (Iwamura, 1980; Poland and Green, 1962). Further evidence of general confinement with localized vertical flow paths include the presence of fresh groundwater beneath San Francisco Bay in geotechnical borings completed for the Dumbarton Bridge.
construction, isolated areas of elevated groundwater salinity separated from the Bay by fresher groundwater, and the seasonal reversal of salinity trends in some wells suggesting localized contamination by relatively small volumes of saltwater (Iwamura, 1980). The Metzger (2002) study of hydrogeologic conditions near San Francisquito Creek concluded that chloride-rich marine sediments and undifferentiated clays are the likely source of high chloride in wells sampled for the study and not saline intrusion from the Bay. This conclusion was based on chloride-to-iodide ratios, which can be used to differentiate sources of chloride. The City’s Hale and Rinconada wells were sampled as part of that study. Hamlin (1983) attributed very high chloride concentrations (significantly higher than in Bay water) in the Baylands area to evaporative concentration and percolation in the salt marshes and salt evaporation ponds, resulting in hypersaline brine in shallow groundwater near Bay (Hamlin, 1983 and 1985).

Chloride concentrations in the Hale and Rinconada wells fluctuate significantly but appear to have generally increased over a historical period when groundwater elevations were generally rising (see Figure 3-49). This is opposite of the expected trend if saline water were intruding from the Bay. In the Eleanor Pardee multi-completion monitoring well, the highest chloride concentrations are found in the second deepest screened interval, which is 720 to 740 ft-bgs (see Figure 3-49). The shallowest interval has the lowest chloride concentrations. These results indicate that elevated chloride concentrations are originating from formation sediments rather than saline intrusion from the Bay. These results raise questions about the potential for saline water intrusion impacts if groundwater levels are drawn down by significant City pumping. Nonetheless, a groundwater level and duration criterion is proposed as a precaution because hypersaline water is documented to occur in the Baylands area and City wells are screened in both the Shallow and Deep aquifers. So, the potential exists to pull shallow hypersaline Baylands water inland.

**Saline Water Intrusion Risk Criterion 1: Water Levels at a Potentially Affected Well**

For a pumping well near San Francisco Bay, the risk of saltwater potentially reaching the well is related to water levels at the well, well screened intervals, and water levels between the well and the Bay. For planning purposes, water level criteria are proposed that provide reasonable assurance that saltwater will not reach the well. For water levels at the well, the criterion defines a combination of water level depth and duration adequate to avoid saline intrusion. In the case of the Hale Well and nearby wells (Figure 3-30), the average water-level depth during 1916-1978 (period of greatest historical groundwater level decline and recovery) was -51 ft-msl, and the average during the declining period (1916-1962) was -57 ft-msl. It would be conservative to assume that future temporary declines in water levels equal to one-fifth of that depth-duration combination would avoid the arrival of saltwater at the well. In other words, if the duration of water levels below sea level does not exceed about 12 years duration and the 12-year running average groundwater elevation is not lower than -10 ft-msl during that time, it is unlikely that groundwater salinity at the well would increase substantially, assuming intrusion is the source of the salinity. The 12-year base period for analysis is appropriate because it is roughly the scale of major historical droughts in California: 7 years of water-level declines followed by 5 years of recovery back to sea level. It matches, for example, simulated hydrograph patterns during the 1987-1992 drought and subsequent recovery.
This depth-duration averaging approach allows for short, intense droughts as well as longer-less intense ones. This is illustrated conceptually by the three hydrograph plots in Figure 4-8. The top plot shows hypothetical annual water levels (blue curve) and 12-year moving-average water levels (red curve) for a major drought during which annual water levels were below sea level for 8 years, reaching a minimum of -25 ft-msl. The 12-year-moving-average water level curve reached a minimum of -8 ft-msl, which is within the 10-foot limit suggested for this exercise. The middle plot shows water levels for a shorter, more intense drought. Annual water levels fell to as much as -40 ft-msl, but the total duration below sea level was only 7 years. In this case, the 12-year-moving-average curve also remained above the -10 ft-msl criterion. In the final example (bottom plot), water levels were low and slowly declining before crossing the sea-level threshold, as might occur during a prolonged mild drought. They continued declining to -14 ft-msl (much shallower than in the previous examples) before recovering to sea level after 12 years. In this example, the 12-year-moving-average curve also remained above the -10 ft-msl criterion. In summary, all three of these drought scenarios would meet the acceptability criterion for water levels based on a depth-duration limit equal to one-fifth of the historical depth-duration combination.

**Saline Water Intrusion Risk Criterion 2: Water Levels Between the Well and Bay**
The second risk criterion is whether groundwater levels between the pumping well and the Bay are above sea level. Specifically, as long as water levels in wells of similar screened interval and located between the pumping well and San Francisco Bay remain above sea level throughout the period when water levels at the pumping well are below sea level, salt water is not likely to reach the pumping well.

**Potential Saline Intrusion Monitoring**
Monitoring wells between a production well and the Bay to provide early detection of intrusion (“sentry wells”) can allow intrusion to be detected and pumping to be reduced before saltwater moves inland. In recent years, for example, sentry wells have been installed at three locations in the Westside Basin (Sunset District, Daly City and San Bruno), in Soquel and in the Seaside Basin near Monterey. The City of East Palo Alto has established a network of water level and quality monitoring wells as part of its Groundwater Management Plan (Todd, 2015). It should be noted that sentry wells do not provide a perfect means of detection because intrusion commonly moves via circuitous pathways, not as a massive front. For example, saltwater that was gradually advancing inland in Los Osos (near San Luis Obispo) bypassed a sentry well and arrived unexpectedly at an important municipal production well. Nonetheless, if the City begins groundwater pumping on a regular basis, it is recommended that sentry wells be identified and/or installed and monitored for saline intrusion.

**Application of Saline Intrusion Criteria**
If a scenario meets criterion 1 but fails criterion 2, or vice versa, it is considered generally feasible, although increased monitoring may be warranted if implemented. If it fails both criteria, it would be deemed infeasible without modifications such as reduced or redistributed pumping, increased IPR volume, and/or increased monitoring. Scenarios meeting both criteria are presumed to be most conservative in protecting against saline intrusion.
4.4.13.2 Subsidence

Subsidence thresholds for groundwater levels have been established by the District for a network of wells in the basin. The nearest subsidence threshold well, located in Mountain View, has a subsidence threshold of -26 ft-msl (Geoscience, 1991). In addition, the District monitors a network of surface elevation benchmark points including several in the Palo Alto area. It is noted that the Palo Alto area experienced less historical subsidence compared with other areas in Santa Clara Valley even though groundwater levels in Palo Alto reached about -135 ft-msl at the end of the peak pumping period in the Hale well. For evaluation of scenarios, sustained (12 years) water levels of greater than -40 ft-msl is proposed as the criterion for subsidence. This threshold elevation is lower than the threshold elevation of -10 ft msl specified for Saline Water Intrusion Risk Criterion 1. Therefore, the intrusion criterion will be the limiting constraint. That is, if water levels meet the intrusion criterion, subsidence will be avoided.

Potential Subsidence Monitoring

As discussed in Section 3.6.3, it is recommended that a new monitoring well in the Palo Alto area be added to the District’s network of subsidence index wells and a subsidence threshold identified for the well if the City initiates increased pumping. During future periods of significant City pumping, water levels in a threshold well in the Palo Alto area should be monitored.

4.4.13.3 Impacts to Creeks

San Francisquito Creek is the primary creek of interest in the Study Area because City wells are located proximate to the creek and it is the only riparian, unchannelized urban creek on the south Peninsula. Baseline conditions (no IPR or City pumping) can be compared to modeled creek flows under each scenario to evaluate potential stream flow gains and losses. The proposed criterion for the acceptable range of streamflow depletion is that a reduction in stream flow at any location along the creek of up to 1 cfs from baseline conditions is acceptable if it does not reduce steelhead passage opportunity by more than 10% in any 3-year period. The location of the critical riffle that first blocks fish passage as creek flows recede has not been identified in San Francisquito Creek, and the flow required to maintain sufficient water depth for smolt and adult passage (typically about 0.3 and 0.6 foot, respectively) is not known. The biological opinion for steelhead in San Francisquito Creek prepared for a flood control project used a simpler and less accurate approach based on flow duration analysis to conclude that the minimum flow for adult passage near the lower end of San Francisquito Creek is 3 cfs and the minimum flow for smolt passage is 1 cfs (National Marine Fisheries Service (2015). In other California coastal streams where flow hydraulics over critical riffles have been studied, minimum passage flows are on the order of a few tens of cfs for adults. The typical rate of flow recession in spring in the 10-80 cfs range is 4 cfs per day. In that case, a 1 cfs reduction in flow would shorten the window of time for passage by a fraction of a day. This criterion proposed in this report that flow depletion of up to 1 cfs is less than significant provided it does not decrease passage opportunity by more than 10% in any 3-year period should be considered preliminary, pending input and evaluation by fisheries biologists. A passage opportunity analysis was not completed for this project but typically consists of tabulating the number of days within the adult and smolt migration seasons each year that exceed the minimum passage flow.
This is compared with the number of days of passable flow if flows were depleted by some amount, which for the scenarios simulated in this study was approximately 0.5 cfs. Flow depletion can potentially impact riparian vegetation in addition to fish. Based on three sites along San Francisquito Creek where flows were measured for this study in 2017, a decrease of 0.5 cfs in flow would decrease creek water surface elevation by about 0.1 foot at low flows. This change in water table elevation immediately adjacent to the creek is well within the facultative rooting depth range for willow, cottonwood, sycamore, box elder and other common California riparian plant species (Nature Conservancy, 2018).

4.4.13.4 Impacts to Nearby Wells

Increased pumping by the City has the potential to lower groundwater levels in nearby pumping wells causing groundwater levels to drop below the top of well screens potentially resulting in screen corrosion. The median top of well screen for domestic/irrigation wells in the Palo Alto/Menlo Park/East Palo Alto area is about 70 ft-bgs. The proposed criterion for negative corrosion impacts is if the City’s pumping wells lower groundwater levels in the Palo Alto/Menlo Park/East Palo Alto area to depths greater than 70 ft-bgs for more than 3 years.

4.4.13.5 High Groundwater in the Shallow Aquifer

The Study Area is known to experience high groundwater levels in the shallow aquifer, which require dewatering at some locations. Many deep aquifer wells currently exhibit artesian conditions with water levels above their respective ground surface elevation. The purified recycled water injection wells will be designed to only inject into the deep aquifer. Significantly increased groundwater levels in the deep aquifer caused by injection of purified water would not cause high groundwater in the shallow aquifer because the aquifer is confined such that groundwater does not readily move from the deep aquifer to the shallow aquifer through the confining zone. Therefore, injection is not expected to cause increased groundwater levels in the shallow aquifer. Because the City’s wells are screened in both the shallow and deep aquifers, the IPR project is expected to reduce high groundwater conditions in the shallow aquifer near the production wells. No criteria are proposed for this potential impact because no negative impacts are expected.

4.4.14 Scenarios Impacts Assessment

Each scenario was modeled and groundwater elevation contour maps, groundwater hydrographs, and stream flows were generated. These outputs were used to evaluate each scenario relative to the criteria presented above to determine scenario feasibility.

4.4.14.1 Simulated Water Levels and Stream Flow

Figures 4-9a through 4-9e show hydrographs of simulated groundwater levels for Scenarios 1 through 5, respectively, at wells where the risk of triggering intrusion or subsidence is greatest. Hydrographs are shown for the Rinconada, El Camino Park and Hale wells, which are the City wells that had the lowest water levels in the scenario simulations and thus were the ones that constrained the maximum amount of pumping. Figure 4-10a shows contours of simulated groundwater elevations for future baseline hydrologic conditions corresponding to hydrologic...
conditions in September 1992 (near the minimum elevation in most hydrographs) in model layer 3. Hydrologic year conditions in 1992 correspond to 2022 in the future model simulations. **Figures 4-10b through 4-10f** show contours of simulated groundwater elevations for hydrologic conditions corresponding to September 1992 for model layer 3 for Scenarios 1 through 5, respectively. **Figures 4-11a through 4-11f** show simulated depth to groundwater contours for hydrologic conditions in September 1992 (corresponding to future model simulation year 2022) in model layer 1 for the baseline and Scenarios 1 through 5, respectively. **Figures 4-12a through 4-12c** show San Francisquito Creek flows compared with baseline flows for each scenario. The figures described above are used to assess the feasibility of each scenario based on the criteria defined above.

### 4.4.14.2 Saline Water Intrusion

For some of the scenarios, one or more City wells did not meet the saline water intrusion Criterion 1 (see **Figures 4-9a through 4-9e**). That is, the 12-year moving-average water level at those wells dropped to lower than -10 ft msl during 1987-1992 hydrologic conditions. Note that the Y axis scale in the hydrographs is based on the NGVD29 elevation datum used in the model. Future (2044) sea level is indicated on the graphs as a horizontal yellow line. Wells that did not meet the criterion were the Rinconada Well in Scenario 2, the El Camino Park Well in Scenario 3, and the Rinconada and Hale Wells in Scenario 5. All wells met the criterion in Scenarios 1 and 4.

The second saline water intrusion criterion can be evaluated using the water-level contour maps for September 1992 (**4-10a through 4-10f**). Those contours are for model layer 3, which generally experienced the greatest pumping effects and lowest water levels. The critical location for all six scenarios—including future baseline—is between the pumping depression at the Palo Alto Park Mutual Water Company (PAPMWC) wells and the shoreline of San Francisco Bay. Under future baseline conditions, the PAPMWC pumping depression was below sea level, but water levels at the shoreline 2 to 7 feet above future sea level (the horizontal yellow line). Also, simulated vertical gradients were upward at the shoreline, which provides additional resistance to seawater intrusion. For Scenarios 1, 2, 3 and 4, City pumping was increased until the simulated September 1992 water level at the Bay shoreline near PAPMWC was at or slightly above future sea level (**Figures 4-10b through 4-10e**). For Scenario 1, the operable yield pumping rate (3,000 AFY) turned out to be very close to the independent estimate obtained from the water balance analysis in **Section 3.4** (2,900 AFY). The contours for Scenario 3 show that heavy pumping at the El Camino Park well creates a large pumping depression that extends as far as PAPMWC, where it lowered 1992 water levels by about 2 feet. However, water levels at the Bay shoreline remained above sea level, and the vertical gradient between model layers was still upward. Scenarios 2 and 4 demonstrate that IPR injection in the general vicinity of City wells counteracts the drawdown caused by pumping. At the Bay shoreline, the net effect is that water levels remained at or slightly above sea level. If the amount of IPR is insufficient to balance the amount of pumping, excessive drawdown extends to the Bay shoreline. This was the case in Scenario 5, in which City pumping exceeded IPR by 3,600 AFY. Water levels at the shoreline were 3 to 4 feet below future sea level, and the vertical water-level gradient between
model layers was downward. Thus, Scenario 5 was the only scenario that did not meet Criterion 2 for saline water intrusion.

The low water levels shown in Figures 4-10b through 4-10f were a temporary condition representing the highest intrusion risk during the 30-year simulation period. As the hydrographs indicated (Figure 4-9a through 4-9e), water levels are substantially higher most of the time. Water-quality degradation from intrusion typically develops when water levels remain below sea level for a number of years. The water levels in Figures 4-10a through 4-10e for Scenarios 1-4, respectively, might not be sustainable as a chronic condition, but are sustainable as a transient condition.

### 4.4.14.3 Subsidence

Scenarios 1 through 4 were sustainable with respect to subsidence because water levels never declined to more than 40 feet below sea level. Scenario 5 did not meet this criterion at the Rinconada Well, where simulated layer 3 water levels were approximately equal to -40 ft msl in normal and wet years and as low as -50 ft msl (as an annual average) during drought conditions (Figure 4-9e).

### 4.4.14.4 Impacts to Creeks

Figures 4-12a through 4-12c show simulated streamflow depletion for baseline and scenarios for various streamflow conditions. The range in streamflow depletion is from 0.5 cfs for Scenarios 1, 2, and 3 to 0.6 cfs for Scenario 4 and 0.7 cfs for Scenario 5. None of the Scenarios results in more than 1 cfs of depletion and therefore pass the criterion.

### 4.4.14.5 Impacts to Nearby Wells

The potential impact of City pumping on water levels at nearby wells was evaluated by the simulated depth to water in model layer 1 in September 1992 for each scenario. The criterion is based on the premise that corrosion might occur near the top of the well screen of an average residential well if the water table were greater than 70 feet below ground surface for more than 3 years. After the first few years of the simulation, drawdown caused by City pumping remained constant throughout the rest of the simulation because City pumping was the same every year. The lowest water levels at nearby wells would thus occur under fall 1992 hydrologic conditions. Model layer 1 contains the water table and is the appropriate model layer to evaluate impacts occurring at relatively shallow depths.

Figures 4-11a through 4-11f shows contours of simulated depth to water in model layer 1 in September 1992 for the future baseline and Scenarios 1 through 5, respectively. They show that depth to water gradually increased with inland distance from the Bay. Depths to water exceeded 100 feet in some locations along the western boundary of the Study Area. This is a common pattern in many groundwater basins, where the ground surface slope is steeper than the water table slope. The 70-foot criterion for well screen exposure does not apply to wells along the inland edge of the subbasins because the water table is naturally that deep and wells are constructed accordingly. The criterion applies in the general vicinity of the City wells, where future baseline depth to water was less than 30 feet under 1992 conditions. None of the
scenarios caused the water table to drop to more than 70 ft-bgs. The closest was Scenario 3, where the depth to water was slightly over 60 feet at the El Camino Park Well.

4.4.14.6 Summary of Impacts Assessment

Table 4-4 provides a summary of the criteria evaluation for each scenario. Scenarios 1 through 4 are feasible at the selected combinations of City pumping and IPR recharge. Scenario 5 did not meet four of the five criteria. Saltwater intrusion Criterion 1 was not met in Scenarios 2 and 3 due to low simulated water levels at the Rinconada and El Camino Park wells. However, water levels at the Bay shoreline remained at or above future sea level throughout the simulation, thereby achieving feasibility by meeting saltwater intrusion Criterion 2. The saline water intrusion criteria were consistently the ones limiting yield, usually because of the low simulated water levels and inland gradients at the PAPMWC well. All scenarios met the sustainability criteria for stream flow depletion and impacts on water levels at nearby wells.

4.4.15 Selected Scenario 4 Feasibility

While four of the scenarios were deemed to be feasible or generally feasible, with modifications, Scenario 4 was selected for continued evaluation and carried forward for cost estimating and development of an implementation strategy. Scenario 4 is the reduced IPR alternative, assuming 2,800 AFY of injection and 5,900 AFY of City pumping, which represents 49% of the City’s 2020 demand. Scenario 4 was selected because the purified water delivery volume was deemed conservative and achievable while still providing a substantial volume for use, the injection wells are all located within City limits, costs for conveyance are lower compared with Scenario 2, it is technically feasible with no projected adverse impacts and more likely to be implemented compared with Scenario 2.

4.4.15.1 Simulated Response Retention Times

The GWR regulation require that recycled water must be retained underground for a period of time necessary to allow a Project Sponsor sufficient response time to identify treatment failures and implement actions, including the plan to provide an alternative water supply or wellhead treatment. For this project feasibility evaluation, an RRT of 6 months was selected. The actual RRT can only be determined through additional modeling once accurate injection well locations and flow rates are determined. Nonetheless, a 6-month RRT is reasonable and conservative given the RRTs typical of other active or proposed IPR projects in California. To account for model uncertainties, DDW GWR regulations require a correction of 2X for a modeled travel time. Therefore, to account for the correction, the 1-year travel time would represent a 6-month RRT.
Table 4-4 Scenario Feasibility Summary

| Scenario No. | Description | City Pumping Volume (AFY)* | Indirect Potable Reuse (IPR) Injection Volume (AFY) | Criteria 1 - Saline Intrusion: 12-year running average groundwater levels is not more than 10 feet below sea level | Criteria 2 - Saline Intrusion: Groundwater levels at locations between pumping well and the Bay are above sea level throughout period when water levels in pumping well are below sea level | Criteria 3 - Subsidence: Sustained (12-year) groundwater elevations are greater than -40 feet mean sea level | Criteria 4 - Streamflow Depletion: Streamflow depletion is <1 cubic foot per second and does not reduce steelhead passage opportunity by more than 10 percent in any 3-year period. | Criteria 5 - Impacts to Nearby Wells: Groundwater levels are not lowered to more than 70 feet below ground surface for more than 3 consecutive years. | Comments |
|-------------|-------------|-----------------------------|-----------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| 0 Baseline scenario. | Goal is to model effects to the aquifer over the 30 year period from 2015-2044 at District-projected levels of pumping and recharge. | 0 | 0 | Yes | Yes | Yes | Yes | Yes | Yes |
| 1 Preliminary yield estimate. | Goal is to determine the operable City pumping over 30 years without IPR. This scenario is meant to refine the preliminary operable yield estimate of 2,900 AFY determined in the groundwater assessment. | 3,000 | 0 | Yes | Yes | Yes | Yes | Yes | Feasible |
| 2 Determine maximum operable yield with injection. | Goal is to model groundwater augmentation with maximum potentially available purified water based on Palo Alto’s existing recycled water allocation. This scenario will use 60% of the City's total projected 2020 water demand for the initial model run. | 7,200 | 5,600 | No | Yes | Yes | Yes | Yes | Generally feasible, recommend monitoring to confirm modeled groundwater levels |
| 3 Realistic near-term scenario. | Goal is to model using El Camino Park Well only to supply 20% of the City’s projected 2020 water demand, and determine if IPR is needed to support this scenario. El Camino Park Well is technically the most feasible location for long-term groundwater production due to available storage, blending facilities, and space for treatment. | 2,400 | 0 | No | Yes | Yes | Yes | Yes | Generally feasible, recommend monitoring to confirm modeled groundwater levels |
| 4 Reduced IPR. | Goal is to model injection at a reduced level and at fewer locations to determine the operable City pumping level with 2,800 AFY injection. This scenario will use 40% of the City’s projected 2020 water demand for the initial model run. | 5,900 | 2,800 | Yes | Yes | Yes | Yes | Yes | Feasible, carry this selected scenario forward for travel time modeling |
| 5 100% Demand. | Goal is to model complete City dependence on groundwater and to determine the IPR volume needed to support this scenario. Pumping is set at 100% of the City’s projected 2020 demand. | 12,000 | 8,400 | No | No | No | No | Yes | Infeasible, would need more than 8,400 AFY of injection |

AFY - Acre-feet per year
* Pumping volumes are in addition to the study area outputs determined in the Groundwater Assessment, such as groundwater supply pumping and construction dewatering
* Total projected 2020 water demand for Palo Alto is 12,000 acre feet based on the City’s Urban Water Master Plan
* IPR = Indirect potable reuse; groundwater augmentation with purified water (highly treated wastewater) via injection wells
* Matadero and Fernando wells are not considered in Scenarios 2 through 5 due to their proximity to known groundwater contamination, distance from injection wells, and ability of remaining wells to provide needed capacity
The direction and rate of movement of injected purified recycled water in the groundwater system was simulated using the MODPATH add-on to the MODFLOW2005 software. MODPATH uses a particle-tracking approach, calculating the movement of hypothetical particles of water based on the flow vector at the particle location at each time step of the flow simulation. It converts the Darcy velocity (flow over the full aquifer cross-sectional area) to pore velocity by dividing by effective porosity, which was 0.2 (dimensionless) in the simulations. For the MODPATH simulations, lines of points were specified as tight circles of particles around the injection wells. For the injection wells, the particles started at the midpoint elevation of layer 5. Particle movement was tracked for a period of 10 years starting in year 4 of the 30-year simulation period (that is, corresponding to 1989-1998 hydrologic conditions). The results did not exhibit noticeable variations in particle movement from year to year, so results were not greatly affected by selection of the tracking period.

**Figure 4-13** shows a map of horizontal particle movement in the Palo Alto area under Scenario 4. The points along each pathline are at travel times of 1, 2, 6 and 12 months, plus annual points for years 2-10. For reference, the red dots are the simulated locations after 1 year. Because of regional flow toward the Bay, the initial circles of points translate laterally downgradient and remain distinct for the first 1 to 2 years. After that, dispersion blurs the circles.

Groundwater flow is not uniformly distributed over the depth of the groundwater system. Most of the flow typically is concentrated in thin sand layers. The model simulates flow through the entire layer thickness. However, for particle tracking purposes, it assumes that flow is through only 20 percent of the cross-sectional area (effective porosity = 0.2). The effective porosity value could underestimate the concentration of flow into a small cross-sectional area.

At most of the IPR injection well locations, the travel time to the nearest downgradient municipal well was 8 or more years. For one IPR well close to the El Camino Park well (B4), the simulated travel time was 5 years.

The analysis indicates that based on the preliminary general injection well locations, there is sufficient underground retention time to meet the planning RRT of 6 months (1-year modeled time) between injection and recovery at the City’s wells and two potable supply wells located in San Mateo County. There is also sufficient retention time to the Stanford irrigation wells, which could potentially be used at potable supply wells in an emergency.

As shown in **Figure 4-1**, there are other pumping wells identified in the District’s pumping database in the vicinity of some of the injection wells. These wells have identified uses for domestic, irrigation, and industrial supply. The RRT only applies to wells used for drinking water supply. Some of the wells have identified domestic uses on their driller’s logs. Once accurate injection well locations are identified, it is recommended that the District verify groundwater use categories for nearby drinking water wells. Well owners should be contacted to confirm the uses for the pumped groundwater. If domestic potable supply wells are found to be located within the RRT, the injection wells could be re-located or negotiations undertaken to destroy the well.
4.5 Scenario 4 Facilities

The goal of the Scenario 4 pipeline is to provide sole purified recycled water service to the five injection well sites in Palo Alto discussed in Section 4.1.2. This alignment is only used for IPR purposes.

The Scenario 4 alignment, along with approximate locations of potential injection wells to be served, are shown in Figure 4-14. The volume of treated water that can be used for injection purposes is 2,800 AFY, while the volume of water that can be extracted by Palo Alto without undesirable impacts (or the “Project Yield”) is 5,900 AFY.

4.5.1 Treatment Plant

Recycled water from the RWQCP will be treated to full advanced treatment (FAT) levels. The FAT train includes membrane filtration, reverse osmosis, and advanced oxidation using ultraviolet light and an oxidant such as hydrogen peroxide or chlorine. The required treatment influent volume to meet Scenario 4’s demand, along with the corresponding rejection rate and effluent volume, are summarized in Table 4-5. The treatment facilities for Scenario 4 are sited near the RWQCP at the adjacent property known as the “Measure E” site. The Measure E site requires voter support to modify the use of this land for an alternate use. Additional information on the Measure E property can be found in the City’s 2017 Measure E White Paper.

<table>
<thead>
<tr>
<th>Total Wastewater Influent Needed</th>
<th>MF/RO Combined Rejection Rate</th>
<th>Total Effluent Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.33 mgd</td>
<td>75.1%</td>
<td>2.50 mgd</td>
</tr>
</tbody>
</table>

mgd – million gallons per day  
MF – microfiltration  
RO – reverse osmosis

Palo Alto’s assumed share of flow to the RWQCP is 7.3 mgd (36% of 20.3 mgd), which is approximately 8,100 AFY. The Scenario 4 wastewater effluent needed is 3.3 mgd, well below Palo Alto’s flow share.

To meet the pressure criteria, Scenario 4 includes one pump station that serves all segments and is assumed to be located at the RWQCP. The pump station’s performance requirements under peak flow conditions are summarized in Table 4-6.

4.5.2 Pipelines

The Scenario 4 distribution system would consist of approximately 5.6 miles of pipeline. A summary of pipe sizes and lengths is provided in Table 4-7. A dedicated IPR transmission main would need to be constructed from the RWQCP to the injection well field.
### Table 4-6  Pump Station Sizing

<table>
<thead>
<tr>
<th>Description</th>
<th>Performance Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Flow</td>
<td>1,736 gpm</td>
</tr>
<tr>
<td>Discharge Head</td>
<td>270 feet</td>
</tr>
<tr>
<td>Pump Configuration (duty + standby)</td>
<td>2 + 1</td>
</tr>
<tr>
<td>Pump Motor Rating (each)</td>
<td>100 hp</td>
</tr>
<tr>
<td>Total Installed Motor Horsepower</td>
<td>300 hp</td>
</tr>
</tbody>
</table>

gpm – gallons per minute  
hp – horse power

### Table 4-7  Pipeline Specifications

<table>
<thead>
<tr>
<th>Modeled Pipe Inner Diameter (in)</th>
<th>Approximate Length of Pipe (linear feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2,000</td>
</tr>
<tr>
<td>8</td>
<td>1,500</td>
</tr>
<tr>
<td>10</td>
<td>5,000</td>
</tr>
<tr>
<td>12</td>
<td>21,000</td>
</tr>
<tr>
<td><strong>Total Length (linear feet)</strong></td>
<td><strong>Total Length (miles)</strong></td>
</tr>
<tr>
<td>29,500</td>
<td>5.6</td>
</tr>
</tbody>
</table>

in – inches

#### 4.5.3  Injection Wells

While the City wells are screened in both the shallow and deep aquifers with some extending to the base of the alluvial aquifer. It is proposed that the injection wells should not be screened in the shallow aquifer since the shallow aquifer exhibits shallow groundwater levels that require dewatering facilities in some areas and also to prevent the injection wells from acting as conduits for movement of water between the two aquifer zones. It is also proposed that the injection wells do not extend to the full depth of the alluvial aquifer to both reduce well costs and to minimize mobilization of poor quality groundwater associated with marine deposits in the lower aquifer and underlying bedrock. Accordingly, it is proposed that the injection wells inject into model layers 3, 4, and 5, which extends from roughly 280 to 790 feet below ground surface in the vicinity of the injection wells. Note that the actual injection well completions will be based on conditions observed during drilling, if the IPR project is implemented.

#### 4.5.4  Extraction Facilities

Extraction is assumed to be at six of the City’s existing wells as shown in Table 4-3. In addition to the use of existing wells, new wellhead treatment for extracted groundwater was included in
the Scenario 4 facilities. The new wellhead treatment for extracted groundwater would allow the City to produce a high-quality potable product water that addresses the community’s expectations of water aesthetics (i.e. taste and odor). The wellhead treatment capital and O&M costs are developed based on calculations completed for the 2017 Water Integrated Resources Plan published by the City’s Utilities Department. These wellhead treatment capital costs do not account for land acquisition costs. Therefore, separate land costs were developed for the Rinconada and Peers wells, which will require additional land to be purchased to locate wellhead treatment facilities. These land costs are also sourced from the City’s 2017 Water Integrated Resources Plan.

4.5.5 Capital Cost Estimate

The capital cost estimate for Scenario 4 is $90,300,000 (June 2018 dollars, Engineering News Record Construction Cost Index for San Francisco Index of 12,015). The capital cost includes:

- Advanced water purification facilities, including land costs for the Measure E property
- Transmission pipeline and pump station from advanced water purification facilities to injection wells sites
- Injection wells (5); land costs are not included as the wells are all sited at City-owned property and assumed to be installed in a manner that maintains the existing use of that property (e.g. in a vault in a parking lot, at the edge of a park, etc.).
- Wellhead treatment at the City’s existing extraction wells, including land costs

Cost estimates reflect a Class 5 estimate as defined by the Association for the Advancement of Cost Engineering International (AACE) Recommended Practice No. 56R-08. Detailed information on the capital cost estimate development will be available in the Northwest Recycled Water Strategic Plan Report (in development; expected 2019).

4.5.6 Operations and Maintenance Cost Estimate

Operations and maintenance (O&M) costs for Scenario 4 include the production, transmission, injection, and extraction costs. In addition to wellhead treatment, O&M costs for extraction wells also included the District’s groundwater pumping charge. This cost was developed based on projected District rates for groundwater pumping in the Study Area.

The O&M costs for Scenario 4, including the groundwater pumping charge, is $14,800,000 per year. Detailed information on the O&M cost estimate development will be available in the Northwest Recycled Water Strategic Plan Report (in development; expected 2019).

4.6 IPR Implementation Strategy

4.6.1 CEQA

The City will need to complete environmental reviews in compliance with the California Environmental Quality Act (CEQA) prior to constructing Scenario 4. This will include doing a preliminary review of potential impacts and determining the appropriate level of environmental documentation to prepare (e.g. Environmental Impact Report, Initial Study/Mitigated Negative
Declaration). As the project owner, it is anticipated that the City would be the lead agency for CEQA compliance.

If the City pursues Federal funding (e.g., from the US Bureau of Reclamation Title XVI program) or blended State/Federal financing (e.g., from the Clean Water State Revolving Fund loan program), additional environmental review would be needed to meet the requirements of these programs (e.g., CEQA Plus or the National Environmental Policy Act (NEPA)).

4.6.2 Governance

The District is the groundwater manager for the Santa Clara Subbasin. Whether the City or District is the project owner, an interagency agreement will be needed between the City and the District to facilitate an IPR project.

4.6.3 Permitting

A variety of permits would be required to construct and operate an IPR project. Many of these are typical for any construction project while some are specific to the IPR project concept.

Depending on the final pipeline alignment and design, permits for construction may include:

- 404 Permit for any fill of wetlands or waters of the United States – issued by US Army Corps of Engineers
- 401 Water Quality Certification (required for 404 permit) – issued by Regional Water Quality Control Board
- Notice of Intent for Coverage under Statewide Construction Stormwater Permit, including dewatering - issued by State Water Resources Control Board
- Streambed Alteration Agreement for pipeline crossings of creek – issued by California Department of Fish and Wildlife
- Encroachment permits for construction in roadways – issued by City of Palo Alto and possibly Santa Clara County
- Encroachment permit for construction under Highway 101 – issued by Caltrans

Permits required for operation of the IPR project after construction include:

- Water Reclamation Permit for groundwater recharge – issued by Regional Water Quality Control Board to allow the injection of purified recycled water into the groundwater basin
- Modification or new NPDES permit – issued by Regional Water Quality Control Board to account for the changes in the RWQCP discharge with the addition of the FAT process train
4.6.4 Regulatory Considerations

4.6.4.1 Division of Drinking Water Recharge with Recycled Water Requirements

Final regulations for use of recycled water for groundwater replenishment via surface and subsurface application are contained in Title 22, California Code of Regulations (CCR), Division 4, Environmental Health, Chapter 3, and Water Recycling Criteria:

- Article 5.1 Indirect Potable Reuse: Groundwater Replenishment – Surface Application.
- Article 5.2. Indirect Potable Reuse: Groundwater Replenishment – Subsurface Application.
- Amendments to Article 1 Definitions
- Amendments to Article 7 – Engineering Report and Operational Requirements.

The terms “Title 22” or “Title 22 Criteria,” as used in this report, refer to the Water Recycling Criteria for groundwater replenishment. The Title 22 Criteria establish the requirements applicable for obtaining approval and permitting of planned Groundwater Replenishment Reuse Projects (GRRPs). A summary of the Title 22 Criteria for subsurface application is presented in Table 4-8; criteria for surface application are not included as surface application was not considered for the City (see Section 4.1).

Table 4-8 June 2014 Final Groundwater Replenishment Regulations

| Source Control                                      | Must administer a comprehensive source control program to prevent undesirable chemicals from entering raw wastewater. The source control program must include: (1) an assessment of the fate of DDW and RWQCB-specified contaminants through the wastewater and recycled water treatment systems; (2) provisions for contaminant source investigations and contaminant monitoring that focus on DDW and RWQCB-specified contaminants; (3) an outreach program to industrial, commercial, and residential communities; and (4) an up-to-date inventory of contaminants.
<p>| Source Control Note: If the agency that administers the source control program is different than the agency producing or distributing the recycled water, DDW will require an agreement between the agencies to ensure the source control requirements are met. |
| Boundaries Restricting Construction of Drinking Water Wells | Project proponents must establish (1) a “zone of controlled potable well construction,” which represents the greatest of the horizontal and vertical distances reflecting the retention times required for pathogen control or for response retention time; and (2) a “secondary boundary” representing a zone of potential controlled potable well construction that may be beyond the zone of controlled potable well construction thereby requiring additional study. |
| Emergency Response Plan | A project sponsor must develop and be willing to implement a DDW-approved plan for an alternative source of potable water supply or treatment at a drinking water well if a GWR project causes the well to no longer be safe for drinking purposes. |
| Adequate Managerial and | A project sponsor must demonstrate that it possesses adequate managerial and technical capability to comply with the regulations. |</p>
<table>
<thead>
<tr>
<th>Subsurface Application</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technical Capability</strong></td>
<td><em>Note: DDW has indicated that project sponsors can use the drinking water Technical Managerial and Financial Assessment to demonstrate compliance with this requirement.</em></td>
</tr>
</tbody>
</table>
| **Pathogen Control** | - The treatment system must achieve a 12-log enteric virus reduction, a 10-log *Giardia* cyst reduction, and a 10-log *Cryptosporidium* oocyst reduction using at least 3 treatment barriers. 
- For each pathogen, a separate treatment process can only be credited up to a 6-log reduction and at least 3 processes must each achieve no less than 1.0-log reduction. 
- Retention time\(^1\) credit for virus of 1-log/month; must be validated by an added or intrinsic tracer approved by DDW. |
| **Nitrogen (N) Control** | Total N must be less than 10 mg/L as N in recycled water or recharge water before or after application. 
*Note: The nitrogen requirements will be more stringent based on the RWQCB Basin Plan groundwater objectives.* |
| **Regulated Chemicals Control** | **Recycled Water:** Must meet all primary MCLs, with the exception of nitrogen compounds; for disinfection byproducts, for surface application projects, compliance can be determined in the recycled water or the recharge water before or after surface application and for subsurface application projects in the recycled water or recharge water; for secondary MCLs, compliance can be determined in recycled water or recharge water. 
**Diluent Water:** Must meet primary and secondary MCLs based on upper limit if not historically used for recharge (except for secondary MCLs for color, turbidity, and odor). 
*Note: For surface spreading projects, compliance with other secondary MCLs for some types of diluent water could be an issue in establishing credit; it may be possible to receive approval for compliance after surface application under the Alternatives Section, which would address this issue.* |
| **Notification Level (NLs)** | **Recycled Water:** The regulations include actions to be taken if an NL is exceeded in the recycled water or recharge water after application (excluding the effects of dilution), including additional monitoring. 
**Diluent Water:** Must ensure that diluent water does not exceed an NL and have a plan in place on actions to be taken if exceed an NL for credit prior to the operation of a project, diluent water must meet NLs. 
*Note: With regard to implementation, DDW has noted that the evaluation of NLs can occur in recharge water (after soil aquifer treatment); and the regulatory language is purposefully flexible in determining credits as part of a monitoring plan proposed by the project sponsor. A chronic exceedance of an NL would be an issue for establishing diluent water credit, while an occasional exceedance would not be an issue.* |
| **Total Organic Carbon (TOC)** | Recycled water TOC = 0.5 mg/L. 
*Note: All recycled water must undergo advanced treatment – see advanced treatment criteria.* |
| **Initial Recycled Water Contribution (RWC)** | - To be determined by DDW (does not preclude starting at 100 percent). 
- The RWC averaging period is 120 months. 
*Note: A subsurface application project has the possibility of starting at a 100 percent RWC if approved by DDW.* |
<table>
<thead>
<tr>
<th>Increased RWC</th>
<th>Increases allowed if:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- The TOC 20-week average for prior 52 weeks = 0.5 mg/L.</td>
</tr>
<tr>
<td></td>
<td>- The increase is approved by DDW and authorized in the project permit.</td>
</tr>
</tbody>
</table>

| Advanced Treatment Criteria | Reverse Osmosis (RO): |
|                            | - Each membrane element must achieve a minimum sodium chloride (NaCl) rejection ≥ 99.0 percent and an average (nominal) NaCl rejection ≥ 99.2 percent using ASTM Method D4194-03 (2008), using the following substitute test conditions: (1) tests are operated at a recovery ≥ 15 percent; (2) NaCl rejection is based on 3 or more successive measurements; (3) influent pH between 6.5 and 8.0; and (4) influent NaCl concentration ≤ 2,000 mg/L. |
|                            | - During the 20 weeks of full-scale operation, the membrane produces a permeate having no more than 5 percent of the sample results having TOC > 0.25 mg/L based on weekly monitoring. |

<table>
<thead>
<tr>
<th>Advanced Oxidation Potential (AOP):</th>
<th>there are two options:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Option 1 - Conduct an occurrence study that identifies 9 indicators representing 9 functional groups, with 0.5-log removals for 7 of the indicators and 0.3-log removals for 2 of the indicators; establish at least one surrogate or operational parameter that reflects the removal of at least 5 of the 9 indicators (one of the surrogates must be monitored continuously); confirm the results using a study via challenge or spiking tests.</td>
</tr>
<tr>
<td></td>
<td>- Option 2 - Conduct testing that includes challenge or spiking tests to demonstrate that the AOP process removes 0.5-log of 1,4-dioxane; establish surrogate or operational parameters that reflect whether the 0.5-log reduction of 1,4-dioxane is attained, and one of the surrogates can be monitored continuously.</td>
</tr>
</tbody>
</table>

| Application of Advanced Treatment | Advance treatment must be applied to the full recycled water volume. |
| SAT Performance | None. |

| Response Retention Time (RRT) | - RRT is the time recycled water must be retained underground to identify treatment failure and implement actions so that inadequately treated recycled water does not enter a potable water system, including the plan to provide an alternative water supply or treatment. |
|                             | - The minimum RRT is 2 months, but must be justified by the project sponsor. |
|                             | - The RRT must be validated using an added tracer or a DDW approved intrinsic tracer. |

<table>
<thead>
<tr>
<th>Project Planning</th>
<th>Method used to estimate the retention time to the nearest downgradient drinking water well</th>
<th>Virus Log Reduction Credit per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tracer study using added tracer¹</td>
<td>1.0 log</td>
</tr>
<tr>
<td></td>
<td>Tracer study utilizing an intrinsic tracer¹</td>
<td>0.67 logs</td>
</tr>
<tr>
<td></td>
<td>Numerical modeling consisting of calibrated finite element or finite difference models using validated and verified computer codes used for simulating groundwater flow</td>
<td>0.50 logs</td>
</tr>
<tr>
<td></td>
<td>Analytical modeling using existing academically-accepted equations such as Darcy’s Law to estimate groundwater flow conditions based on simplifying aquifer assumptions</td>
<td>0.25 logs</td>
</tr>
</tbody>
</table>
### Subsurface Application

<table>
<thead>
<tr>
<th>Method</th>
<th>Per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracer study using added tracer</td>
<td>1 month</td>
</tr>
<tr>
<td>Tracer study utilizing an intrinsic tracer</td>
<td>0.67 months</td>
</tr>
<tr>
<td>Numerical modeling consisting of calibrated finite element or finite difference models using validated and verified computer codes used for simulating groundwater flow.</td>
<td>0.5 months</td>
</tr>
<tr>
<td>Analytical modeling using existing academically-accepted equations such as Darcy's Law to estimate groundwater flow conditions based on simplifying aquifer assumptions.</td>
<td>0.25 months</td>
</tr>
</tbody>
</table>

### Alternatives

Allowed for all provisions in the regulations if:
- The project sponsor has demonstrated that the alternative provides the same level of public health protection.
- The alternative has been approved by DDW.
- If required by DDW or RWQCB, the project sponsor will conduct a public hearing.
- An expert panel must review the alternative unless otherwise specified by DDW.

### Engineering Report

The project sponsor must submit an Engineering Report to DDW and RWQCB that indicates how a GWR project will comply with all regulations and includes a contingency plan to ensure that no untreated or inadequately treated water will be used. The report must be approved by DDW.

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1. The retention time represents the difference from when the water with the tracer is to when either 2 percent of the initially introduced tracer concentration has reached the downgradient monitoring point, or 10 percent of the peak tracer unit value is observed at the downgradient monitoring point. With DDW approval, an intrinsic tracer may be used in lieu of an added tracer with no more credit provided than 0.67-log per month.

### 4.6.4.2 Regional Water Quality Control Board Requirements

Waste Discharge Requirements/Water Recycling Requirements (WDRs/WRRs) issued by the RWQCB are required to implement applicable state water quality control policies and plans, including water quality objectives and implementation policies established in the Water Quality Control Plan for the San Francisco Bay Region (Basin Plan). The Basin Plan designates beneficial uses and groundwater quality objectives.

The Basin Plan states that the Santa Clara Groundwater Subbasin is designated for several beneficial uses including municipal and domestic water supply, industrial process and service water supply, and agricultural water supply. Permit limits for groundwater replenishment projects are set to ensure that groundwater does not contain concentrations of chemicals in amounts that adversely affect beneficial uses or degrade water quality. These water quality objectives will need to be met in addition to the requirements of the Title 22 subsurface application regulations.
4.6.4.3 State Water Resources Control Board Requirements

The California Water Code allows the SWRCB to adopt state policies for water quality control. There are two policies particularly relevant to groundwater replenishment projects: the Anti-Degradation Policy and the Recycled Water Policy.

4.6.4.3.1 Anti-Degradation Policy

The state’s anti-degradation Policy is captured in Resolution No. 68-16, which is titled “Statement of Policy with Respect to Maintaining High Water Quality in California.” It is also specifically cited in the Basin Plan. The first two sections of the Policy state that:

- Whenever the existing quality of water is better than the quality established in policies as of the date on which such policies become effective, such existing high quality water will be maintained until it has been demonstrated to the state that any change will be consistent with maximum benefit to the people of the state, will not unreasonably affect present and anticipated beneficial use of such water, and will not result in water quality less than that prescribed in the policies.
- Any activity which produces or may produce a waste or increased volume or concentration of waste and which discharges or proposes to discharge to existing high quality waters will be required to meet waste discharge requirements which will result in the best practicable treatment or control of the discharge necessary to ensure that (a) pollution or nuisance will not occur and (b) the highest water quality consistent with maximum benefit to the people of the State will be maintained.

4.6.4.3.2 Recycled Water Policy

The Recycled Water Policy was adopted by the SWRCB in February 2009. It was subsequently amended in 2013 with regard to monitoring constituents of emerging concern (CECs) for groundwater replenishment projects and is in the process of being updated again in 2018. The Recycled Water Policy was a critical step in creating uniformity in how RWQCBs were individually interpreting and implementing Resolution 68-16 for water recycling projects, including groundwater replenishment projects. The critical provisions in the Policy related to groundwater replenishment projects are:

- Salt and Nutrient Management Plans
- Groundwater Replenishment Provisions
- Anti-degradation and Assimilative Capacity
- Constituents of Emerging Concern

Compliance with these provisions would be documented in the Title 22 Engineering Report prepared for the Division of Drinking Water and RWQCB as described in Section 4.6.3.1.

4.6.4.4 Federal Requirements for Underground Injection Control

At this time there are no Federal permitting requirements for surface application groundwater replenishment projects; the U.S. EPA’s underground injection control (UIC) program does apply to injection wells, but has no permitting consequences for the Project. The UIC program has categorized injection wells into five classes, only one of which (Class V) applies to groundwater
replenishment projects. Under the existing Federal regulations, Class V injection wells are “authorized by rule” which means they do not require a Federal permit if they do not endanger underground sources of drinking water and comply with other UIC program requirements. For California, U.S. EPA Region 9 is the permitting administrator for Class V wells. Any injection project planned in California must meet the State Sources of Drinking Water Policy, which ensures protection of groundwater quality for drinking water supplies, and therefore a Federal permit would not be necessary. All Class V injection well owners in California are required to submit information to U.S. EPA Region 9 on the well for U.S. EPA’s inventory.
5  INDIRECT POTABLE REUSE FEASIBILITY EVALUATION AND IMPLEMENTATION STRATEGY FINDINGS

Four of the City pumping/IPR scenarios were found to be feasible or generally feasible with additional monitoring. The modeling indicated that 3,000 AFY of groundwater could be pumped by the City from multiple wells with no IPR without negative impacts. Up to 2,400 AFY could be pumped solely from the El Camino Park Well with no IPR without negative impacts; although additional saline intrusion monitoring well(s) are recommended. A total of 7,200 AFY of groundwater could be safely pumped by the City if 5,800 AFY of purified recycled water injection is implemented. A total of 5,900 AFY of City pumping would not result in negative impacts if a reduced level of injection (2,800 AFY) was implemented. Pumping 100% of the City 2020 water demand from groundwater would require more than 8,400 AFY of purified recycled water injection or other managed recharge in order to prevent negative impacts.

The selected Scenario 4, assuming 2,800 AFY of IPR and 5,900 AFY of City pumping was modeled to assess subsurface travel times of purified recycled water between injection wells and potable supply wells. The modeling found that subsurface residence times were sufficient to meet a 6-month RRT.

Estimated capital costs for Scenario 4 project facilities would be $90.3 million (2018 dollars) with an annual O&M cost of $14.8 million. Implementation strategy would follow established steps to prepare environmental documentation and permit approvals for construction, and would follow Title 22 regulations for subsurface application to obtain permission to operate an IPR project. Results for Scenario 4 will subsequently be incorporated into the final Northwest County Recycled Water Strategic Plan for comparison to other potential water reuse expansion opportunities.

6  DATA GAPS AND RECOMMENDATIONS

6.1  Recommended Actions Prior to Future Implementation of IPR

Five IPR/pumping scenarios were developed. Two scenarios (1 and 3) included pumping but no IPR, while three scenarios included both pumping and IPR. Four of the five scenarios were considered feasible or generally feasible with additional monitoring. Model scenario 4 (5,900 AFY of City pumping and 2,800 AFY of purified recycled water injection) was carried forward for further evaluation in the Northwest County Recycled Water Strategic Plan as described above.

- If the City moves forward with IPR, additional site-specific studies should be conducted to refine recharge scenarios to better assess recharge rates, number of injection wells, refined parcel injection well sites; identify required monitoring well locations; determine potential for dissolution of naturally-occurring constituents; and determine overall project costs.
- Once accurate injection well locations are identified, it is recommended that the District review other databases to more accurately define groundwater use category and status of nearby existing wells. Well owners should be contacted to confirm the uses for the pumped groundwater. If domestic potable supply wells are found to be located within...
the RRT, the injection wells could be re-located or negotiations undertaken to destroy the domestic well.

- Once accurate injection well locations are identified and RRT confirmed or modified, groundwater modeling should be conducted to verify adequate subsurface residence time to meet regulatory requirements.
- The City/District should begin a process of information exchange with the DDW and SFRWQCB regarding IPR plans.
- DWSAP reports should be conducted for each planned pumping well to assess potential local environmental contamination sources.
- It is recommended that if Scenario 3 – pumping the El Camino Park Well at 2,400 AFY with no IPR – is implemented, that a sentry well be installed between the well and the Bay or an existing well(s) be identified to monitor for potential saline water intrusion.
- If IPR is implemented, the City should resample for a complete suite of water quality constituents in all City well pumped prior to IPR implementation.
- A re-review of environmental site contamination should be redone prior to IPR implementation.
- Domestic productions wells potentially used for drinking water were identified in the IPR injection well area. Prior to implementing an IPR project, the District should verify the use of these wells. If well use cannot be verified, the City/District should contact well owners to verify well use. If domestic wells are being used for drinking water and are within the zone of controlled drinking water wells, negotiations should be conducted with the well owners to destroy the wells or eliminate drinking water use. Alternatively, IPR facilities could be relocated.
- All other recommendations presented in the following section could be implemented after IPR startup.

### 6.2 Recommended Actions for Improved Hydrogeologic Characterization

#### 6.2.1 Groundwater Levels and Flow

The analysis of groundwater levels and flow would benefit from recent water level data in San Mateo County and additional water level data throughout the Study Area.

Limited water level data within San Mateo County were available from the San Mateo Groundwater Basin Assessment (EKI et al., 2017) through March 2016. For this study, groundwater elevation contour maps were prepared for fall 2016 and spring 2017, and therefore, did not include water levels in San Mateo County. The District does not have jurisdiction in San Mateo County; nonetheless, local agencies recognize the need for collaboration. The San Mateo Plain Groundwater Basin Assessment (EKI et al., 2017) cited the need for San Mateo County to collect additional water level data throughout the San Mateo Plain Basin by forming partnerships with other entities within their subbasin. If the PMOD model is refined in the future, it is recommended that the District collaborate with San Mateo County to obtain any future water level data that they are able to collect in the vicinity of the
Study Area. A water level monitoring program in San Mateo County would also provide data for future model calibration.

Additional water level data are necessary throughout the Study Area if the City moves forward with IPR and increased pumping. This monitoring could begin after startup of an IPR project. The available water level data is primarily from shallow wells (screened less than or equal to 200 ft-bgs) within San Mateo County and deep wells (screened greater than 200 ft-bgs) within Santa Clara County. Therefore, data from deep monitoring wells are necessary in San Mateo County, especially in the northwestern region of the Study Area in Redwood City. The District would benefit from additional water level data from shallow wells in Santa Clara County, especially near the Bay in Mountain View. This could be achieved by either monitoring existing shallow monitoring wells or installing new shallow monitoring wells.

The District’s Eleanor multi-completion monitoring well (ELNR), located near the City’s Eleanor Pardee production well, provides near continuous water level data from four depth intervals. These water level data yield valuable information about water level trends and vertical gradients. It is recommended that the District or City consider installing additional multiple-depth completion monitoring wells if the City moves forward with increased pumping.

It is recommended that if Scenario 3 – pumping the El Camino Park Well at 2,400 AFY with no IPR – is implemented, that a sentry well be installed between the well and the Bay or an existing well(s) be identified to monitor for potential saline water intrusion.

6.2.2 Aquifer Parameters

The City has had pumping tests conducted, primarily to assess yields of its emergency supply wells. Only one of the tests included an observation well (Bonkowski, 2010a); however, the data included for the observation well (ELNR multi-completion well) with the report was not concurrent with the pumping/recovery test and no analysis was performed for the observation well. Pumping tests with observation wells are useful in defining the cone of depression of the pumping well, potential well interference with other wells, storativity values and, in the case of a multi-completion monitoring well such as ELNR, information on the connectivity of the shallow and deep aquifers. The City may want to consider conducting a pumping test while monitoring multiple observation wells to better define these characteristics. Pumping of City wells near the District’s Eleanor Park multi-completion wells provides an opportunity to observe the response of shallow and deep aquifers to City well pumping.

6.2.3 Ambient Groundwater Quality

The City’s Hale and Rinconada wells show increasing trends in TDS and chloride. The City may want to conduct a geochemical investigation (chloride ratios) similar to those conducted by Metzger (2002) to attempt to determine the source of the increases. The City may also want to consider increased monitoring for TDS and chloride in the City emergency supply wells nearest to the Bay (Eleanor Pardee, Hale, Main Library, and Rinconada).

Based on water quality data in the District database, which includes data from the DDW database, it appears that some data for City wells may not have been reported to DDW or not
made available by DDW. The City should confirm that DDW has all relevant data to allow potable supply production from the City wells.

If IPR is implemented, the City should resample for a complete suite of water quality constituents in all City well pumped prior to IPR implementation.

6.2.4 Environmental Release Site Contamination

Several significant environmental release site contamination plumes exist in Palo Alto, some in close proximity to City emergency supply wells. The following actions are recommended prior to increased pumping:

- Comprehensive DWSAP reports documenting all potentially contaminating activities near the City wells and well vulnerability to contamination should be prepared for all City wells.
- If the Fernando, Matadero and Peers Park wells are pumped for water supply, a program of frequent testing (more frequent than required by DDW) for environmental contaminants should be developed and implemented. In addition, the City may want to review ongoing monitoring and remedial activities at groundwater contamination sites located near these wells.
- The City should engage with environmental site regulators to inform them of the potential for groundwater use by the City and support complete site remediation.
- The Fernando well should be videoed to determine location of wells screens.
- Due to their proximity to known contaminant plumes, the Fernando and Matadero wells should not be pumped at capacity or for long periods of time. The City may want to consider replacing the Fernando and Matadero wells. If used for short-term emergency supply, increased water quality monitoring is recommended.
- It is recommended that potential recharge project locations avoid known contaminant plume areas. No contamination plumes were identified other than those shown in Figure 3-59. A re-review of environmental site contamination should be redone prior to IPR implementation.

6.2.5 Shallow Saline Water in the Baylands and Seawater Level Rise

Due hyper-saline water in the Baylands area, the City may want to consider increased monitoring for TDS and chloride in the City emergency supply wells nearest to the Bay after any IPR/pumping project is implemented.

Future operation of recharge and groundwater production facilities may need to account for higher groundwater levels and changing water quality conditions. Groundwater monitoring is recommended to track both water levels and inorganic water quality in City wells.

6.2.6 Subsidence

Because of the potential economic cost of additional land subsidence, land subsidence monitoring should be a part of any future plans for increased pumping by the City.
• The existing District municipal survey benchmarks should continue to be monitored for changes in land surface elevations on a regular basis.

• Identify an existing or install a new monitoring well that could be added to the District subsidence index wells in the Palo Alto area. The well would need to be completed below the primary clays layers and located close to a well with a sufficiently long groundwater level history. An analysis would be required to define a subsidence threshold for the well comparable to the Geoscience (1991) Study.

• The use of InSAR to monitor land subsidence in the Study Area could be used in conjunction with an agency, such as the USGS (under their Local Agency Partnership program), that has experience with this method of monitoring.

A mitigation plan would need to be developed to determine what action would be required to mitigate potential subsidence should any of the thresholds be exceeded. These monitoring activities would need to be coordinated with the District and other local agencies.
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Figure 3-1
Hydrogeologic Study Area
Figure 3-2
Contours of Average Annual Rainfall

Legend
- Average Annual Precipitation (inches)
- Hydrogeologic Study Area
- Uplands Watershed Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

Source: Rantz, 1971
Figure 3-4
Land Use

Legend
- Hydrogeologic Study Area
- Lake
- Uplands Watershed Area
- Natural - Riparian
- Natural - Grassland
- Natural - Brush
- Natural - Trees
- Rural Residential
- Urban Commercial
- Urban Industrial
- Irrigated Turf
- Urban Residential
- Urban Residential - Lush
- Urban Vacant
Figure 3-6
Geologic Map

Figure 3-8
Bedrock Elevation

Legend
- Oliver Bedrock Elevation (NGVD 29)
- Hydrogeologic Study Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

NGVD 29: National Geodetic Vertical Datum 1929
Modified from: Oliver, 1980; Wentworth, et al., 2015
Faulting in Recharge Area

Legend

- Faults
- Hydrogeologic Study Area
- City of Palo Alto
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin
Figure 3-10
San Francisquito Cone Alluvial Fan and City Wells
Figure 3-11
Locations of Wells with Data for Cross Sections

Legend
- Well with Geophysical Log
- Well with Lithology and Construction
- Well with Lithology
- Well with Construction
- Hydrogeologic Study Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin
Figure 3-12
Cross Section Location Map

Legend
- Well with Lithology and Construction
- Well with Lithology
- Well with Construction
- Well with Geophysical Log
- Fault
- Reverse or Thrust Fault
- Section Line
- Hydrogeologic Study Area
- COE Contaminant Plume
- Hewlett Packard Contaminant Plume
- Hillview Porter Contaminant Plume
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

Explanation included on Figure 3-7
Geologic map and explanation from Brabb et al., 2001

Scale in Feet

Copyright © 2014 Esri
Notes:
Cross section only extended to depth of available information.

Scale in Feet
30 x Vertical Exaggeration
Notes:
Cross section only extended to depth of available information.

Legend:
- Short Normal
- Geophysical Log
- Well Screen
- Total Drilled Depth
- Fault
- Sand and Gravel
- Silt and Clay
- QTsc - Santa Clara Formation
- Tlrd - Ladera Sandstone Formation
- Tm - Monterey Formation
- Tpm - Page Mill Basalt Formation
- Tw - Whiskey Hill Formation
- fg - Greenstone
- Undifferentiated Bedrock
- Water
- No Information

Figure 3-14
Cross Section B-B'
Figure 3-15
Cross Section C-C'

Legend
- Short Normal
- Geophysical Log
- Sand and Gravel
- Silt and Clay
- QTsc - Santa Clara Formation
- Tlad - Ladera Sandstone Formation
- Tm - Monterey Formation
- Tpm - Page Mill Basalt Formation
- Tm - Monterey Formation
- fg - Greenstone
- Undifferentiated Bedrock
- Water
- No Information

Notes:
Cross section only extended to depth of available information.

Figure 3-16
Cross Section D-D'
Cross section only extended to depth of available information.


Legend:
- Short Normal
- Geophysical Log
- Well Screen
- Total Drilled Depth
- Fault
- Sand and Gravel
- Silt and Clay
- QTsc - Santa Clara Formation
- Tlad - Ladera Sandstone Formation
- Tm - Monterey Formation
- Tpm - Page Mill Basalt Formation
- Tw - Whiskey Hill Formation
- fg - Greenstone
- Undifferentiated Bedrock
- Water
- No Information

Notes:
- Figure 3-17

Path: T:\Projects\Palo Alto IPR - 79001\GIS\Maps\GAR IPR Feas and Impl Strategy\Fig 3-17 - Cross Section E-E'.mxd
Cross section only extended to depth of available information.


Figure 3-18
Cross Section F-F’
Figure 3-19
Cross Section G-G'
Figure 3-20
Cross Section H-H'
Figure 3-21
Cross Section I-I'

Legend
- Short Normal
- Geophysical Log
- Well Screen
- Total Drilled Depth
- Fault
- Sand and Gravel
- Silt and Clay
- Qtsc - Santa Clara Formation
- Tlad - Ladera Sandstone Formation
- Tm - Monterey Formation
- Tpm - Page Mill Basalt Formation
- Tw - Whiskey Hill Formation
- fg - Greenstone
- Undifferentiated Bedrock
- Water
- No Information

Notes:
Cross section only extended to depth of available information.
Cross section only extended to depth of available information.

Figure 3-23
Aquifer Hydraulic Conductivities

Legend
Test Type
- Average shallow alluvial or Santa Clara formation aquifer value at site
- Pumping test
- Well log specific capacity

Hydraulic Conductivity, K (ft/day)
- <10
- 10-49
- 50-99
- >=100

Legend
- Creek
- Hydrogeologic Study Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin
Figure 3-24
Aquifer Transmissivities

Legend
Test Type

- Pumping test
- Well log specific capacity

Transmissivity, T (ft²/day)
- <500
- 500-999
- 1,000-9,999
- >=10,000

Creek

Hydrogeologic Study Area

Santa Clara Subbasin Confined Area

Alluvial Aquifer Recharge Area

Santa Clara Formation Recharge Area

San Mateo Plain Subbasin

San Francisco Bay

Mountain View

Los Altos Hills

Palo Alto

Atherton

Menlo Park

Los Altos

Redwood City

East Palo Alto

San Francisquito Creek

Scale in Feet

0 5,000 10,000
Figure 3-27
Spring 2017
Shallow Groundwater Elevation Contours

Legend
- Well
- Groundwater Elevation Contour (NGVD 29)
- Stream
- Hydrogeologic Study Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

NGVD 29 - National Geodetic Vertical Datum 1929
Figure 3-28
Spring 2017
Deep Groundwater Elevation Contours

Legend
- Well
- Groundwater Elevation Contour (NGVD 29)
- Stream
- Hydrogeologic Study Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

NGVD 29 - National Geodetic Vertical Datum 1929
Figure 3-29
Map of Well Locations With Hydrographs
Figure 3-31
April 1962 Deep Groundwater Elevation Contours

Legend
- General Groundwater Flow Direction
- Wells used to determine water level contours
- Water Level Elevation Contour (ft NGVD 29)
- Approximate Water Level Elevation Contour (ft NGVD 29)
- Streams
- Hydrogeologic Study Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

NGVD 29: National Geodetic Vertical Datum 1929
Contours adapted from Sokol, 1964
Figure 3-32
Groundwater Level Hydrographs Showing Selected Long-Term Trends

TD - total depth
ft-bgs - feet below ground surface
ft-msl - feet mean sea level
NGVD 29 - National Geodetic Vertical Datum 1929
Note: ground surface elevation is 62.25 ft-mls

NGVD 29 - National Geodetic Vertical Datum 1929
acre-ft/yr - acre feet per year

Notes: Annual production through 2002 from Carollo (2003).
Annual production not available for Eleanor Pardee, El Camino Park, and Library Wells.
Eleanor (ELNR) Multi-Completion Monitoring Well

<table>
<thead>
<tr>
<th>Well</th>
<th>Screen Depth (ft)</th>
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</thead>
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<tr>
<td>ELNR4</td>
<td>180-200</td>
</tr>
<tr>
<td>ELNR3</td>
<td>540-560</td>
</tr>
<tr>
<td>ELNR2</td>
<td>720-740</td>
</tr>
<tr>
<td>ELNR1</td>
<td>830-850</td>
</tr>
<tr>
<td>Ground Surface</td>
<td></td>
</tr>
</tbody>
</table>

TD - total depth
ft-bgs - feet below ground surface
ft-msl - feet mean sea level
NGVD 29 - National Geodetic Vertical Datum 1929

06S02W05F001/002/003

- Groundwater elevation above ground surface in deep well

05S02W35R001/002

- Groundwater elevation above ground surface in deep well

Figure 3-34
Groundwater Level Hydrographs, Shallow/Deep Well Clusters
Figure 3-35
Artesian Conditions
Figure 3-36
Historical (1934-1967) Subsidence

Legend
- Extensiometer
- Subsidence Index Well
- Historical (1934-1967) Subsidence (in feet)
- Hydrogeologic Study Area
- Streams
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

Modified From: Poland and Ireland, 1988; Metzger and Fio, 1997
Figure 3-37
Water Purveyor Service Areas
Figure 3.39: Cumulative Departure of Annual Precipitation

- **San Jose:**
  - 1900-2014 Average: 14.14 inches
  - 1985-2014 Average: 14.54 inches

- **Redwood City:**
  - 1924-2015 Average: 18.69 inches
  - 1985-2014 Average: 18.06 inches
Figure 3-41
Low Flows in Four Gaged Small Creeks

11166000 Matadero Creek

11162800 Redwood Creek

11162900 Sharon Creek

11163500 Los Trancos Creek

cfs - cubic feet per second

TODD GROUNDWATER
Figure 3-42
Water Supply Pumping, 2005-2014

Legend

Irrigation (acre-feet per year)
- 0 - 8
- 9 - 56
- 57 - 187
- 188 - 344
- 345 - 664

Domestic/Irrigation (acre-feet per year)
- 0 - 8
- 9 - 56
- 57 - 187
- 188 - 344
- 345 - 664

Municipal/Industrial (acre-feet per year)
- 0 - 8
- 9 - 56
- 57 - 187
- 188 - 344
- 345 - 664

Hydrogeologic Study Area
Santa Clara Subbasin Confined Area
Alluvial Aquifer Recharge Area
Santa Clara Formation Recharge Area
San Mateo Plain Subbasin
Figure 3-44
Sewer Flow Hydrographs

<table>
<thead>
<tr>
<th>Water Year</th>
<th>Palo Alto</th>
<th>Sunnyvale</th>
<th>Redwood City</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base Flow Threshold (cfs)</td>
<td>April-Nov Infiltration (AF)</td>
<td>Base Flow Threshold (cfs)</td>
<td>April-Nov Infiltration (AF)</td>
</tr>
<tr>
<td>2010</td>
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<td>1556.901685</td>
<td>18</td>
<td>724</td>
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<td>2011</td>
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<td>2013</td>
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<td>260</td>
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<td>2014</td>
<td>25</td>
<td>516</td>
<td>17.5</td>
<td>379</td>
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<tr>
<td>2015</td>
<td>24</td>
<td>614</td>
<td>16</td>
<td>401</td>
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<tr>
<td>Average</td>
<td>--</td>
<td>1,094</td>
<td>--</td>
<td>452</td>
</tr>
<tr>
<td>Percent in PAIPR Study Area</td>
<td>100%</td>
<td>50%</td>
<td>90%</td>
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</tr>
<tr>
<td>Volume in PAIPR Study Area</td>
<td>1,094</td>
<td>226</td>
<td>177</td>
<td>1,498</td>
</tr>
</tbody>
</table>

Abbreviations: cfs = cubic feet per second; AF = acre-feet; GW = groundwater; Apr = April; Nov = November
Notes
Groundwater infiltration equals base flow above the indicated threshold during April-November. Annual infiltration estimated to be at least 33 percent greater.
Figure 3-46
Contemporary Average Annual Inflows and Outflows

ET - evapotranspiration
Legend

Most Recent TDS (mg/L)
Shallow Wells (screened <200 ft bgs)
- >3000
- 2000-2999
- 1000-1999
- 500-999
- <500

Creek
Hydrogeologic Study Area
Santa Clara Subbasin Confined Area
Vallejo
Maiha Aquifer Recharge Area
ESF
Santa Clara Formation Recharge Area
San Mateo Plain Subbasin

Shallow Wells: Screened less than 200 feet below ground surface (ft-bgs) mg/L: milligrams per liter

Figure 3-48
TDS in Shallow Groundwater
Shallow Wells: Screened less than 200 feet below ground surface (ft-bgs) mg/L- milligrams per liter

Legend
Shallow Wells (screened <200 ft bgs)
- >500
- 250-499
- 150-249
- 50-149
- <50

Creek
Hydrogeologic Study Area
Santa Clara Subbasin Confined Area
Palo Alto Aquifer Recharge Area
Santa Clara Formation Recharge Area
San Mateo Plain Subbasin

Figure 3-50
Chloride in Shallow Groundwater
Figure 3-51
Extent of Elevated Chloride in Shallow Aquifer

Legend
- Streams
- 1945 Chloride Contour (100 mg/L)
- Maximum known extent of intrusion circa 1980
- 2015 Chloride Contour (100 mg/L)
- Hydrogeologic Study Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

mg/L: milligrams per liter
Modified from: District, 2016
Legend
Most Recent Iron (ug/L)
Deep Wells (screened >=200 ft bgs)

- >=600
- 300-599
- 150-299
- 0.01-149
- ND

Creek
Hydrogeologic Study Area
BGS: Santa Clara Subbasin Confined Area
BAS: Mawai Aquifer Recharge Area
BFG: Santa Clara Formation Recharge Area
San Mateo Plain Subbasin

Deep Wells: Screened greater than 200 feet below ground surface (ft-bgs)
ug/L: micrograms per liter

Figure 3-52
Iron in Deep Groundwater
Figure 3-53  Iron in Shallow Groundwater

Legend
Most Recent Iron (µg/L)
Shallow Wells (screened <200 ft bgs)
- >500
- 300-599
- 150-299
- 0.01-149
- ND

Creek
Hydrogeologic Study Area
Santa Clara Subbasin Confined Area
Mawal Aquifer Recharge Area
BSF
Santa Clara Formation Recharge Area
San Mateo Plain Subbasin

Shallow Wells: Screened less than 200 feet below ground surface (ft-bgs)
µg/L: micrograms per liter

Legend
Iron in Shallow Groundwater
Most Recent Iron (µg/L)
Shallow Wells (screened <200 ft bgs)
- >500
- 300-599
- 150-299
- 0.01-149
- ND

Creek
Hydrogeologic Study Area
Santa Clara Subbasin Confined Area
Mawal Aquifer Recharge Area
BSF
Santa Clara Formation Recharge Area
San Mateo Plain Subbasin

Shallow Wells: Screened less than 200 feet below ground surface (ft-bgs)
µg/L: micrograms per liter

Figure 3-53  Iron in Shallow Groundwater
**Legend**

Most Recent Manganese (µg/L)

- **ND**
- 0.01-24.99
- 25-49.99
- 50-99.99
- >100

Deep Wells (screened >=200 ft bgs)

- Creek
- Santa Clara Subbasin Confined Area
- Matábal Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

Deep Wells: Screened greater than 200 feet below ground surface (ft-bgs)

ug/L: micrograms per liter

Figure 3-54

Manganese in Deep Groundwater
Legend

Shallow Wells (screened <200 ft)
- 100
- 50-99.99
- 25-49.99
- 0.01-24.99
- ND

Creek
Hydrogeologic Study Area
Santa Clara Subbasin Confined Area
Sanitary Aquifer Recharge Area
Santa Clara Formation Recharge Area
San Mateo Plain Subbasin

Figure 3-55
Manganese in Shallow Groundwater

Shallow Wells: Screened less than 200 feet below ground surface (ft-bgs)
µg/L: micrograms per liter
Deep Wells: Screened greater than 200 feet below ground surface (ft-bgs)
mg/L: milligrams per liter

Most Recent Nitrate as NO₃ (mg/L) Deep Wells (screened >=200 ft bgs)

Legend
- Hydrogeologic Study Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

Figure 3-56
Nitrate (as NO₃) in Deep Groundwater
Most Recent Nitrate as NO₃ (mg/L) Shallow Wells (screened <200 ft bgs)

- >60
- 45-59
- 30-44
- 15-29
- <15

Legend
- Shallow Wells- Screened less than 200 feet below ground surface (ft-bgs)
- mg/L - milligrams per liter

Eleanor (ELNR) Multicompletion Monitoring Well (Shallow and Deep)
- 05S03W36P002 (830-850 ft-bgs)
- 05S03W36P003 (720-740 ft-bgs)
- 05S03W36P004 (540-560 ft-bgs)
- 05S03W36P005 (180-200 ft-bgs)

Secondary MCL

Legend
- Hydrogeologic Study Area
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

Figure 3-57 Nitrate (as NO₃) in Shallow Groundwater
Figure 3-58
Open and Closed Contaminated Sites
Figure 3-59
Major Solvent Plumes

Legend
- Palo Alto Emergency Supply Well
- Open Lust Cleanup Site
- Open DTSC Cleanup Site
- Open RWQCB Cleanup Program Site

Lateral Extent, Sampling Date of Plume
Depth to Base of Plume (ft-bgs) with >5 ppb VOC
- \(<=50 \text{ ft-bgs}\)
- 50.1-75 ft-bgs
- 75.1-100 ft-bgs
- 100.1-125 ft-bgs
- >125 ft-bgs

*plume depth unknown; maximum investigated depth is 40 feet

Source:
DTSC (Department of Toxic Substances Control) Envirostore Website
LUST: Leaking Underground Storage Tanks
RWQCB: Regional Water Quality Control Board
Cross Section A-A'
Focused on Hillview Porter Plume

Cross Section B-B'
Focused on COE Plume

Cross Section J-J'-
Focused on COE Plume

Legend
- Well Sanitary Seal
- Well Gravel Pack
- Well Screen
- COE Contaminant Plume
- Hewlett Packard Contaminant Plume
- Hillview Porter Contaminant Plume
- Fault
- Sand and Gravel
- Silt and Clay
- QTsc - Santa Clara Formation
- Tlad - Ladera Sandstone Formation
- Tw - Whiskey Hill Formation
- Undifferentiated Bedrock

Notes:

Scale in Feet
30 x Vertical Exaggeration

Figure 3-60
Cross Sections Showing Contaminant Plumes and Nearby Well Completions
Annual Storage Change (Acre-Feet) vs. Annual Pumping (Acre-Feet)

Mid-1960s

2010s

1920s

1950s

Likely range of sustainable pumping in San Francisquito Cone

Figure 3-61
Yield Based on Practical Rate of Withdrawal
Figure 4-2a
Potential Model Injection Well Locations

Legend
- Preliminary Injection Well Locations
- CityWells
- Model Grid
- Target Injection Well Area
- City of Palo Alto
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin

- Scale in Feet
- Palo Alto
- East Palo Alto
- Menlo Park
- Stanford
- Hale
- El Camino Park
- Peers Park
- Main Library
- Rinconada
- Eleanor Bardee
- Fernando
- Matadero
- El Camino Park
- Park
- Rinconada
- Eleanor Bardee
- Fernando
- Matadero
Figure 4-2b
Modeled Injection Well Locations for Scenario 2
Figure 4-2c
Modeled Injection Well Locations for Scenario 4

Legend
- Preliminary Injection Well Locations
- CityWells
- Model Grid
- Target Injection Well Area
- City of Palo Alto
- Santa Clara Subbasin Confined Area
- Alluvial Aquifer Recharge Area
- Santa Clara Formation Recharge Area
- San Mateo Plain Subbasin
Figure 4-2b
Modeled Injection Well Locations for Scenario 2
A. Cross Section of Model Grid along Row 53

B. Cross Section of Model Grid along Column 45

Legend
- Drain
- Fault
- Creek
- General head boundary

Figure 4-4
Cross Sections Showing Model Layer Elevations
Kh - horizontal hydraulic conductivity in feet per day
Kv - vertical hydraulic conductivity in feet per day
So - specific storativity (dimensionless)
Sy - specific yield (dimensionless)
Note: Green ovals enclose data points omitted from statistical analysis.

ft NGVD 29 - feet National Vertical Datum of 1929
Figure 4-6b
Water-Level Hydrographs at Calibration Wells

Note: Green ovals enclose data points omitted from statistical analysis.
ft NGVD - feet National Vertical Datum of 1929
Note: Green ovals enclose data points omitted from statistical analysis.
ft NGVD - feet National Vertical Datum of 1929
Figure 4-6d
Water-Level Hydrographs at Calibration Wells

Note: Green ovals enclose data points omitted from statistical analysis.
ft NGVD - feet National Vertical Datum of 1929
Note: Green ovals enclose data points omitted from statistical analysis.

ft NGVD - feet National Vertical Datum of 1929
Figure 4-6f
Water-Level Hydrographs at Calibration Wells

Note: Green ovals enclose data points omitted from statistical analysis.
ft NGVD - feet National Vertical Datum of 1929
Note: Green ovals enclose data points omitted from statistical analysis.
ft NGVD - feet National Vertical Datum of 1929
Simulated Water Level (ft NGVD29)

Measured Water Level (ft NGVD29)

Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6

Number of observations: 3,359
Range of observations (ft): 129
Mean residual (ft): -0.3
Standard deviation of residuals (ft): 11.8
Scaled root-mean-squared error (% of range): 9.2

ft NGVD - feet National Vertical Datum of 1929

Figure 4-7
Scatterplot of Simulated versus Measured Water Levels
Figure 4-8
Hypothetical Drought Water-Level Scenarios

Drought A

Drought B

Drought C
Figure 4-9a
Hydrographs of Simulated Water Levels for Scenario 1

Note: Hydrologic conditions from 1985 to 2014 projected to simulate future 2015 to 2044 scenario impacts ft NGVD 29 - feet National Vertical Datum of 1929
Figure 4-9b
Hydrographs of Simulated Water Levels for Scenario 2

Note: Hydrologic conditions from 1985 to 2014 projected to simulate future 2015 to 2044 scenario impacts ft NGVD 29 - feet National Vertical Datum of 1929
Figure 4-9c
Hydrographs of Simulated Water Levels for Scenario 3

Note: Hydrologic conditions from 1985 to 2014 projected to simulate future 2015 to 2044 scenario impacts.
ft NGVD 29 - feet National Vertical Datum of 1929.
Figure 4-9d
Hydrographs of Simulated Water Levels for Scenario 4

Note: Hydrologic conditions from 1985 to 2014 projected to simulate future 2015 to 2044 scenario impacts ft NGVD 29 - feet National Vertical Datum of 1929
Figure 4-9e
Hydrographs of Simulated Water Levels for Scenario 5

Note: Hydrologic conditions from 1985 to 2014 projected to simulate future 2015 to 2044 scenario impacts ft NGVD 29 - feet National Vertical Datum of 1929
Figure 4-10a
Simulated Water Levels
Hydrologic Year 1992
Future Baseline
Scenario 1
September 1992 Hydrology
Model Layer 3

Legend
- Contour of Simulated Groundwater Elevation, ft NGVD29
- Major Production Well
- Study Area
- Historical Marshland

ft NGVD 29 - feet National Vertical Datum of 1929
PAPMWC - Palo Alto Park Mutual Water Company

Figure 4-10b
Simulated Water Levels
Hydrologic Year 1992
Scenario 1
Figure 4-10c
Simulated Water Levels
Hydrologic Year 1992
Scenario 2

Legend
- Contour of Simulated Groundwater Elevation, ft NGVD29
- Active Injection Well
- Major Production Well
- Study Area
- Historical Marshland

San Francisco Bay
Palo Alto Park Mutual Water Company (PAPMWC)

Active Injection Wells
Major Production Wells
Study Area
Historical Marshland
Scenario 3
September 1992 Hydrology
Model Layer 3

Legend
- Contour of Simulated Groundwater Elevation, ft NGVD29
- Major Production Well
- Study Area
- Historical Marshland

ft NGVD 29 - feet National Vertical Datum of 1929
PAPMWC - Palo Alto Park Mutual Water Company

Figure 4-10d
Simulated Water Levels
Hydrologic Year 1992
Scenario 3
Legend
- Contour of Simulated Groundwater Elevation, ft NGVD29
- Active Injection Well
- Major Production Well
- Study Area
- Historical Marshland

ft NGVD 29 - feet National Vertical Datum of 1929
PAPMWC - Palo Alto Park Mutual Water Company

Scenario 4
September 1992 Hydrology Model Layer 3

Figure 4-10e
Simulated Water Levels
Hydrologic Year 1992
Scenario 4

Scale in Miles
Figure 4-10f
Simulated Water Levels
Hydrologic Year 1992
Scenario 5
Figure 4-11b
Simulated Depth to Water
1992 Hydrologic Year
Scenario 1

Legend
- Major Production Well
- Contour of Simulated Depth to Water
  (feet)
- Study Area
- Historical Marshland

PAPMWC - Palo Alto Park Mutual Water Company

Scenario 1
September 1992 Hydrology
Model Layer 1
Figure 4-11c
Simulated Depth to Water
Hydrologic Year 1992
Scenario 2

Legend
- Major Production Well
- Active Injection Well
- Contour of Simulated Depth to Water (feet)
- Study Area
- Historical Marshland

Scenarios 2
September 1992 Hydrology
Model Layer 1

PAPMWC - Palo Alto Park Mutual Water Company
Scenario 3
September 1992 Hydrology
Model Layer 1

Legend
● Major Production Well
Contour of Simulated Depth to Water (feet)
Study Area
Historical Marshland

PAPMWC - Palo Alto Park Mutual Water Company

Figure 4-11d
Simulated Depth to Water Hydrologic Year 1992 Scenario 3
Figure 4-11e
Simulated Depth to Water
Hydrologic Year 1992
Scenario 4

Legend
- Major Production Well
- Active Injection Well
- Contour of Simulated Depth to Water (feet)
- Study Area
- Historical Marshland

PAPMWC - Palo Alto Park Mutual Water Company
Figure 4-11f
Simulated Depth to Water
Hydrologic Year 1992
Scenario 5

Legend
- Major Production Well
- Active Injection Well
- Contour of Simulated Depth to Water (feet)
- Study Area
- Historical Marshland

PAPMWC - Palo Alto Park Mutual Water Company
San Francisquito Creek Flow Profiles

Scenario 1

Maximum Reduction in Flow = 0.5 cfs

Scenario 2

Maximum Reduction in Flow = 0.5 cfs

cfs - cubic feet per second

Figure 4-12a
San Francisquito Flow Depletion under Scenario 1 and 2
San Francisquito Creek Flow Profiles

Scenario 3

Maximum Reduction in Flow = 0.5 cfs

Scenario 4

Maximum Reduction in Flow = 0.6 cfs

cfs - cubic feet per second

Figure 4-12b
San Francisquito Flow Depletion under Scenario 3 and 4
San Francisquito Creek Flow Profiles

Scenario 5

Maximum Reduction in Flow = 0.7 cfs

Reach

Flow (cfs)

cfs - cubic feet per second

Figure 4-12c
San Francisquito Flow Depletion under Scenario 5
Figure 4-13
Simulated Movement of Particles Releases at IPR Wells under Scenario 4

Legend
- Injection Well Location
- Particle Coordinates
- Particle Locations at 1 Year
- Municipal Wells
- Groundwater Elevation Sept. 1992
- Particle Paths
- Stream

Bold numbers indicate years of travel at downgradient end of particle trace cluster.
Figure 4-14 Scenario 4 Facilities
City of Palo Alto
Task 3 - IPR Feasibility Evaluation

Legend

- IPR Wells
- Scenario 4 Alignment
- Existing Pipeline

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the user's sole risk.

Project #: 0018-032.00
Appendix A – Pumping Test Analysis
An aquifer pumping test was conducted by Stanford University using Stanford Well 4R as the pumping well. The well was pumped continuously for 4 days at 650 gallons per minute. Transducers and data loggers were installed in Stanford Wells 1, 2, 3R, and 5, and in a Palo Alto-owned multicompletion monitoring well with 3 screened intervals located in El Camino Park near the City’s El Camino Park production well.
WELL 4R PUMPING/RECOVERY
Data Set: T:\Projects\Palo Alto IPR - 79001\Data and Docs\Stanford\4R Pumping_Recovery.aqt
Date: 07/24/17
Time: 15:48:41

PROJECT INFORMATION
Company: Todd Groundwater
Client: City of Palo Alto
Project: 79001
Location: Stanford
Test Well: Stanford 4R
Test Date: Oct 2011

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Name</td>
<td>X (ft)</td>
</tr>
<tr>
<td>Well 4R</td>
<td>6072524</td>
</tr>
</tbody>
</table>

SOLUTION
Aquifer Model: Confined
Solution Method: Theis

\[
T = 1.637E+4 \text{ ft}^2/\text{day} \\
Kz/Kr = 0.1 \\
S = 0.04532 \\
b = 700. \text{ ft}
\]
WELL TEST ANALYSIS

Data Set: T:\Projects\Palo Alto IPR - 79001\Data and Docs\Stanford\4R with 2 observation wells.aqt
Date: 07/24/17  Time: 15:52:01

PROJECT INFORMATION

Company: Todd Groundwater
Client: City of Palo Alto
Project: 79001
Location: Stanford
Test Well: Stanford 4R
Test Date: Oct 2011

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>X (ft)</th>
<th>Y (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4R Pumping Well</td>
<td>6072524</td>
<td>1984191</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observation Wells</th>
<th>X (ft)</th>
<th>Y (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well 2 Observation Well</td>
<td>6073230</td>
<td>1986141</td>
</tr>
<tr>
<td>Observation Well 1</td>
<td>6074407</td>
<td>1986747</td>
</tr>
</tbody>
</table>

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

\[ T = 1.324 \times 10^4 \text{ ft}^2/\text{day} \]

\[ K_z/K_r = 0.1 \]

\[ S = 0.0007275 \]

\[ b = 700 \text{ ft} \]
WELL TEST ANALYSIS

Data Set: T:\Projects\Palo Alto IPR - 79001\Data and Docs\Stanford\4R with observation wells.aqt
Date: 07/24/17 Time: 15:57:22

PROJECT INFORMATION
Company: Todd Groundwater
Client: City of Palo Alto
Project: 79001
Location: Stanford
Test Well: Stanford 4R
Test Date: Oct 2011

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Name</td>
<td>X (ft)</td>
</tr>
<tr>
<td>4R Pumping Well</td>
<td>6072524</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

\( T = 1.262E+4 \text{ ft}^2/\text{day} \)
\( K_z/K_r = 0.1 \)

\( S = 0.0006716 \)
\( b = 700. \text{ ft} \)
24-HR RECOVERY
Data Set: T:\...\24hr recovery_Theis Confined solution.aqt
Date: 07/24/17 Time: 16:21:37

PROJECT INFORMATION
Company: Todd Groundwater
Client: City of Palo Alto
Project: 79001
Location: Palo Alto
Test Well: El Camino Park
Test Date: 2/14/13

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Name</td>
<td>X (ft)</td>
</tr>
<tr>
<td>El Camino Park</td>
<td>0</td>
</tr>
</tbody>
</table>

SOLUTION
Aquifer Model: Confined
Solution Method: Theis
T = 4.213E+4 ft²/day
Kz/Kr = 0.1
S = 1.069
b = 500. ft