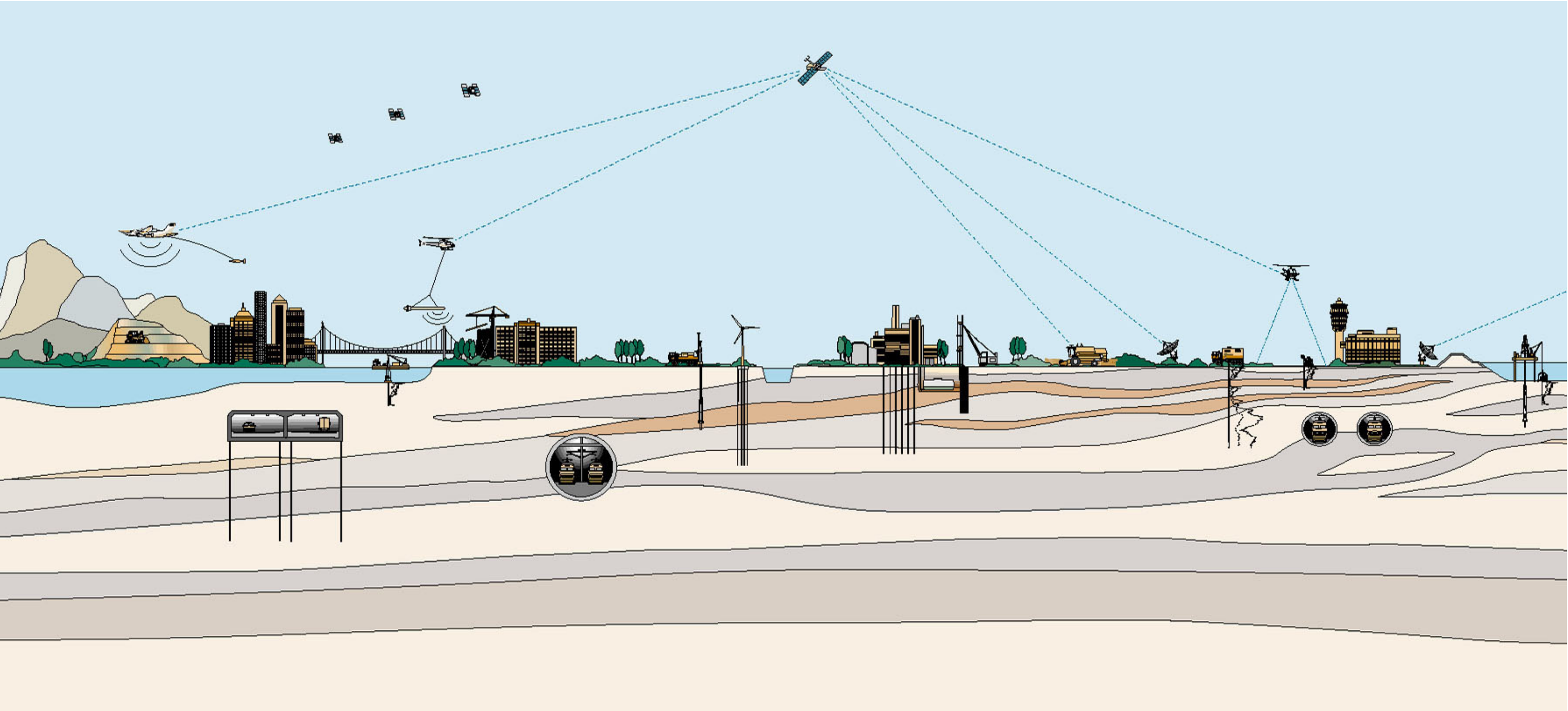
FUGRO CONSULTANTS, INC.

SANTA MARIA GROUNDWATER BASIN CHARACTERIZATION AND PLANNING ACTIVITIES STUDY
FINAL REPORT

Prepared for:
San Luis Obispo County Flood Control and Water Conservation District

December 2015
Fugro Job No. 04.62130111



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December 30, 2015
Project No. 04.62130111

San Luis Obispo County Flood Control and Water Conservation District
County Government Center
1050 Monterey Street, Room 207
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Attention: Mr. Raymond Dienzo, P.E.
Program Manager/Project Engineer

Subject: Final Report
Santa Maria Groundwater Basin Characterization and Planning Activities Study

Fugro Consultants, Inc., in collaboration with GEI Consultants, Inc., is pleased to submit this report for a groundwater basin characterization study of the Santa Maria Groundwater Basin. The objectives of the overall study are to compile previous studies and data, develop a lithologic database and prepare geologic cross-sections, perform and analyze pumping tests, and evaluate several key hydrogeologic issues for the study area.

It is important to understand that this Report is primarily intended to be a basis for future studies related to a Salt and Nutrient Management Plan and the development of a numerical groundwater model. It includes the results of our efforts to compile existing data, gather new data, and organize and prepare key lithologic and aquifer parameter databases for use in the future studies.

If you have any questions, please do not hesitate to contact us.

Sincerely,

FUGRO CONSULTANTS, INC.

Paul A. Sorensen

Paul Sorensen, PG, CHg
Principal Hydrogeologist

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1.0 INTRODUCTION

This Final Report was prepared to document work performed by Fugro Consultants, Inc. and GEI Consultants, Inc. on behalf of the County of San Luis Obispo Flood Control and Water Conservation District (SLOFCWCD or District) for the Santa Maria Groundwater Basin Characterization and Planning Activities project (study).

1.1 PURPOSE OF STUDY

The SLOCFCWCD is leading the development of the San Luis Obispo Regional Integrated Regional Water Management (IRWM) Plan Update. The Santa Maria Groundwater Basin Characterization and Planning Activities (SMBC) project is being funded by an IRWM planning grant. The project was intended to be included as a component of the IRWM Plan update; however, the respective schedules did not allow for results of this study to be fully incorporated into the IRWM Plan update.

The District conducted the SMBC study with the intention to provide a foundation for future development of a Salt and Nutrient Management Plan and development of a numerical groundwater flow model. This report provides a summary of available hydrogeologic studies and databases that have previously been developed for the study area. An extensive effort was devoted to requesting and obtaining available California Department of Water Resources (DWR) Well Completion Reports (well logs) and associated data (e.g., geophysical logs, pumping test data) from the various water purveyors within the SMBC study area and a formal well log request was submitted to the DWR. The databases developed from this effort are included in this report.

This report also documents groundwater basin characterization efforts that included preparation of thirteen geologic cross-sections, performance of six pumping tests, assessment of areas for supplemental recharge, and evaluation of offshore aquifers and seawater intrusion. The selection of four wells for installation of permanent pressure transducers to continuously monitor and record groundwater levels is also described in this report.

1.2 BACKGROUND

The Santa Maria Groundwater Basin (SMGB or Basin) provides an essential component of the water supply for the southern portion of San Luis Obispo County. The Basin went through an adjudication process beginning in 1997, with a resulting 2008 Court Judgment that divided it into three different management areas: Northern Cities Management Area (NCMA), Nipomo Mesa Management Area (NMMA), and Santa Maria Valley Management Area (SMVMA). The Northern Cities Management Area and Nipomo Mesa Management Area are included in this study, whereas the Santa Maria Valley Management Area lies outside the boundaries of this study (Plate 1). However, limited data (e.g., well logs) were compiled for SMVMA and are included in this study to assess the hydrogeologic relationships between Nipomo Mesa and Santa Maria Valley management areas.

2.0 PREVIOUS HYDROGEOLOGIC STUDIES

2.1 INTRODUCTION

A number of previous geologic and hydrogeologic studies have been conducted within the SMBC study area and the adjacent Santa Maria Valley Management Area (Plate 1). In addition, there are ongoing data collection programs within the study area. Several previous studies and ongoing data collection programs are identified and summarized in the following sections of this report.

A bibliography of many previous hydrogeologic studies and reports conducted within and adjacent to the SMBC study area is included as Appendix A. These studies were obtained from Fugro's in-house files, internet research, and from NMMA Technical Group members. Authors of the various studies include the Management Area technical groups, DWR, United States Geological Survey (USGS), United States Department of Agriculture (USDA), and various consultants. Brief summaries of the major studies are included in the following paragraphs. More detailed technical summaries are provided in Appendix A for previous studies that are particularly relevant to subtasks completed during this study.

2.2 MANAGEMENT AREA TECHNICAL GROUP REPORTS

The NMMA Technical Group includes several hydrogeologic consultants who have been retained by most of the water purveying entities within the Management Area, along with staff from one water purveying entity. They compile and analyze hydrogeologic data collected by each water purveying entity, and data obtained from other sources (e.g., water demand, groundwater levels, and groundwater quality), and prepare an annual report summarizing groundwater conditions. The available annual reports are listed in Appendix A. Each annual report provides a summary of water demand, climatic, surface water, and groundwater conditions over the previous year, and updates groundwater hydrographs, groundwater contour maps, and groundwater quality plots, with the latest data collected over the most recent year. Important changes in groundwater conditions are noted, along with conclusions and recommendations. Technical recommendations included development of a supplemental water supply, evaluation of subsurface inflow and outflow, installation of transducers to measure water levels, improved methods of estimating/calculating groundwater pumping, and more detailed delineation of aquifers and aquitards.

The NCMA Technical Group is comprised primarily of staff from the various water purveying entities within the Management Area. They have elected to retain outside consultants to collect and compile hydrogeologic data (e.g., water demand, groundwater levels, groundwater quality) each year and prepare an annual report summarizing groundwater conditions. The available annual reports are listed in Appendix A. Each annual report provides a summary of water demand, climatic, surface water, and groundwater conditions over the past year, including groundwater level contour maps, groundwater hydrographs, groundwater chemistry plots, and other graphics to illustrate the latest hydrogeologic data collected over the previous year. Important changes in groundwater conditions are noted, along with an overall assessment of current groundwater conditions.

2.3 DWR REPORTS

Five reports covering all or portions of the SMBC study area were prepared by DWR between 1958 and 2002. The first report was county-wide (DWR, 1958), two reports focused on seawater intrusion (DWR, 1970; DWR, 1975), another report addressed the Arroyo Grande Area (DWR, 1979), and most recently, (DWR 2002), was a broad and comprehensive hydrogeologic study of the Tri-Cities Mesa–Arroyo Grande Plain, Nipomo Mesa, and northern Santa Maria Valley areas.

The DWR (1958) report encompassed all of San Luis Obispo County; therefore, only a small portion of the report applies to the SMBC study area. The report was prepared at a time of rapidly increasing population and irrigated agriculture in San Luis Obispo County. It described the overall geology and hydrology (climate, surface water, soils, groundwater) of several hydrologic units, including the Arroyo Grande Subunit (which includes most of NCMA and NMMA) of the Coastal Unit. Within the Arroyo Grande Subunit, the Arroyo Grande Basin comprised an area of 12,500 acres recharged by stream infiltration, precipitation, irrigation return flow and subsurface inflow (from Nipomo Mesa). The Nipomo Mesa (as defined by DWR) was comprised of 16,000 acres recharged primarily by percolation of precipitation. Groundwater discharge from both Arroyo Grande Basin and Nipomo Mesa was through pumping, subsurface outflow, and evapotranspiration. It was noted that Pismo Beach had obtained water from the Oceano area of Arroyo Grande Basin since 1929. A more detailed summary of hydrogeologic data and analyses from DWR (1958) is presented in Appendix A.

The DWR (1970) report covers sea water intrusion specific to the Pismo-Guadalupe area. A DWR field investigation conducted in the mid to late 1960’s included the drilling and installation of multi-level completion monitoring wells along the coast (including POO-1 through POO-5: denoted as well log numbers 90021, 90022, 90015, 90016, and 40-1518 in this report), and subsequent monitoring of water levels and quality in these and other wells. The report conclusions stated the elevated chloride levels in shallow coastal groundwater (less than 100 feet below ground surface) were not attributed to lateral sea water intrusion, but were more likely related to other factors such as the natural salinity of the geologic environment, salt concentration from evapotranspiration, and/or downward percolation of sea water through channels during high tide. A more detailed summary of hydrogeologic data and analyses from DWR (1970) is presented in Appendix A. Several DWR multi-level completion monitoring wells installed for the 1970 study were incorporated into the current NCMA and NMMA monitoring programs as described later in this report.

The DWR (1975) report covers the entire state of California with respect to sea water intrusion in coastal basins. The Arroyo Grande Basin was discussed briefly, and the report stated there was no evidence of sea water intrusion and the hydraulic gradient was generally seaward. The report noted that chloride concentrations ranged from 100 to 200 parts per million (ppm) in shallow coastal groundwater, but that elevated chloride appeared to be related to a non-sea water source. However, it was noted that increased pumping could create a threat of sea water intrusion. The report also noted that basin geologic conditions near and off-shore are conducive to an extensive accumulation of fresh water in off-shore aquifers.

The DWR (1979) report described water supply and demand, hydrogeologic conditions (formations, structure, water levels, storage, quality), and potential for sea water intrusion in the

Arroyo Grande area. The study included drilling of two additional deep, multi-completion monitoring wells (PSBO-1 and PSBO-2; denoted as well log numbers 90019 and 90020 in this report). The report stated that the on-shore aquifer appeared to extend some distance off-shore, although the details of stratigraphic relationships off-shore remain uncertain. Between the mid-1960s and mid-1970s groundwater storage in the NCMA area was estimated to have increased by 5,800 acre-feet (AF), whereas groundwater storage in Nipomo Mesa area declined by 22,000 AF. The authors also stated that no evidence of sea water intrusion was found based on the previously constructed series of coastal piezometers. Additional details regarding hydrogeologic data and analyses from DWR (1979) are presented in Appendix A.

The DWR (2002) report was comprehensive in addressing geology, water demand and supply, hydrogeology (groundwater levels, flow, storage, aquifer parameters, etc.), water quality, and the water budget. The study area of the report was bounded by the San Luis Obispo–Santa Barbara County line on the south, the Wilmar Avenue Fault on the east, the City of Pismo Beach on the north, and the Pacific Ocean on the west. The overall study area was subdivided into the Tri-Cities Mesa–Arroyo Grande Plain (approximately equal to the area of NCMA), Nipomo Mesa (approximately equal to NMMA), and the northern portion of the Santa Maria Valley. The total inflows were about equal to outflows for the study period in the Tri-Cities Mesa–Arroyo Grande Plain area, but outflows in Nipomo Mesa were estimated to exceed inflows by 1,400 acre-feet per year (AFY). The study defined a “dependable yield” for each area as follows: 4,000 to 5,600 AFY for Tri-Cities Mesa–Arroyo Grande Plain and 4,800 to 6,000 AFY for Nipomo Mesa. The report also provides extensive discussion of the geology of the groundwater basin and includes geologic formation descriptions, cross-sections, and evaluation of fault offsets and stratigraphic relationships. A more detailed summary of hydrogeologic data and analyses from DWR (2002) is presented in Appendix A.

2.4 USGS REPORTS

Two foundational reports for the region prepared by USGS in the 1950s were Woodring and Bramlette (1950) and Worts (1951). The 1950 report described the geology and paleontology of the region, and the 1951 report addressed groundwater resources in the Santa Maria Valley. Neither report is directly focused on the Nipomo Mesa or Northern Cities areas, but they provided important geologic formation descriptions and other information/data that are relevant to the SMBC study area. Other USGS reports summarized below are Miller and Evenson (1966) and Hall (1973).

The Woodring and Bramlette (1950) study is strictly geologic in nature (does not address groundwater), but provides detailed descriptions of the color, texture, and sequence of lithologic units that comprise the primary geologic formations in the SMBC study area (e.g., Paso Robles Formation, Careaga sandstone, Sisquoc Formation). This geologic information was useful for interpretation of lithologic descriptions from well logs (i.e., assigning each layer to a particular geologic formation) in the SMBC study area, and preparation of geologic cross-sections for this report. A more detailed summary of hydrogeologic data and analyses from USGS (Woodring and Bramlette, 1950) is presented in Appendix A.

The Worts (1951) report describes how regional geologic conditions (sequence of formations, geologic structure) relate to the occurrence of groundwater in the Santa Maria Valley. Again, the report is not focused on the SMBC study area, but provided some useful information nonetheless since Nipomo Mesa borders Santa Maria Valley on the north. In addition, the hydrogeologic implications of geologic structure and stratigraphic relationships are discussed in detail. The report also included a detailed water budget, and assessment of perennial yield for the Santa Maria Valley. A more detailed summary of hydrogeologic data and analyses from USGS (Worts, 1951) is presented in Appendix A.

Miller and Evenson (1966) prepared a brief report to update the Worts (1951) report. Specifically, the 1966 report updated the perennial yield analysis, and evaluated the magnitude of overdraft in Santa Maria Valley and its effects on groundwater storage and seawater intrusion. The northern end of the study area for the 1966 report did include the southern end of Nipomo Mesa, but the main focus of the report is in the Santa Maria Valley. Overall, the 1966 report did not include any additional information specifically related to Nipomo Mesa (beyond that already included in the 1951 report).

Hall (1973) is a USGS Map Sheet showing the geology of the Arroyo Grande 15 minute quadrangle. It covers nearly the entire study area – just missing the southeastern-most portion of Nipomo Mesa. The map shows the surficial geology of the study area, which largely consists of older (vegetated) dune sand throughout Nipomo and Tri-Cities mesas and alluvium in the Arroyo Grande Creek and Los Berros Creek valleys. Younger dune sands are present in the western portion of the study area, and a thin layer of Paso Robles Formation is mapped between Los Berros Creek and Highway 101. A few very small and isolated knobs of Jurassic Franciscan and Tertiary tuffs are present in the area surrounding Los Berros Creek valley. The Map Sheet also provides detailed descriptions of the various geologic formations.

2.5 CONSULTANTS REPORTS

Consultant reports summarized below include Chipping (1994), Hoover and Associates (1985), Cleath and Associates (1996), Luhdorff & Scalmanini Consulting Engineers (LSCE, 2000), Papadopulos & Associates (2004), Fugro/Cleath (2005), Todd (2007), Fugro West (2008a), and Cleath-Harris Geologists (2013). The Chipping report addressed the Black Lake Canyon area of Nipomo Mesa, the Hoover report covered Arroyo Grande Creek stream flow percolation, the Cleath study was for the Woodlands development, the LSCE study covered Santa Maria Valley and southern Nipomo Mesa, the Papadopulos report involved the Nipomo Mesa area, and the Todd report was a water balance for the NCMA. Three additional reports by Fugro and Cleath that document individual well pumping tests are also summarized below.

The Chipping (1994) report was funded by the Land Conservancy of San Luis Obispo County to evaluate the hydrogeology of Black Lake Canyon and assess management options relative to canyon wetlands. The report stated that the canyon geology is comprised of older dune sands that overlie Paso Robles Formation. Chipping stated that their review of groundwater level data indicated canyon water tables had been declining at a rate of 0.37 feet/year since 1975 (as of early 1990's). It was determined that the upper part of the canyon is underlain by a clay layer that supports a perched (upper) aquifer, where water levels appeared to be rising (possibly due to changed land use in the area). The upper aquifer is not present in the central to western portion of the canyon where the canyon floor has cut through the perching clay layer. The groundwater table in the lower canyon had been falling since the 1970's and the springs had reportedly dried up – thereby causing wetland degradation. The report included various recommendations to enhance wetlands within the canyon. Additional details regarding hydrogeologic data and analyses from Chipping (1994) are presented in Appendix A.

Cleath and Associates (1996) conducted a hydrogeologic study for the Woodlands development. The primary purpose of the study was to evaluate potential groundwater impacts from proposed development of four new production wells for the property. The report includes a detailed evaluation of geologic formations present in the area (e.g., cross-sections, structure contour maps), groundwater conditions (levels, quality, etc.), and development of a groundwater model. Potential impacts to groundwater levels, storage, and quality from the proposed development were analyzed and quantified in the report. A more detailed summary of hydrogeologic data and analyses from Cleath (1996) is presented in Appendix A.

A copy of the Hoover (1985) report was unable to be obtained for this study. However, the Hoover report results were briefly described by Todd Engineers (2007). Todd reported that the Hoover study included collection of synoptic stream flow measurements in June 1984 on Los Berros Creek. A flow of 3 cubic feet per second (cfs) was observed at the upstream USGS gauge station, while no flow was observed in the stream at 22nd Street Bridge. Thus, Hoover concluded 3 cfs of stream flow percolated into the subsurface between the two locations.

Luhdorff & Scalmanini Consulting Engineers (2000) developed a numerical groundwater flow model (MODFLOW) for the Santa Maria Valley basin. The primary focus of the LSCE study area was the Santa Maria Valley, but it also encompassed the southern portion of Nipomo Mesa (the area south of Black Lake Canyon). The purpose of the model was to assess basin conditions, evaluate potential future projects and land use, and to assess the perennial yield of the basin. The basin was determined to have a perennial yield of 124,000 AFY and was not in overdraft. Additional details regarding hydrogeologic data and analyses from LSCE (2000) are presented in Appendix A.

The Papadopulos and Associates (2004) Resource Capacity report for Nipomo Mesa was largely a review of previous studies by DWR and various consultants, which had varying conclusions regarding sustainable groundwater pumping. The purpose of the study was to evaluate the existing studies and make recommendations regarding groundwater management and the appropriate level of severity designation by the County. Papadopulos concluded that the Nipomo Mesa was in overdraft (based on reinterpretation of data presented in the DWR 2002 report), and corresponded to the County designation of Level of Severity III (i.e., existing water demand equals or exceeds the dependable supply). Despite these findings, Papadopulos concluded there was not imminent danger of sea water intrusion. Additional details from Papadopulos (2004) are included in Appendix A.

The Fugro/Cleath (2005) report was an evaluation of Pismo Beach Wells 9 and 10 and the surrounding geology to evaluate the continuity of the aquifer, to evaluate if separate perennial yield calculations were required, and to calculate individual production capacities. It was determined that the aquifer tapped by Wells 9 and 10 is in hydraulic communication with the Tri-Cities Mesa/Arroyo Grande Plain portion of Santa Maria Groundwater Basin; thus, a separate perennial yield calculation was not needed. Pumping tests were conducted on Wells 9 and 10 and well capacities on both wells were calculated to be 150 to 175 gallons per minute (gpm). Additional details of the Fugro/Cleath (2005) study are described in the pumping test section of this report.

The Todd Engineers (2007) report was a water balance for the NCMA that quantified the various recharge and discharge components. The recharge components included rainfall percolation, stream flow infiltration, irrigation recharge, subsurface inflow, and infiltration from storm water basins. The main components of recharge were determined to be stream flow infiltration (2,015 AFY), rainfall percolation (1,615 AFY), and subsurface inflow (3,470 AFY). The total average annual inflows of 8,500 AFY were balanced by 8,500 AFY of average annual outflows comprised of urban pumping (2,270 AFY), agricultural pumping (3,300 AFY), and subsurface outflow (2,960 AFY). The Todd report also included some field work to collect synoptic stream flow measurements and better quantify stream flow infiltration on Los Berros Creek. Additional technical details from the Todd (2007) report are included in Appendix A.

Fugro West (2008a) completed a study for the Nipomo Community Services District (NCSD) Southland Waste Water Treatment Facility (WWTF) that included pumping tests and near-site groundwater modeling. The overall purpose of the study was to evaluate feasibility of extracting treated discharge water from the groundwater mound beneath the percolation basins for subsequent disposal at other sites. In general, the preliminary investigation indicated the proposed concept appeared to be viable, but that additional testing was needed and the project design concept needed to be further developed. The results of pumping tests included in the Fugro (2008a) study are described in more detail in the pumping test section (Section 5) of this report.

The Cleath-Harris Geologists (2013) report documented their evaluation of the current production capacity of City of Pismo Beach Well 5 and Well 23. The wells were reported to have had a decrease in pumping capacity in 2009. The assessment included collection of existing data on well construction, pumping tests, production, and water levels; performance of pumping tests that included measurement of sand production and field water quality parameters; and determination of specific capacity and current production capacity. Additional details of the Cleath-Harris (2013) report are provided in the pumping test section (Section 5) of this report.

2.6 US DEPARTMENT OF AGRICULTURE

The United States Department of Agriculture (USDA) Soil Conservation Service conducted a soil survey of the coastal part of San Luis Obispo County in 1984. The General Soil Map shows the Nipomo Mesa covered by Oceano–Dune land–Baywood Unit, which is comprised of excessively drained fine sand and sand deposits (windblown deposits). The NCMA area is comprised of the Oceano-Dune land-Baywood Unit in the Tri-Cities Mesa area, and the Salinas-Marimel soil in the Arroyo Grande Plain area (somewhat poorly drained to well drained silty clay loam and sandy clay loam soils on alluvial plains). The soil survey contains maps that delineate and describe soil types in more detail over the SMBC study area. A more detailed summary of the distribution of soil types from USDA (1984) is presented in Section 10.0 of this report, the Evaluation of Areas for Enhanced Recharge.

2.7 ENVIRONMENTAL IMPACT REPORTS

Environmental Impact Reports (EIRs) have been prepared for various proposed projects in the SMBC study area. Several of these EIRs are listed in Appendix A. Our review indicates that, in general, EIR documents do not provide significant hydrogeologic information and data that would be useful for the SMBC study. However, some EIRs are based on separate hydrogeologic technical reports that provide good sources of information and data, and are incorporated in relevant sections of this report. For example, the Cleath (1996) report summarized above was used to support the Woodlands Development EIR, and pumping test data are from the Cleath study are incorporated in the pumping test section (Section 5) of this report.

2.8 APPLICATION OF PREVIOUS STUDIES TO SMBC HYDROGEOLOGIC EVALUATIONS

Previous studies provide a significant amount of information and data that were applicable to work conducted for the SMBC study documented in this report. In particular, the development of geologic cross-sections described in Section 7.0 of this report included interpretation of geologic formation contacts between Older Dune Sand, Paso Robles Formation, and Careaga sandstone. Several previous studies (e.g., Woodring and Bramlette (1950); Worts (1951); Cleath (1996), LSCE (2000); DWR (2002); NMMA and NCMA annual reports) provide discussions, data, and cross-sections that describe/illustrate geologic structure, geologic formation characteristics, and geologic interpretations that were considered in preparation of the geologic cross-sections developed for this study.

Evaluation of stream flow infiltration in Section 9.0 was facilitated by past studies conducted by Hoover (1985), Todd (2007), and USDA (1984). The seawater intrusion analysis in Section 11.0 utilized previous studies by DWR (2002), Papadopulos (2004), and NCMA annual reports (GEI Consultants (2011, 2012, 2013), Fugro (2014)). The discussion of recharge areas included a review of USDA (1984) and Todd Engineers (2007). In addition, the geologic cross-sections developed for this study provided input to assessment of seawater intrusion, stream flow infiltration, and enhanced recharge areas described in subsequent sections of this report.

3.0 ONGOING HYDROGEOLOGIC DATA COLLECTION PROGRAMS

The NMMA Technical Group (TG) coordinates an ongoing groundwater monitoring and data collection program that focuses on groundwater levels, groundwater quality, and water demand. The data are compiled and databases updated each year during preparation of the NMMA Annual Report. The current monitoring program involves compilation of semi-annual (April and October) groundwater level measurements from approximately 80 to 100 wells collected by the SLOCFCWCD, NCSD, Phillips 66, Woodlands, Golden State Water Company (GSWC), Cypress Ridge Golf Course, and the USGS. Nine key wells have been designated in the NMMA to evaluate longer term water level trends. The most recent review of the key wells water level trends indicated a general decline in key wells groundwater levels since 2000, and development of a persistent pumping depression in the west-central part of Nipomo Mesa.

NMMA water quality data are collected from a number of sources including the California Department of Public Health (DPH), the Regional Water Quality Control Board (RWQCB), the State Water Resources Control Board (SWRCB), the California Department of Toxic Substances and Control (DTSC), the USGS, and other groundwater production monitoring data. The NMMA groundwater quality database contains data for about 200 wells that contain records for at least one sampling event. Longer term trends for electrical conductivity, total dissolved solids (TDS), and chloride show relatively stable concentrations in the coastal area. For inland areas, chloride and TDS concentrations have generally remained stable over the long term, and nitrate concentrations for most wells in the primary aquifers (except for two potable water supply wells) remained below the Maximum Contaminant Level (MCL).

Similar to NMMA, the focus of the NCMA monitoring program is on groundwater levels, groundwater quality, and water demand. The data are published each year in the NCMA Annual Report. The current monitoring program involves measurement of groundwater levels in 38 wells by the SLOCFCWCD and NCMA agencies in the NCMA on a semi-annual basis (April and October), and quarterly water level measurements in coastal sentry wells by NCMA.

Pressure transducers were installed in the deep wells at three of the sentry well sites (24B03, 30F03, and 30N02) in February 2011 to measure potential short-term water level fluctuations due to pumping, tidal fluctuation, or other factors. A similar pressure transducer was installed in well 24B01 at the North Beach Campground in March 2011 to gain insight into tidal fluctuation effects on groundwater levels, as well as tidal and other events (such as storm surge) that may influence salinity in shallow formations. To understand water level fluctuation and water quality variation in the area between the NCMA and NMMA, another pressure transducer was installed in well 32C03 in April 2012.

NCMA groundwater quality monitoring includes quarterly sampling from five sentry wells (which include several monitoring wells described in the DWR 1970 report) and District MW #3 (32C03), and compilation of DPH data for municipal wells. In general, coastal monitoring well TDS, chloride, and nitrate concentrations have remained stable or improved (decreased) compared to 2008-2010 levels. Water quality data from DPH for municipal wells continued to show generally stable concentrations over the long term.

4.0 DEVELOPMENT OF WELL LOG DATABASE

4.1 INTRODUCTION

As part of this study, the Fugro/GEI Team obtained a relatively complete set of well logs, plotted individual well locations, and developed an extensive well log database based on review of previous studies and data, requests to SMBC study area stakeholders, and a well log request to DWR. Well log information/data was obtained from the following sources: DWR; California State Division of Oil, Gas, and Geothermal Resources (DOGGR); NCSD; GSWC; Woodlands; Rural Water Company (RWC); Cypress Ridge; City of Arroyo Grande; County of San Luis Obispo Public Works (limited due to confidentiality agreements); City of Grover Beach; Oceano Community Services District; and City of Pismo Beach.

The well log data obtained was quite voluminous (due to the 3,781 pages of well logs and data obtained from DWR. There are typically one to four pages per well depending on whether or not the one-page DWR form was accompanied by a separate well location map(s) and/or a driller’s own standard forms for recording lithology and well construction details. Ultimately, the vast majority of well logs that could be located relatively accurately were plotted in Google Earth and those well locations subsequently converted to a GIS well location map (Plate 2). In some cases of multiple wells on single or adjacent small properties, only a representative well was plotted and included in the database. The lithologies described on well logs that could be located were given lithologic symbols (Appendix B) and entered into an Excel spreadsheet database (Appendix C). The well log database is organized by well log number, top of lithologic layer, bottom of lithologic layer, lithologic material symbol, supplemental lithologic descriptions, color, presence of shells, and the township/range/section (T/R/S) assigned by DWR. Copies of the confidential DWR well logs are provided in Appendix D (on CD, presented separately). Additional details of the lithology database are described below.

4.2 WELL LOG NUMBER AND LAYER TOP/BOTTOM

The vast majority of the well logs have a unique well log number that was preassigned to each well log form. However, a small number of logs were recorded on non-standard (or very old) DWR well log forms, in which case they have no preassigned well log number. Due to the need in the SMBC study for a unique identifying number for each well log for input to the database, these logs were assigned numbers beginning with 90001 and running through 90025. The Excel database column labeled “Point ID” contains the well log number.

Each lithologic description on a well log has a depth interval recorded by the driller. In the database, separate columns are provided for the top and bottom of each layer. The bottom depth of a given layer is the top depth of the layer just below it. The Excel database columns labeled “Depth” and “Layer Bottom” contain the depth (in feet) to the top and bottom of each layer, respectively.

4.3 LITHOLOGIC SYMBOLS

A system for lithologic symbols was developed based on the United Soil Classification System (USCS). Additional lithologic symbols were added to be more descriptive of the individual lithologic descriptions. For example, the USCS symbol for sandy clay is CL, whereas the system used in this study designates that lithologic description as CL-S. Similarly, poorly sorted gravel with sand (or Sandy Gravel) is GP in the USCS, whereas the symbol assigned in this study for that lithology is GP-S. A complete listing of lithologic symbols used in this study is provided in Appendix B. The goal of the lithologic symbol system used in this study is to provide as much lithologic descriptive information as possible in a short-hand format. The Excel database column labeled “Material Graphic” contains the lithologic symbol for each layer.

There are some important aspects of our interpretation of lithologic descriptions for this study that should be noted. For example, the term “Shale Gravel” is commonly used by drillers for layers in the Paso Robles Formation. Based on Fugro field experience with drilling in the Paso Robles Formation, the material that drillers describe as Shale Gravel typically includes a clay component. Thus, the symbol GPGC was assigned to Shale Gravel. If clay is emphasized in the description, such as clay and shale gravel, the assigned symbol is CL-GPGC. Similarly, if sand is emphasized, such as sand and shale gravel, the assigned symbol is SP-GPGC. Also worth noting is that many driller lithologic descriptions use the word “and”; for example, sand and clay or gravel and sand. In these cases, the first term is assumed to represent the primary lithology and the second term is the minor lithology. Thus, these two lithologic descriptions are assumed equivalent to clayey sand and sandy gravel, respectively.

4.4 SUPPLEMENTAL LITHOLOGIC DESCRIPTIONS

This column in the database is commonly blank if there is nothing additional to note, and the assigned lithologic symbol readily identifies the components of the lithologic description. However, driller lithologic descriptions may include additional details not indicated by the symbol alone (e.g., “hard” clay, “cemented” sand), in which case the drillers descriptive comment is noted in this column. In addition, the lithologic symbol system does not readily handle mixed descriptions that include both unconsolidated and consolidated rock names (e.g., Clay and Shale, Sand and Shale). In these cases, the first unit mentioned is the basis for assigning a lithologic symbol (e.g., CL or SP), but the full description is given in this column. Also, a notation of bedrock or consolidated rock (e.g., Shale, Sandstone) is specifically noted in this column. The column heading in the Excel database is "Material Description."

4.5 COLOR AND SHELLS

The notations with regard to color and presence of sea shells were deemed important in trying to distinguish geologic formations (e.g., Older Dune Sand, Paso Robles Formation, Careaga sandstone), and for lithologic correlations on cross-sections. Therefore, separate columns are included in the database to denote these characteristics for each lithologic unit. If no color is given, this column is blank. The presence of sea shells is noted with an X; otherwise this column is left blank. It should be noted that drillers may not always notice or make note of shells even if they are present; thus the absence of an X in the shells column does not necessarily mean no shells are present. These columns in the Excel database are labeled "Color" and "Seashells."

4.6 ASSIGNED T/R/S

The notations in the column for township, range, and section are based on designations and organization of the well logs by DWR and/or the County Environmental Health Department. The particular assignment of T/R/S on a given log by either the driller (and subsequently adopted by DWR) or as assigned by DWR, may or may not accurately reflect where the particular well is located. However, this column contains the T/R/S assigned by DWR to make tracking the hard copy of the log easier (because we have retained the organization of the well logs by DWR assigned T/R/S). This column in the database is labeled "TRS."

4.7 DEVELOPMENT OF GEOLOGIC CROSS-SECTIONS

The lithology database described above is provided in Appendix C, and was used to develop thirteen geologic cross-sections across the study area (presented in Section 7.0). The lithology database and extensive compilation of hard copy well logs (Appendix D) completed for this study will facilitate any number of additional cross-sections that others may wish to develop in the future beyond those prepared as part of the SMBC study.

5.0 PUMPING TEST AND SPECIFIC CAPACITY DATABASE

5.1 INTRODUCTION

Pumping test and specific capacity data were included in our data request from SMBC study area stakeholders. In addition, in the course of reviewing well logs received from DWR, specific capacity data (i.e., for logs that reported both a pumping rate and drawdown) were compiled into a table. The specific capacity data obtained from study area water purveyors and DWR well logs are summarized in Table 1, and the pumping test data are described in Section 8.0 of this report.

Table 1 includes the conversion of specific capacity data to estimated transmissivity values (based on methodology of Driscoll, 1986) which, when divided by saturated aquifer thickness, provide estimated hydraulic conductivity values. Interpreted formation(s) within well screen intervals are provided for each well. In addition, a zone is defined for each well location as follows: Zone 0 is northeast of Wilmar Avenue Fault, Zone 1 is between Wilmar Avenue Fault and Santa Maria River Fault, Zone 2 is between Santa Maria River Fault and Oceano Fault, and Zone 3 is west of Oceano Fault.

Overall, the existing pumping test data (i.e., several measurements of time versus drawdown and/or plots of these measurements) are limited in comparison to specific capacity data. The vast majority of data collected are specific capacity data that consist of a single measurement of drawdown at a given pumping rate after several hours of pumping. The following sections discuss the available data in more detail. It should also be pointed out that data related to full saturated aquifer thickness is not always known; well screen length, or cumulative lengths of screened intervals, are often used as a means of estimating saturated aquifer thickness. However, improper use of screened intervals in lieu of aquifer thickness in estimating hydraulic conductivity may result in overestimating the hydraulic conductivity value. Thus, the data presented in Table 1 is understood to be based on the best available data, and should be viewed with that in mind if used for other specific purposes, such as groundwater flow model input values.

5.2 PUMPING TEST DATA

For the purposes of the SMBC study, pumping test data are defined as a data set consisting of several measurements of drawdown versus (vs.) time that are sufficient for plotting and allow for calculation of transmissivity (T) values. Such data were requested from local water purveyors/stakeholders in our overall well log data request. Well logs from DWR typically do not contain pumping test data (with exception of Cypress Ridge wells), although some DWR well logs include specific capacity data (described in following section). The wells with pumping test data that were able to be collected for this study included four Pismo Beach wells (5, 9, 10, and 23), four Woodlands wells, three NCSD wells (Bevington and Southland WWTF MW-1 and MW-3), four Cypress Ridge Golf Course wells, and a Grover Beach well. These data sets were obtained from NMMA, NCMA, DWR well logs (for Cypress Ridge Golf Course wells), and Fugro in-house files. The pumping test data are tabulated and described in Section 8.0 of this report.

5.3 SPECIFIC CAPACITY DATA

Specific capacity is defined as the pumping rate divided by drawdown at some given duration of pumping. The conversion factor of 2,000 used to estimate T (in units of gallons per day per foot of aquifer (gpd/ft)) from specific capacity (Q/s, in units of gallons per minute per foot of drawdown (gpm/ft)) is derived from Driscoll (1986). Several assumptions are used to derive this conversion factor, as described in the cited reference. Included in these assumptions are that the well is pumped for 24 hours, that it is a 100 percent efficient pumping well, there was no vertical leakage, and that no boundary (recharge and discharge) conditions were encountered over the pumping duration. The various assumptions need to be considered in each individual case, and can lead to over or under estimation of T values using the conversion factor. The intent of the conversion factor is to provide a general approximation of the T values for well tests that only have a specific capacity value. T values derived from a full set of pumping test data (time-drawdown, recovery data, distance-drawdown data) should be considered more reliable estimates than those obtained from conversion of specific capacity values.

The available specific capacity data are summarized in Table 1, and locations of these wells are shown on Plate 3. Based on preliminary interpretations of geologic formations screened in several wells and conversion of Q/s values to T and hydraulic conductivity (K) values, average K values have been calculated as summarized at the bottom of Table 1. Many of the wells with Q/s data appear to be screened exclusively within the Paso Robles Formation in either Zone 2 or Zone 3. These wells have an estimated geometric mean K of 4 to 8 feet/day. A very limited number of wells were screened exclusively in the Careaga sandstone (and only in Zone 2). The Careaga wells had an estimated geometric mean hydraulic conductivity of 3 feet/day. The formations underlying the Careaga, either Sisquoc or Tertiary undifferentiated, had geometric mean K values of 0.10 to 0.14 feet/day. Slightly higher K values were calculated for wells that were screened in both Paso Robles Formation and Careaga sandstone with geometric mean K values of 12 to 35 feet/day for Zones 2 and 3. Wells screened in Paso Robles Formation within NCMA had a relatively high geometric mean K value of 109 feet/day, whereas wells screened in Careaga sandstone in NCMA had a geometric mean K value of 10 feet/day.

5.4 PUMPING TEST SITE SELECTION

Based on review of Table 1 and Plate 3, and the general lack of pumping test data (i.e., most existing data is specific capacity data), essentially the entire SMBC study area was considered for potential pumping test site selection for this study. Even in areas with abundant specific capacity data, it is preferable to collect pumping test data to better quantify aquifer parameters. Other considerations for pumping test site selection were wells located near known or suspected fault traces (if observation wells were available) in order to develop greater understanding of hydraulic continuity across fault zones, wells located in both NMMA and NCMA, and wells screened in different aquifers to allow characterization of multiple aquifers and depth zones. The pumping tests conducted as part of this study are described in Section 8.0 of this report.

6.0 IDENTIFICATION OF DATA GAPS

6.1 LITHOLOGY DATABASE

The locations of wells with available borehole lithology data are relatively evenly distributed throughout most of the Nipomo and Tri-Cities mesas. Areas lacking in lithologic data include the Arroyo Grande Alluvial Plain between the Nipomo and Tri-Cities mesas, and the area between Highway 1 and the Pacific Ocean in the southern portion of NCMA and western portion of NMMA (see Plate 2).

6.2 PUMPING TEST DATA

The locations of wells with pumping test and specific capacity data tend to mirror the overall distribution of wells with lithologic data (Plate 3). However, there are additional data gaps along the upper portion of Black Lake Canyon north of Oceano Fault, and in the northwestern portion of Nipomo Mesa north of Santa Maria River Fault.

6.3 GEOPHYSICAL LOGS

The locations of water wells with geophysical logs compiled for the SMBC study are shown in Plate 4, and geophysical log hard copies are provided in Appendix E. In addition to the lack of geophysical logs in areas mentioned as generally lacking lithologic data, wells with geophysical logs are generally lacking in the northern portion of Nipomo Mesa. It is likely that a significantly greater number of geophysical logs exist for the study area than were able to be compiled for this study. NMMA (2010) references approximately 65 geophysical logs for just the NMMA area, however due to confidentiality constraints, some of those logs were not available for this study. Because availability of geophysical logs in DWR well log files is limited, the majority of the 25 geophysical logs reviewed for this study were obtained directly from well owners.

6.4 OIL WELL LOG DATA

Oil well log data were obtained from DOGGR (Appendix F). Data were available for about 10 oil wells within the SMBC study area (Plate 5). In general, the oil well log data were of somewhat limited value for a water resources study due to lack of detailed lithologic descriptions in the upper 1,000 feet of sediments and geophysical logs that sometimes bypass the upper several hundred feet of sediments. Nonetheless, oil well log data are incorporated to the extent that it is useful for the depths of interest in this study.

7.0 REGIONAL GEOLOGY AND GEOLOGIC CROSS-SECTIONS

7.1 INTRODUCTION

A number of previous geologic and hydrogeologic studies have been conducted within the SMBC study area and the adjacent Santa Maria Valley. In addition, this study has included compilation and review of well and geophysical log data. This information provides the basis for descriptions of the geologic formations and structure described in the following paragraphs. The geologic cross-sections developed for this study are then presented and described, with particular emphasis on interpretation of formation contacts and potential offsets across fault zones.

7.2 GEOLOGIC FORMATIONS

The major geologic formations in the NMMA and NCMA areas from youngest to oldest are Recent Alluvium, Young and Old Dune Sand, Paso Robles Formation, Careaga sandstone, Sisquoc Formation (and/or other formations older than Careaga sandstone such as the Squire Member of the Pismo Formation), Monterey Formation, and the Franciscan Formation bedrock (Plate 6). The primary water-bearing formations in the study area include Recent Alluvium, Paso Robles Formation, and Careaga sandstone.

7.2.1 Alluvium

Holocene Alluvium (Qa) occurs on the floor of Arroyo Grande Plain and valley bottoms of Arroyo Grande and Pismo creeks, and in Santa Maria Valley (Plates 1 and 6). It is comprised of sand, gravel, silt, and clay, with cobbles and boulders. Within Santa Maria Valley, the alluvium is comprised of a lower coarse-grained member and an upper fine-grained member, but the lower member is missing in the Oso Flaco District. Alluvium of Arroyo Grande Plain ranges in thickness from 40 feet near the coast to 130 feet near the confluence of Los Berros and Arroyo Grande creeks, and is about 50 feet thick near Pismo Beach. Alluvium is about 60 feet thick in Oso Flaco District and about 30 feet thick in Black Lake Canyon. Individual beds in the formation are laterally discontinuous and difficult to correlate between wells – nonetheless, DWR cross-sections did identify fairly continuous clayey silt to silty clay beds is some areas (DWR, 2002). Alluvium is most commonly brown in color.

7.2.2 Dune Sand

The Dune Sand (Qds) includes older dune deposits (Qos) with developed soil mantle and vegetation, and younger actively drifting dune sand (Qs). The Dune Sand is generally above the main aquifer, but does contain locally perched aquifers on top of interbedded clay layers (aquitards). Dune Sand ranges from late Pleistocene to Holocene age with older Dune Sand that forms the Tri-Cities Mesa and Nipomo Mesa (Plates 1 and 6) from 40,000 to 120,000 years old. Dune Sand is fine to coarse-grained sand with some silt and clay. Older Dune Sand ranges up to 60 feet thick in Tri-Cities Mesa to 300 feet thick beneath Nipomo Mesa (Worts, 1951; DWR, 1979, 2002). Dune Sand is typically brown to yellow in color.

As stated above, clay layers within the Older Dune Sands create perched groundwater in some areas, including in the Black Lake Canyon area. Cleath (1996) described the perched layers as widespread but discontinuous across the Nipomo Mesa, and defined an elevation surface for the bottom of a shallow aquitard (clay layer with low vertical permeability) and an isopach (thickness) map of the clay layer. The base of the shallow aquitard is indicated to range from about -60 feet Mean Sea Level (MSL) along the southwestern edge of Nipomo Mesa to +120 feet MSL in northeastern Nipomo Mesa with an aquitard thickness ranging from less than 10 feet (southwestern area) to 70 feet (northwestern area).

7.2.3 Paso Robles Formation

The Paso Robles Formation (QTpr) is upper Pliocene to lower Pleistocene in age. It is comprised of lenses of fine to coarse sand and gravel, clayey to silty sand and gravel, fine to medium silty sand, silt, and clay. In general, the base of Paso Robles Formation is comprised of 50 to 100 feet of clay or clay and limestone. In some areas the clay may be missing at the base of Paso Robles Formation, in which case the base may consist of conglomerate that is difficult to distinguish from the upper Careaga sandstone. The Paso Robles Formation is typically either brown or gray in color, and contains light brown silty clay and silty sand beds in the upper part of the formation. However, a variety of colors have been described in lithologic logs including gray, brown, tan, white, blue, green, and/or yellow. Where Paso Robles Formation overlies Careaga sandstone or Pismo Formation it can be difficult to distinguish in well logs (Woodring and Bramlette, 1950; Worts, 1951; DWR, 1970, 1979, 2002; Cleath, 1996).

The lenticular nature of the sediments (due to its largely non-marine origin) makes it difficult to correlate clay layer or sand/gravel layers from one well log to the next. Within the Paso Robles Formation, sand and gravel zones are typically separated by gray to greenish-gray clay beds. Gravels in the Paso Robles Formation are primarily porcelaneous shale from the Monterey Formation, but also include porphyries and sandstone pieces. Chert and cherty shale pieces may also be present in the upper portion of Paso Robles Formation. The Paso Robles Formation generally becomes finer grained near the coast (predominantly sand and clay) and locally may be of marine origin (Woodring and Bramlette, 1950; Worts, 1951; DWR, 1979, 2002; Cleath, 1996). DWR (2002) suggested that the Paso Robles Formation was deposited under a range of conditions from fluvial to estuarine-lagoonal in inland areas and nearshore marine at the coast.

The formation was described by Worts (1951) as being 280 to 400 feet thick beneath Nipomo Mesa and becoming thicker as it extends beneath Santa Maria Valley (Plate 1). Cleath (1996) stated that the formation thickness ranges from about 600 feet in the southwest portion of Nipomo Mesa to less than 100 feet in the northeast portion along the Los Berros Creek area. DWR (1979) stated the Paso Robles Formation attains its maximum thickness of 1,000 feet beneath the Santa Maria River. Vertical offset of the formation across the Oceano Fault was estimated to be 370 feet (Cleath, 1996).

7.2.4 Careaga Sandstone

The Careaga sandstone (Tca) is considered to be upper (late) Pliocene in age and of marine origin. It is not exposed at ground surface in the study area. It is generally described in lithologic logs as fine to coarse grained, blue, blue-gray, white, gray, green, yellow, brown, and/or yellow-brown sand, gravel, silty sand, silt, and clay. Shell fragments are common in clays and sometimes in sands/gravels. It is comprised of two units/members, a lower member (Cebada) that is finer-grained than the upper member (Graciosa). The Graciosa member is comprised of unconsolidated to consolidated sandstone and conglomerate. The lower portion of Graciosa contains gray to brown coarse-grained sandstone and conglomerate, with localized interbeds of medium-grained sandstone. The upper portion of Graciosa contains gray coarse-grained sand/sandstone with localized thin interbeds of gravel/conglomerate. The upper portion of the Graciosa member typically has a distinct sandy horizon between the clay at the base of Paso Robles Formation and conglomerate of the lower portion of Graciosa member. The Cebada member is comprised of unconsolidated very fine to fine-grained sand. The lower portion of Cebada is light gray to white and very fine-grained, but other portions of the Cebada are light yellow-brown. The distinction of members described above is very common throughout the Santa Maria Valley region but locally the members are not well defined and the formation is considered undifferentiated (Woodring and Bramlette, 1950; Worts, 1951; DWR, 2002). It should be noted that member descriptions described above from Woodring and Bramlette (1950) were derived from outcrops/data to the south of the study area, and it is unknown how distinct the member characterization is within the study area.

Woodring and Bramlette (1950) stated the gravel in the lower portion of Graciosa is mostly porcelaneous shale except for red-gray quartzite and rhyolite porphyry in the upper third of the lower part of the member. Cleath (1996) stated the Graciosa member is generally gray in color and can be further subdivided into upper red-gray coarse sand with quartzite and rhyolite porphyry constituents and a lower conglomerate comprised of porcelaneous shale.

Worts (1951) showed the formation to be 85 to 130 feet thick beneath Nipomo Upland and becoming thicker beneath Santa Maria Valley. Woodring and Bramlette (1950) said the overall thickness of Careaga sandstone in the region was 50 to 1,425 feet, with the Cebada member ranging from 0 to 1,000 feet and the Graciosa member ranging from 25 to 425 feet in thickness. According to DWR (2002), the Careaga sandstone is about 150 feet thick under Nipomo Mesa (south of Santa Maria River Fault) but thickens to 700 feet under the Santa Maria River (Plate 1). Cleath (1996) stated that the Careaga thins to the east and northeast beneath Nipomo Mesa, and is offset across the Oceano Fault.

7.2.5 Sisquoc Formation

Woodring and Bramlette (1950) stated the two primary lithologic units of the Sisquoc Formation (Tms) are a fine-grained basin facies and a marginal sandstone facies. The fine-grained unit is comprised of white to buff and brown or gray diatomaceous and porcelaneous mudstone and claystone. The coarse-grained unit consists of fine to coarse sandstone and siltstone.

Worts (1951) described the Sisquoc Formation as being Miocene to Pliocene in age, with a coarse-grained shallow water facies and a fine-grained deep water facies. The coarse-grained unit described by Worts included hard siltstone beds and some conglomerate, while the fine-grained unit was composed primarily of diatomaceous mudstone with some porcelaneous shale and claystone beds.

7.2.6 Obispo Formation

Dibblee (2006a,b) described Obispo Formation (Tov/Tot) as extrusive volcanic rocks and/or marine pyroclastic rocks of early to middle Miocene age. The Tov unit consists of black basalt with some dark gray andesitic rock, and tan rhyolitic (silicified or zeolitized) tuff. The Tot unit is light tan tuff breccia comprised of rhyolitic fragments in a zeolitized rhyolitic matrix and white fine to medium grained tuff, and may occur as lenses in basaltic rocks.

DWR (2002) described Obispo Formation as silicified or zeolitized tuff and fine to coarse grained crystalline tuff, basaltic and andesitic lavas, calcareous siltstone/claystone, and mudstone. The tuff is locally cut by dikes and sills that are black to green in color and may contain up to 40 percent montmorillonite clay. On water well logs the Obispo Formation is often described as volcanic sandstone, black or gray volcanic shale or volcanic rock, interbedded with hard or soft black shale or clay, and occasionally with crystals of quartz or pyrite.

7.2.7 Franciscan Formation

Dibblee (2006a, b) described Franciscan Formation (KJf) as marine submetamorphosed sedimentary and mafic volcanic rocks of Jurassic-Cretaceous age. Franciscan Formation occurs as a mixture of graywacke, greenstone (metabasalt), and green to red chert within a claystone matrix. DWR (2002) described the Franciscan Formation as a heterogeneous assemblage of marine and continental metasedimentary rocks. The primary rock type is greywacke, but includes shale, altered mafic volcanic rocks, chert, and minor limestone.

7.3 GEOLOGIC STRUCTURE

The Santa Maria Groundwater Basin is effectively bounded by the Wilmar Avenue Fault on the north and east – separating it from Pismo Creek Valley, Arroyo Grande Valley, and Nipomo Valley (Plate 6). The western boundary is the Pacific Ocean, although geologic units (aquifers and aquitards) do extend offshore. The water-bearing sediments in the basin are underlain by bedrock, which is vertically displaced across the Wilmar Avenue, Santa Maria River, and Oceano faults (DWR, 2002). These faults also displace the Paso Robles Formation, Careaga sandstone, and older units that overlie bedrock in the basin. The Santa Maria River and Oceano Faults are concealed by younger sediments, and their existence was initially determined from oil well logs. Fault movement is thought to be dominantly vertical (Worts, 1951; DWR, 2002).

A major syncline occurs in the study area and site vicinity with its axis beneath the south side of Santa Maria Valley. The north limb of the syncline extends beneath Nipomo Mesa, resulting in Paso Robles Formation and older beds dipping towards the south. The overall syncline structure appears to extend out beneath the ocean along with the geologic formations.

Thus, there are no known structural or depositional features that would preclude contact between the fresh water body and seawater (Worts, 1951).

DWR identified the Oceano and Wilmar Avenue faults as northeast-dipping reverse faults. The Santa Maria River Fault is noted as being proposed by Hall (1982), and is postulated to occur between the Wilmar and Oceano faults within the study area. DWR noted evidence of Santa Maria River Fault from differences in groundwater levels between Highway 1 and one mile east of Zenon Way. DWR geologic cross-sections show vertical offset along these faults of 90 to 250 feet. The faults are shown as offsetting Paso Robles and older formations beneath Nipomo Mesa. The Santa Maria River and Oceano faults are shown as merging at the coast and evidence indicates the fault extends offshore south of Oceano (DWR, 2002).

The Oceano Fault was first recognized by DWR (1970) and later by Pacific Gas & Electric onshore/offshore seismic reflection and oil well data. The Oceano Fault extends offshore south of Oceano. Previous work indicates downward (on the coast side) vertical movement along the Oceano and Santa Maria River faults of up to hundreds of feet. Well logs suggest overlapping/multiple slip surfaces along these faults, interpretation of which is complicated by general lack of continuity of layers within the Paso Robles Formation (NMMA Technical Group, 2010).

7.4 GEOLOGIC HISTORY

During upper Pliocene time the sea advanced inland and the Careaga sandstone was deposited. In lower Pleistocene time the Paso Robles Formation was deposited; generally of continental origin but locally of lagoonal or brackish water origin due to deposition in synclinal troughs submerged near the coastline. Deformation and folding occurred during middle Pleistocene time to establish the present configuration of the groundwater basin. During this time period there was some erosion/removal of Paso Robles Formation in the Nipomo Mesa and Arroyo Grande areas (and/or there were some areas of non-deposition). The deformation included formation of the syncline and associated faulting. A period of quiescence occurred into the upper Pleistocene, although there did appear to be some time periods of extended uplift in upper Pleistocene time based on extent/elevation of marine terraces. At the end of Pleistocene time sea level was considerably lower and streams further entrenched. Subsequent rise in sea level after last glacial period caused backfilling of coastal valleys (DWR, 1970).

It is thought that ancestral Arroyo Grande Creek discharged to ocean further south than its present-day location, but was forced northward to current location by dune sands. In addition, DWR noted that the Santa Maria River formerly flowed out to sea near present-day Oso Flaco Lake, but this channel is now blocked from the ocean by sand dunes that form Oso Flaco Lake. The offshore topography shows a very gentle and smooth slope with no submarine canyons or extensions of present-day (or former) channels, thereby allowing offshore extensions of water-bearing formations to continue beneath the ocean bed for some distance offshore (DWR, 1970).

7.5 GEOLOGIC CROSS-SECTIONS

Thirteen geologic cross-sections were prepared for this study based on the well log database compiled for this report. Seven cross-sections are aligned northeast to southwest across Nipomo Mesa, one cross-section is aligned northeast-southwest across Tri-Cities Mesa, one cross-section extends northwest-southeast across Tri-Cities Mesa and Arroyo Grande Plain, two cross-sections are aligned between the Santa Maria River and Oceano faults across Arroyo Grande Plain and Nipomo Mesa, and two cross-sections are located along the coast line extending from the northern portion of NCMA to Santa Maria Valley. An insufficient number of geophysical logs were available to be useful in correlations on the cross-sections except for M-M' (although they were used to assist in determining geologic formation contact elevations where available on other cross-sections).

7.5.1 Distinction of Formation Boundaries

An attempt was made to distinguish between geologic formations on the basis of DWR well log lithologic descriptions, geologist logs, geophysical logs, and location of wells relative to geologic faults. The process utilized and assumptions made in assigning geologic formations are described below.

Within Nipomo Mesa, each well was assigned to one of three zones: Zone 1 is located southwest of the Wilmar Avenue Fault and northeast of the Santa Maria River Fault, Zone 2 is located between the Santa Maria River and Oceano faults, and Zone 3 is located southwest of the Oceano Fault. Based upon previous studies and review of the many well logs compiled for this study, Zone 1 is generally characterized by thin or missing Paso Robles and Careaga sandstone formations (50 feet or less), but rather tends to be characterized by Older Dune Sand (up to 300 feet) underlain by Sisquoc Formation (up to 150 feet). Zone 2 is typically characterized by Older Dune Sand at the surface to depths of up to 300 feet. The Older Dune Sand is underlain by a thickness of 150 to 300 feet of Paso Robles Formation and/or Careaga sandstone, and 150 to 300 feet of Sisquoc Formation. Franciscan Formation bedrock is present beneath Sisquoc Formation in both Zones 1 and 2. Zone 3 is characterized by 150 to 300 feet of Older Dune Sand underlain by 200 to 650 feet of Paso Robles Formation and 150 to 300 feet of Careaga sandstone.

In terms of the formations, the Older Dune Sand is generally present at land surface to depths up to about 300 feet. Older Dune Sand is typically brown fine sand, but may also include coarse sand and thin clay layers and may be red in color. Paso Robles Formation is largely comprised of alternating beds of clay and sand/gravel, and so-called shale gravel. The top of the formation may consist of clay and/or silt with sand, and the bottom of the formation is commonly about 20 feet or more of clay. The basal clay may be of different colors including brown, blue, green, and white. The description of white clay possibly may include limestone that is sometimes present in the basal unit of the Paso Robles Formation. The top of the Careaga sandstone is commonly coarse sand and gravel or clean sand (i.e., little or no clay). Another distinctive feature of Careaga sandstone is presence of shells, which are typically indicative of marine deposition (a characteristic of Careaga but not Paso Robles Formation, except near the coast).

The primary formation in the region beneath the Careaga sandstone is interpreted to be the Sisquoc Formation. This formation is generally not considered to yield significant quantities of water to wells. Sisquoc Formation is commonly screened in wells located in Zone 1 where Paso Robles Formation and Careaga sandstone appear to be thin or missing. The available specific capacity data from well logs were used to further confirm the likely presence of the Sisquoc Formation, which is characterized by Q/s values of 0.1 gpm/ft or less, T values of less than 250 gpd/ft, and K values of less than 0.5 feet/day. The Paso Robles Formation and Careaga sandstone have typical Q/s value in excess of 1 gpm/ft, T values of greater than 1,000 gpd/ft, and K values in excess of 1 ft/day.

In the Tri-Cities Mesa area the general geologic unit sequence is 20 to 60 feet of Dune Sand, underlain by 100 to 300 feet of Paso Robles Formation. Approximately 100 to 300 feet of Careaga sandstone underlie the Paso Robles Formation. T and K values in the Paso Robles Formation beneath Tri-Cities Mesa are much higher than in the Nipomo Mesa area, as described under the pumping test section of this report. Aquifer parameters for the Careaga sandstone in the Tri-Cities Mesa are generally similar to aquifer parameters for the Careaga sandstone beneath Nipomo Mesa.

7.5.2 DWR Zones

DWR (1970) identified five stratigraphic zones that they labeled A, B, C, D, and E in Paso Robles Formation in the Santa Maria Plain. In general, each zone is comprised of coarse-grained sediments (e.g., sand, gravel) separated by fine-grained layers (e.g., clay, silt). These zones are still present to a degree along the coast in the Arroyo Grande-Tri Cities area, but the zones begin to merge to the northwest of Santa Maria Plain along the coast and inland as various clay layers become discontinuous and/or pinch out. In addition, while the zones are limited to the Paso Robles Formation from the Santa Maria Plain to the Oceano Fault, they extend into what is interpreted to be the underlying Careaga sandstone in the Arroyo Grande-Tri Cities area. The DWR zone locations are labeled on cross-sections H-H’, I-I’, L-L’, and M-M’ (Plates 15, 16, 19, and 20).

7.5.3 Discussion/Interpretation of Geologic Cross-Sections

The geologic cross-sections prepared for this report are labeled A-A’ through M’-M’, and the locations of each are shown on Plates 6 and 7. A summary of the top and thickness of Paso Robles Formation (QTpr) and Careaga sandstone (Tca) is provided in Table 2. Cross-sections A-A’ through G-G’, J-J’, and K-K’ cover the NMMA area, cross-sections H-H’ through I-I’ generally represent the NCMA area, and cross sections L-L’ and M-M’ are aligned along the coast (Plates 8 through 20). The cross-sections display lithology, screen intervals, faults, and interpretations of geologic formation contacts (see key on Plate 21). Each geologic cross-section is described in the following paragraphs.

Cross-section A-A’ is aligned from southwest to northeast in the far eastern portion of Nipomo Mesa (Plate 8). It extends from Santa Maria Valley on the south, across Nipomo Mesa, to north of Highway 101 and into Nipomo Valley on the north. Faults crossing the section include Wilmar Avenue Fault at the far northern end and Santa Maria River Fault across the middle of the section. Interpretation of geologic formations penetrated by well logs south of Santa Maria River Fault in this section indicate about 100 feet of alluvium in Santa Maria Valley underlain by up to 200 feet of predominantly coarse-grained Paso Robles Formation, with at least 80 feet of Careaga sandstone. The Santa Maria Valley alluvium forms a lateral contact with Older Dune Sand of the Nipomo Mesa, with the Paso Robles and Careaga sandstone formations laterally continuous until encountering the Santa Maria River Fault. The limited well log data shown on this section indicates vertical offset (north side up) across the Santa Maria River Fault in excess of 150 feet. The geologic units present between the Santa Maria River and Wilmar Avenue faults (Zone 1) consist of Older Dune Sand, a thin (10-20 feet) layer of

Careaga sandstone, Sisquoc Formation (about 150 feet), and Franciscan Formation bedrock. This geologic unit sequence is in turn further offset vertically with only Franciscan Formation bedrock present beneath Dune Sand or alluvium north of Wilmar Avenue Fault.

Cross-section B-B’ is generally parallel to A-A’ and located slightly more than one mile northwest of A-A’, still in the eastern portion of Nipomo Mesa (Plate 9). The southern portion of this section extends about 8,000 feet into Santa Maria Valley. The interpreted thickness of Santa Maria Valley alluvium is from 120 to 180 feet, and it forms a lateral contact with Older Dune Sand of Nipomo Mesa that has a typical thickness of about 200 feet south of Santa Maria River Fault. The thickness of Paso Robles Formation ranges from in excess of 400 feet beneath Santa Maria Valley alluvium to about 120 feet where it abuts the Santa Maria River Fault zone. Screened zones intervals of wells on this section occur in Paso Robles Formation under confined to semi-confined conditions. The top of Careaga sandstone and top of Sisquoc Formation are vertically offset upwards north of the Santa Maria River Fault. The geologic formations (and thicknesses) present between Santa Maria and Wilmar Avenue faults (Zone 1) include Older Dune Sand (20 to 140 feet), Paso Robles Formation (50 to 140 feet), Careaga sandstone (40 to 50 feet), and Sisquoc Formation (in excess of 80 feet). The Wilmar Avenue Fault has significant vertical offset with only Franciscan Bedrock present northeast of the fault.

Cross-section C-C’ is generally parallel to B-B’ and located about 4,000 to 5,000 feet northwest of B-B’ in the eastern portion of Nipomo Mesa (Plate 10). The Santa Maria Valley alluvium is 60 to 150 feet thick, and underlain by more than 300 feet of Paso Robles Formation. The Nipomo Mesa between the Santa Maria River and Oceano faults (Zone 2) is comprised of 200 to 300 feet of Older Sand Dunes, underlain by 230 to 300 feet of Paso Robles Formation and at least 70 feet of Careaga sandstone. There appears to be about 200 feet of vertical offset of the formations beneath the Older Sand Dunes across the Santa Maria River Fault. Between the Santa Maria River Fault and Wilmar Avenue Fault (Zone 1) the Paso Robles Formation is 40 to 160 feet thick, the Careaga sandstone is 30 to 80 feet thick, and the Sisquoc Formation is in excess of 250 feet thick. The Franciscan Formation is present beneath a thin covering of alluvium on the north side of Wilmar Avenue Fault.

Cross-section D-D’ is located in the central portion of Nipomo Mesa and aligned in a southwest to northeast direction (Plate 11). The Santa Maria Valley alluvium is about 120 feet thick at 3,000 feet away from the edge of Nipomo Mesa, where it is underlain by at least 600 feet of Paso Robles Formation. The thickness of Older Dune Sand southwest of Oceano Fault ranges from 200 to 400 feet. The vertical offset across the Oceano Fault cannot be determined for this cross-section because the Careaga sandstone was not encountered on either side of the fault in logs examined during this study. Significant vertical offset is apparent across the Santa Maria River Fault, where the Careaga sandstone and Sisquoc formations were encountered northeast of but not southwest of the fault. The Paso Robles Formation is at least 250 feet thick southwest of Santa Maria Valley Fault (Zone 2), but only about 150 feet thick northeast of the fault (Zone 1). The Careaga sandstone is 20 to 60 feet thick and Sisquoc Formation is in excess of 130 feet thick northeast of the fault. Franciscan Formation is again the primary geologic unit present northeast of the Wilmar Avenue Fault.

Cross-section E-E’ is aligned southwest to northeast across central Nipomo Mesa (Plate 12). The section includes two deep oil well logs that help to define the deeper units southwest of Oceano Fault. The Paso Robles Formation ranges from 470 to 630 feet thick beneath the Santa River Valley alluvium that is in excess of 80 feet thick and Older Dune Sand (100 to 250 feet thick) beneath the Nipomo Mesa southwest of Oceano Fault (Zone 3). The Careaga sandstone is approximately 170 to 200 feet thick, and Sisquoc Formation is in excess of 500 feet southwest of Oceano Fault. The vertical offset across Oceano Fault is approximately 230 feet with formations northeast of the fault at the higher elevations. Geologic formation thicknesses between the Oceano Fault and Santa Maria River Fault (Zone 2) are up to 200 feet of Older Dune Sand, 180 to 310 feet for Paso Robles Formation and 190 to 300 feet for Careaga sandstone. Between the Santa Maria Valley and Wilmar Avenue faults (Zone 1) the Paso Robles Formation is 160 to 200 feet thick beneath 100 to 200 feet of Older Dune Sand. Northeast of the Wilmar Avenue Fault the geologic units include Paso Robles Formation (up to 100 feet), Obispo Formation (60 to 170 feet), and Franciscan Formation.

Cross-section F-F’ (Plate 13) is aligned southwest to northeast and located in western Nipomo Mesa. The Older Dune Sand is 200 to 260 feet thick southwest of Oceano Fault (Zone 3) and underlain by at least 380 feet of Paso Robles Formation (well logs not deep enough to encounter Careaga sandstone). Based on interpretation of well logs near the Santa Maria River Fault zone, there may be at least two strands of the fault in this area. The Paso Robles Formation is notably thinner and the Careaga sandstone is interpreted to be encountered between -20 and -120 feet MSL north of the southern fault strand (Zone 2). The Careaga sandstone is interpreted to be missing with the Paso Robles directly overlying Sisquoc Formation across the northern strand of the Santa Maria River Fault (Zone 1). Further northeast along the cross-section line the Paso Robles Formation is present at ground surface north of Los Berros Creek. The boring logs along the cross-section suggest the Wilmar Avenue Fault is further south than shown on the geologic map (Plate 6). The Franciscan Formation is present within about 20 feet of ground surface in logs 158730 and 153002, but much deeper in oil well log 07900592. The Wilmar Avenue Fault appears to be located between logs 07900592 and 158730.

Cross-section G-G’ is the westernmost section that is aligned southwest to northeast across Nipomo Mesa, and includes some deeper well logs to help define the deeper units southwest of the Oceano Fault (Plate 14). Along the section south of Oceano Fault (Zone 3) the top of Paso Robles Formation is about 240 to 290 feet thick (at -150 to -10 feet MSL), and the Careaga sandstone is up to 400 feet thick (at -650 to -250 feet MSL). The top of Careaga sandstone rises from south to north until it reaches Oceano Fault, where there may be some vertical upwards offset of the top of Careaga sandstone. However, the boring logs are not deep enough to penetrate the top of Careaga sandstone between the Oceano and Santa Maria River faults; therefore offset across the fault is not defined nor is the thickness of Paso Robles Formation defined in Zone 2. Further north across the Santa Maria River Fault the Paso Robles Formation occurs between 50 and 260 feet MSL and its thickness ranges from a minimum in excess of 100 feet to a maximum of at least 340 feet. Where encountered in one well log, the top of Careaga sandstone was encountered at an elevation of -80 feet MSL.

Cross-section H-H’ is aligned approximately west to east across Tri-Cities Mesa from the ocean to Highway 101 (Plate 15). The western portion of the section includes the Oceano CSD monitoring well and a production well, and the middle of the section includes some Grover Beach and Arroyo Grande wells. The Paso Robles Formation is encountered below a surficial layer of dune sand that is 30 to 40 feet thick. The Paso Robles Formation ranges from 110 to 280 feet thick and the contact between Paso Robles and Careaga occur between -30 and -290 feet MSL. The Careaga sandstone is greater than 300 feet thick. The deeper boring logs indicate Sisquoc Formation (or other Tertiary Formation) is encountered between -500 and -620 feet MSL.

Cross-section I-I' is oriented northwest to southeast from Tri-Cities Mesa and across Arroyo Grande Plain to Nipomo Mesa (Plate 16). Older Dune Sand deposits range up to 80 feet in thickness, and top of Paso Robles Formation is encountered from 10 to 30 feet MSL. The top of Careaga sandstone is encountered from -40 to -230 feet MSL beneath Tri-Cities Mesa, defining a thickness of 50 to 250 feet for Paso Robles Formation. The base of Careaga sandstone was encountered in only one well, but the thickness appears to be in excess of 400 feet thick below Tri-Cities Mesa. Well logs are generally lacking in the Arroyo Grande Plain to define thickness of alluvium and underlying formations. However, based upon the limited available well logs and various references (DWR, 2002; Todd, 2007) the thickness of alluvium deposited by Arroyo Grande Creek along I-I' is estimated to range up to about 100 feet.

Cross-sections J-J' (Plate 17) and K-K' (Plate 18) represent one continuous section aligned northwest to southeast across the middle of Nipomo Mesa and generally perpendicular to cross-sections A-A' though G-G'. It begins in the Arroyo Grande alluvial plain and ends in Santa Maria Valley alluvium. It is aligned in between the Oceano and Santa Maria River faults (Zone 2). The thickness of Older Dune Sand across this section generally ranges from 200 to 300 feet. The Paso Robles Formation thickness ranges from 110 to 330 feet. Where encountered (i.e., where borings/wells are deep enough), the Careaga sandstone ranges from about 30 feet to greater than 150 feet. The top of Sisquoc Formation is only encountered in the eastern portion of cross-section K-K' (boring logs are not deep enough in other areas), where the thickness of Sisquoc Formation appears to be in excess of 200 feet.

Cross-sections L-L' and M-M' define a continuous section generally parallel to the coast (Plates 19 and 20). Cross-section L-L' occurs entirely within the NCMA area, whereas most of M-M' is located within the NMMA area. Along L-L' the top of Paso Robles Formation is encountered either below a thin surficial layer of dune sand at elevation near 0 feet MSL, or beneath 20 to 50 feet of alluvium. The top of top of Careaga sandstone is encountered at -180 to -400 feet MSL, indicating a Paso Robles Formation thickness of 130 to 390 feet. The top of Sisquoc Formation (or other Tertiary Formation) ranges from -560 to -740 feet MSL in along L-L'. The thickness of Careaga sandstone in this area is 200 to 380 feet. Cross-section L-L' crosses near the combined Oceano/Santa Maria River fault zone near well 40-1518. No offset of the top of Careaga sandstone is shown according to our well log interpretation in this area as occurs at other locations; however, the top of Sisquoc may be offset by about 150 feet. The interpreted thickness of Careaga sandstone increases significantly to the north of well log 40-1518.

The relatively deep monitoring well and oil well logs along M-M' (Plate 20) help to define the top of formation and thickness of Paso Robles and Careaga sandstone. Available geophysical logs (resistivity) are posted on M-M' to assist in the interpretation. The top of Paso Robles Formation is encountered between 30 and -130 feet MSL along M-M' with a thickness of 380 to 520 feet. Careaga sandstone was encountered at -400 to -650 feet MSL with a thickness of 200 to 290 feet where defined. The top of Sisquoc Formation was encountered at -600 to below -900 feet MSL.

8.0 REGIONAL HYDROGEOLOGY AND PUMPING TESTS

This section describes the general regional hydrogeology, pumping test data collected and analyzed for this study, and overall assessment of aquifer parameters.

8.1 REGIONAL HYDROGEOLOGY

8.1.1 Previous Studies

The Santa Maria Groundwater Basin consists of aquifers under unconfined conditions, semi-confined to confined aquifer conditions, and perched zones, with discontinuous clay layers separating the aquifer zones. The most productive aquifers are in alluvium and Paso Robles Formation (DWR, 2002). Paso Robles Formation contains 2 to 5 aquifers labeled by DWR (top to bottom) as A to E zones, and these aquifers are separated by silt and clay confining beds near the coast but merge inland (DWR, 1970). In general, aquifers/aquitards are noted as being more continuous near the coast than inland (NMMA, 2010). The groundwater basin extends offshore to the west – possibly extending to the Hosgri Fault zone (about 10 miles offshore).

A study conducted by DWR (1958) indicated that groundwater flow in the Arroyo Grande Basin (as of 1954) was generally towards the ocean, although a pumping depression was noted in the area north of Oceano since 1945. However, groundwater elevations were still above sea level – indicating that sea water intrusion likely had not occurred. The report stated this cone of depression occurred within the Paso Robles Formation, which was less permeable than alluvium in the basin. It was believed that the area west of the pumping depression had a discontinuous clay layer that allowed deep percolation from the Old Dune Sands into Paso Robles Formation that helped maintain a seaward hydraulic gradient. Groundwater contours also indicated flow from Nipomo Mesa to the Arroyo Grande Basin (DWR, 1958).

The DWR (1970) report included hydrogeologic cross-sections parallel and perpendicular to the coast in the Tri-Cities-Arroyo Grande Plain area. The Paso Robles Formation at the coast was depicted as extending from sea level to about -300 feet MSL and was divided into three zones (A, B, and C) – each with overlying confining clay layers. The contact with the underlying Careaga sandstone was shown as sloping upward towards the City of Arroyo Grande well field where the base of the Paso Robles Formation was at -150 to -200 feet MSL. The cross-sections showed clay confining layers pinching out beneath the Grover Beach and Arroyo Grande well fields, and coarse-grained layers in the Paso Robles Formation were more continuous in the vertical direction. In Grover Beach well field, the Well 4 report (LeRoy Crandall and Associates, 1978) showed the Paso Robles Formation – Careaga sandstone contact at a higher elevation than in DWR (1970). Essentially, the upper Careaga sandstone in the Grover Beach Well 4 report is equivalent to Paso Robles Zone C in DWR (1970). Aquifers in Paso Robles Formation were considered to occur under confined conditions near the coast, and ranged from unconfined to confined beneath the mesas (DWR, 1970). DWR (1979) stated that the coastal aquifer system for Nipomo Mesa was comprised of an upper aquifer overlain by not more than 20 feet of clay and underlain by 60 feet of clay.

In Nipomo Mesa the surficial 200 to 300 feet of Older Dune Sand commonly contains perched groundwater above the regional water table. Although the perching clay layer in the

Older Dune Sand is not continuous, it is prevalent enough that the base of the aquitard has been mapped as ranging from -60 feet MSL in the southwestern portion of the mesa to +120 feet MSL in northeastern Nipomo Mesa (Cleath, 1996). In most areas of Nipomo Mesa, the Dune Sand is underlain by Paso Robles Formation with estimated formation thicknesses ranging from 600 feet in southwestern Nipomo Mesa to 100 feet in the northeastern portion of the mesa. It has been estimated that there is approximately 370 feet of offset of the base of Paso Robles Formation along the Oceano Fault, resulting in a significantly thinner section of the formation northeast of the fault zone (Cleath, 1996). The base of Careaga sandstone has been estimated to range from -900 feet MSL along the southwest edge of Nipomo Mesa to +100 feet MSL near Highway 101. The Careaga sandstone things to the east and northeast beneath Nipomo Mesa and is offset across the Oceano Fault (Cleath, 1996).

DWR (2002) showed the regional water table beneath Nipomo Mesa being located in either the lower portion of Dune Sand or the upper portion of Paso Robles Formation. Except near the coast where confined conditions prevail, the cross-sections are generally indicative of unconfined to semi-confined conditions across Nipomo Mesa. DWR geologic cross-sections show vertical offset along the Oceano Fault ranging up to 250 feet.

8.1.2 Discussion

Based upon review of previous studies and geologic cross-sections constructed for this study, the delineation of unconfined and confined aquifer conditions remains a challenge. However, cross-sections constructed for this study are consistent with previous work with respect to the presence of relatively continuous clay layers in the coastal area within the Paso Robles Formation. There are relatively clearly defined confined to semi-confined aquifers alternating with clay aquitards in the Paso Robles Formation near the coast. These aquifers and aquitards are best illustrated on Cross-sections L-L’ and M-M’ (Plates 19 and 20), which combine to form one continuous cross-section along the coastline. A 30 to 60-foot thick clay layer is present from -100 feet MSL in the northern part of Cross-section L-L’ and dips southward to -400 feet MSL at the south end of Cross-section M-M’. A thinner 10 to 30-foot thick clay layer is present at the base of the Paso Robles Formation from -200 feet MSL in the north to -650 feet MSL in the south. These two clay layers serve as confining layers for the coarse-grained aquifers beneath them.

Further inland the continuous clay layers present at the coastline tend to pinch out or become discontinuous. The depths to water become much greater in inland areas of NMMA (200 to 350 feet), which means clay layers that are present up to 350 feet below ground surface are not acting as semi-confining or confining layers. The Nipomo Mesa area is further complicated by the presence of the Oceano and Santa Maria River faults. In general, the Careaga sandstone and underlying units are displaced upwards north of the faults, and the Paso Robles Formation decreases in thickness northward across each fault zone. The Careaga sandstone and underlying formations likely decrease in thickness northward across each fault as well, although the base of Careaga sandstone is not well defined because it is not encountered in most well logs.

Review of geologic cross-sections prepared for this study generally indicate alternating coarse and fine-grained layers beneath Nipomo Mesa south of Santa Maria River Fault in cross-sections A-A’ through C-C’, and south of Oceano Fault. Further north along cross-sections A-A’ through D-D’, the Paso Robles Formation is comprised of a greater percentage of fine-grained sediments. North of Wilmar Avenue Fault is mostly Obispo Formation and Franciscan Formation bedrock, which typically has very low well yields. The area of Nipomo Mesa covered by cross-sections E-E’ through G-G’ shows considerable interbedding of fine and coarse-grained sediments and a general lack of continuity of the clay layers that is observed at the coast. Characterization of aquifers (as unconfined, semi-confined, or confined) within Paso Robles Formation across the inland portion of Nipomo Mesa is a function of coarse- and fine-grained layers described above and depth to water. However, it should be pointed out that characterization of an aquifer by interpretation of geologic and hydrogeologic conditions and setting (cross sections) may, at times, not necessarily be confirmed by calculated aquifer parameters based on aquifer pumping tests (see Sections 5.1, 5.3, and 8.2). Caution must be used on placing too much dependence on any one methodology of estimating aquifer parameters if the values are used for specific purposes, such as groundwater flow model input.

8.2 PUMPING TESTS

The aquifer parameters described in this section were obtained from three general types of sources: 1) previous studies (that don’t include time-drawdown data), 2) previous pumping tests (that include time-drawdown data either plotted by others or plotted by Fugro), and 3) pumping tests conducted specifically for this study. The data obtained from these various sources are described in the following paragraphs, summarized in tables following the text, and detailed data, plots, and tables are provided in appendices.

8.2.1 Previous Studies

Several previous studies have described the aquifer parameter values of various geologic formations in the study area. The previously defined aquifer parameter most often quantified in previous studies is hydraulic conductivity (K). However, transmissivity (T) and storativity (S) values are also mentioned in a few reports. Transmissivity is equal to K times aquifer thickness, and S represents the amount of water extracted from a unit volume of geologic formation for a unit drop in water level. Q/s values, defined as pumping rate (Q) divided by drawdown (s), are also described in some previous reports. The following paragraphs provide summaries of aquifer parameter values described in previous reports, and these data are summarized in Table 3.

Worts (1951) briefly mentioned that the K for Paso Robles Formation derived from a recovery test at one well (T11N/R35W-20E1) was about 9 feet/day. Laboratory testing of Careaga sandstone samples from the Santa Ynez Basin (about 20 miles south of study area where the formation was assumed to be similar) indicated hydraulic conductivities were also on the order of 9 feet/day (Table 3).

According to DWR (1970), the Arroyo Grande Creek alluvium upper zone has an estimated K value of 110 feet/day, and the lower zone an estimated K range of 300 to 400 feet/day. The range of K values estimated for Paso Robles Formation is 70 to 230 feet/day. No wells were reported to be screened exclusively in the Careaga sandstone at this time, so no K values were provided for this geologic formation. The upper portion of the Pismo Formation is considered to be equivalent to Careaga sandstone. The Pismo Formation is stated to be limited to the San Luis Hills, where it is unconfined and tapped by domestic wells (DWR, 1970).

Cleath (1996) indicated their review of pumping test data showed a range of hydraulic conductivity from 5 to 50 feet/day and storativity of 0.002 to 0.003 (indicative of semi-confined aquifer conditions) for Paso Robles Formation in the Woodlands area. Hydraulic conductivity values assigned to various geologic formations by Todd (2007) for the NCMA water balance study are included in Table 1. Todd stated these K values are approximately equal to the geometric mean values of data provided by DWR (2002). K values estimated for Paso Robles Formation range from 13 to 52 feet/day south of Nipomo Mesa and from 2 to 15 feet/day beneath Nipomo Mesa (NMMA, 2010).

Aquifer characteristics in Santa Maria Valley were evaluated by LSCE (2000) based upon pumping test data presented in Worts (1951), specific capacity data from USGS (Hughes and Freckleton, 1976), and specific capacity data from Water Well Drillers Reports. Hydraulic conductivity values ranged from 270 to 600 feet/day for Santa Maria Valley alluvium, 2 to 15 feet/day for Paso Robles Formation beneath the Nipomo Mesa and western part of Santa Maria Valley, and 13 to 50 feet/day for Paso Robles Formation in the Sisquoc Plain/Orcutt Upland/central valley areas. Careaga sandstone was assumed to be 9.5 feet/day based on very limited laboratory test data from Worts (1951). No data were available for Older Dune Sand and it was assumed to have a hydraulic conductivity value of 175 feet/day. Specific yield values of 8 to 12 percent for Paso Robles and Careaga sandstone formations, and 13 percent for Older Dune Sand were derived from DWR (2002).

DWR (2002) reported that lower K values occur north of Santa Maria River Fault beneath Nipomo Mesa. T values for alluvium in Santa Maria River Valley were reported to range from 200,000 to 400,000 gpd/ft and up to 100,000 gpd/ft in Arroyo Grande Valley alluvium. T values of 100 to 160,000 gpd/ft were reported for Paso Robles Formation in the Nipomo Mesa/Santa Maria Valley area, with the higher values occurring south of Oceano Fault and in Santa Maria Valley. Paso Robles Formation T values in the Tri-Cities/-Arroyo Grande Plain area were reported to be 20,000 to 130,000 gpd/ft. T values of 3,000 to 30,000 gpd/ft were reported for the Squire Member (also referred to as Careaga sandstone) in the Tri-Cities/-Arroyo Grande Plain. Transmissivity values for the Careaga sandstone were stated to be similar to Paso Robles Formation, with the lowest values of 100 to 4,000 gpd/ft occurring north of Santa Maria River Fault in Nipomo Mesa. The range of hydraulic conductivity values cited from DWR based on pumping tests and specific capacity (pump efficiency) tests are summarized in Table 1.

A summary of hydraulic conductivity data from existing studies for the NMMA and NCMA is provided in Table 3. With the exception of Paso Robles Formation, the data are limited for most formations. The range of K for Paso Robles Formation from existing data is less than 1 to 360 feet/day. The values for the other formations are 175 feet/day for Dune Sand, 5 to 10 feet/day for Careaga sandstone, 100 to 800 feet/day Santa Maria Valley alluvium, and 27 to 400 feet/day for Arroyo Grande Plain alluvium.

8.2.2 Existing Pumping Test Data

The previously derived pumping test data collected for this study were reviewed and analyzed, and results summarized in Table 4. The data analysis plots for existing pumping test data are provided in Appendix G. Results from evaluation of existing aquifer pumping test data indicate transmissivities of about 30,000 gpd/ft for Careaga sandstone and 7,500 to 11,500 gpd/ft for Squire Member of Pismo Formation beneath Tri-Cities Mesa; and transmissivities of 1,000 to 85,000 gpd/ft for Paso Robles Formation beneath Nipomo Mesa. Paso Robles Formation transmissivity was notably higher in Zone 3 (27,000 to 85,000 gpd/ft) as compared to Zone 2 (1,000 to 18,000 gpd/ft). Existing data were not available for wells screened exclusively in Paso Robles Formation beneath Tri-Cities Mesa or wells screened exclusively in Careaga sandstone beneath Nipomo Mesa.

8.2.3 2014 Pumping Tests

A major task in this study was to conduct aquifer pumping tests in the NMMA and NCMA. Several groups of wells were targeted for conducting pumping tests, based on obtaining a good geographic distribution and emphasizing pumping wells with nearby observation/monitoring wells. A brief technical memorandum (TM) was prepared with a list of proposed aquifer pumping test sites (Fugro, March 18, 2014), and is included as Appendix H. The proposed pumping test TM was submitted to the District and circulated to the Technical Groups for review. The well owners considered for pumping tests included: NCSD, GSWC, RWC, agricultural well owners in Arroyo Grande Plain, City of Arroyo Grande, Oceano Community Services District (OCSD), and City of Grover Beach. It was determined that sufficient pumping test data were already available for City of Pismo Beach wells; therefore, additional pumping tests were not requested from Pismo Beach.

There were many logistical hurdles to overcome in conducting these tests, and some agencies were better able to accommodate the proposed testing schedule than others. The ideal pumping test procedure/schedule proposed to each entity was as follows: installation of pressure transducers, no pumping from both the pumping and observation wells for two days prior to testing, pumping of the designated pumping well for 12 hours continuously (monitor drawdown during this pumping phase in both pumping and observation wells), no pumping from both the pumping and observation wells for 12 hours after pumping stopped (monitor groundwater levels during the recovery phase), and remove transducers from the wells.

The pumping test program required no pumping from multiple wells for most of a three day time period. Five of the seven targeted well owners were able to accommodate such a pumping schedule with at least one set of wells. RWC and agricultural well owners were not able to conduct the requested pumping tests due to logistical constraints. A summary of pumping tests conducted on wells from the other five well owners are described in the following paragraphs. A total of six aquifer pumping tests were able to be conducted at five locations (Plate 22). Two aquifer pumping tests were completed at City of Grover Beach well field, because transducers were installed for a longer time period and recorded drawdown from pumping of a well screened in a separate deeper aquifer that is isolated from the shallower aquifer targeted for the primary test at this location. The aquifer parameter calculations are summarized in Table 5 and the plots and raw data are provided in Appendices I and J.

8.2.3.1 City of Arroyo Grande

The proposed pumping test at Arroyo Grande targeted the use of Well 8 (339665) as the pumping well, and Wells 3 (90008) and 7 (90010) as the observation wells (Plate 22). Based on conversations with City of Arroyo Grande staff at the pre-test field meeting for transducer installation, it was determined that Well 1, Well 4, and Well MW-7 were also available to be added to the observation well network. Review of geologic conditions at this pumping test location indicate a thin surficial layer of Dune Sand (about 35 feet) underlain by Paso Robles Formation (to a depth of about 290 feet), and Careaga sandstone (to a depth of at least 610 feet). Well 8 (136 to 230 feet below ground surface (bgs)), Well 1 (total depth of 175 feet), Well 3 (100 to 219 feet bgs), and Well 4 (92 to 232 feet bgs) are screened in Paso Robles Formation. Well 7 (290 to 460, 475 to 490, 500 to 515, 525 to 545, and 555 to 570 feet bgs), and Well 7 monitoring well (screen interval is unknown) are screened just in the Careaga sandstone.

A clay layer is present in the shallow portion of the Paso Robles Formation (about 35 to 65 feet bgs), but is in the unsaturated zone based on measured static groundwater levels of about 75 feet bgs. No other substantial clay layers appear to be present in the upper 180 feet with only very thin clay layers (about 5 feet) present at 75, 110, 130, and 185 feet bgs, indicating mostly unconfined conditions to this depth interval. A substantial clay layer is present at the base of the Paso Robles Formation from 220 to 290 feet bgs but its thickness may be locally variable. No substantial clay layers appear to be present in the Careaga sandstone from 290 to 610 feet bgs, although several very thin (less than 5 feet) clay layers may be present. The clay layer present at the base of the Paso Robles Formation may reduce hydraulic communication of the screen zone of the pumping well with the underlying Careaga sandstone (Well 7); however, pumping test results indicate a delayed response from Careaga sandstone wells.

Transducers were successfully installed in Wells 3, 4, 7, and MW-7 on April 25, 2014. Transducer installation was attempted but unsuccessful for the pumping well (Well 8); therefore, the only measurements able to be obtained for Well 8 were airline measurements. Manual sounder measurements were collected from Well 1. The pumping phase of the test occurred between approximately 8:30 AM and 8:30 PM on April 28, 2014. Recovery measurements were collected until the morning of April 29, 2014. Groundwater level hydrographs and pumping test data analysis plots are provided in Appendix I. The pumping test data are provided in Appendix J (separately, on CD).

Well 8 was pumped at an average rate of 470 gpm – starting out at 480 gpm and declining to 465 gpm. Drawdown was observed at wells 1, 3, and 4 soon after pumping began – each of these observation wells has overlapping relatively shallow well screens that are generally similar to the pumping well, except that Well 1, 3, and 4 well screens extend to shallower depths than Well 8. A relatively small amount of drawdown (0.33 to 1.63 feet) was observed in wells 1, 3, and 4, and the most representative transmissivity values calculated from drawdown data were considered to be 117,000 gpd/ft (from distance-drawdown analysis) to 123,000 gpd/ft (from observation Well 3). The total amount of drawdown and shape of the drawdown curves suggests unconfined to semi-confined conditions. The transmissivity calculated from Well 8 drawdown data was 30,000 gpd/ft, but Well 8 data have less accuracy and greater uncertainty due to the indirect (airline) measurement method. In addition, well efficiency issues sometimes results in lower calculated T values for pumping wells compared to observation wells. Overall representative aquifer parameter values for Paso Robles Formation are considered to be 120,000 gpd/ft for transmissivity, 115 feet/day for hydraulic conductivity, and 0.01 for storativity (Table 5). The term overall representative values as applied in this study are based on an average of pumping and observation well data (and/or time-drawdown and recovery data) or by emphasizing a data set thought to be more reliable and representative of the aquifer parameter values.

Analysis of recovery data for Arroyo Grande Wells 3 and 4 resulted in T values of 171,000 to 174,000 gpd/ft, while Well 8 recovery data yields a T value of 29,000 gpd/ft. The recovery T values from Wells 3 and 4 are likely too high and not representative due to the semi-confined type response not being suitable for the Theis Recovery analysis method. As mentioned above, Well 8 recovery data are impacted by indirect (airline) measurement method.

Well 7 and MW-7 are screened deeper and below the bottom of Well 8, and drawdown was observed starting about 100 minutes after the onset of pumping. Approximately 0.9 feet of drawdown was observed in Well 7 and MW-7 at the end of the 12-hour pumping period, and drawdown continued for the duration of the 12-hour recovery period with a final drawdown measurement of 1.2 feet in both deep wells.

8.2.3.2 Oceano CSD

The proposed pumping test at Oceano CSD utilized Well 8 (219080) as the pumping well, and Wells 7 (219084) and the Oceano CSD nested monitoring well cluster as the observation wells (221036) (Plate 22). The Oceano CSD nested monitoring well cluster casings are designated by the colors green, blue, yellow, and silver from top to bottom, with each casing screened at the depth intervals stated below. Review of geologic conditions at this pumping test location indicate a thin surficial layer of Dune Sand (about 30 feet) underlain by Paso Robles Formation (to a depth of about 280 feet), Careaga sandstone (to a depth of about 650 feet), and Sisquoc Formation. Well 7 (90 to 140 feet bgs), the Oceano CSD green monitoring well (110 to 130 feet bgs), and the blue monitoring well (190 to 210 and 245 to 265 feet bgs) are screened in Paso Robles Formation. Well 8 (380 to 520 feet bgs), the silver monitoring well (395 to 435 and 470 to 510 feet bgs), and the yellow monitoring well (625 to 645 feet bgs) are screened in the Careaga sandstone.

A clay layer is present in the shallow portion of the Paso Robles Formation (about 40 to 75 feet bgs), which suggests semi-confined to confined conditions for the upper Paso Robles Formation screened in Well 7 and the green monitoring well. Other thin clay layers are present at 170 to 185 bgs and 215 to 225 bgs in the Paso Robles Formation, indicating some further confinement and potential isolation of the blue monitoring well zone (located in lower Paso Robles Formation) from wells screened above. A thin clay layer from 300 to 310 feet bgs and a thin sandy clay layer at about 370 feet provide some limited hydraulic isolation of the screen zone of the pumping well from the overlying lower Paso Robles Formation (blue monitoring well). There does not appear to be a distinct clay layer within the Careaga sandstone between the bottom of the pumping well screen (520 feet) and the yellow monitoring well screen zone (625 to 645 feet). Based on the sediments present, the screen zone of the pumping well is considered to occur under confined conditions, with potential for some vertical leakage from the overlying Paso Robles Formation.

Transducers were successfully installed in the four Oceano CSD monitoring wells on April 29, 2014, and in Wells 7 and 8 on May 1, 2014. The pumping phase of the test occurred between approximately 8:00 AM and 8:00 PM on May 3, 2014. Recovery measurements were collected until the morning of May 5, 2014. The average pumping rate was about 800 gpm, starting out at a rate of 850 and declining to 795 gpm. The well pumped 850 gpm for the initial 10 minutes, and then stayed within a relatively narrow range and averaged about 820 to 825 from 10 to 85 minutes. The pumping rate gradually declined down to 800 gpm at about 200 minutes of pumping and stayed near 800 gpm through about 370 minutes of pumping. The pumping rate for the remainder of the testing period averaged approximately 795 gpm.

Groundwater level hydrographs and pumping test data analysis plots are provided in Appendix I. Drawdowns in the Oceano CSD monitoring wells after 12 hours of pumping were 0, 0.05, 14.8, and 11.5 feet for the green, blue, silver, and yellow wells, respectively. Drawdowns in Wells 7 and 8 were 0 and 105.3 feet, respectively. It should be noted that drawdown continued in the blue monitoring well from 0.05 feet at the end of pumping to 0.53 feet 24 hours after pumping ceased. This observation in the blue monitoring well indicates that the zone from 190 to 265 feet bgs that is located above the screened zone of the pumping well (380 to 520 feet bgs) contributes some vertical leakage to the cone of depression.

The time-drawdown data indicate a transmissivity of 17,500 gpd/ft in the Oceano CSD silver monitoring well and 26,000 gpd/ft in the Well 8 pumping well. Minimal (if any) drawdown was observed in Well 7 and the two shallow Oceano CSD green and blue monitoring wells, which are screened no deeper than 140 feet compared to the pumping well screen from 380 to 520 feet. These two shallower wells appear to be responding to stresses other than pumping of Well 8, but overall fluctuations are less than about 0.5 feet. The deeper Oceano CSD yellow monitoring well (screened 625 to 645 feet) showed significant drawdown of 11.5 feet – generally indicating the deeper aquifer zone screened in the yellow monitoring well and the pumping well zone from 380 to 520 feet are hydraulically connected. Representative aquifer parameter values include a transmissivity of 21,500 gpd/ft, hydraulic conductivity of 11 feet/day, and storativity of 0.003 (Table 5).

8.2.3.3 Nipomo CSD

The preferred well sites for Nipomo CSD were not able to be tested due to logistical issues. However, the two wells available for use in an aquifer pumping test (Black Lake No. 3 (222813) and No. 4 (276929) provided for a good test as they were relatively close together (about 240 feet apart) and had similar screen zones (330 to 550 and 310 to 520 feet, respectively) (Plate 22). Both wells are screen in the Paso Robles Formation and are located just north of the Oceano Fault. Transducers were installed in the two wells on May 5, 2014, the pumping phase of the test was conducted on May 8, 2014, and the transducers were removed on May 9, 2014.

Black Lake No. 4 (was pumped at an average rate of 360 gpm, with a range of 340 to 380 gpm. Pumping rates fluctuated due to system pressure fluctuations. The pumping rate ranged from 365 to 380 gpm over the first 90 minutes of the test, and gradually declined to 345 gpm by 300 minutes or pumping. The pumping rate remained at 345 gpm until about 480 minutes of pumping. The pumping rate quickly increased to 365 gpm over the next 30 minutes and remained at that rate until the end of the pumping period. Given the fluctuations in pumping rate and resulting influence on time-drawdown data during the pumping period, the recovery data are particularly useful for confirmation of aquifer parameters.

Groundwater level hydrographs and pumping test data analysis plots are provided in Appendix I. The drawdowns at the end of 12 hours of pumping were 1.4 feet at the observation well 240 feet away and 57.4 feet in the pumping well. The calculated transmissivity value for the observation well was 70,000 gpd/ft. The pumping well transmissivity was 25,000 gpd/ft based on time-drawdown data from the pumping phase. Recovery data transmissivity values were 85,000 gpd/ft for the observation well and 18,000 gpd/ft for the pumping well. The calculated K values range from 10 to 15 feet/day for the pumping well and 41 to 50 feet/day for the observation well. Based on an average of pumping and observation well data, the transmissivity value is 45,000 gpd/ft, hydraulic conductivity is 26 feet/day, and storativity is 0.02 (Table 5).

8.2.3.4 Golden State Water Company

The preferred well sites for Golden State Water Company (GSWC) were not able to be tested due to logistical issues. Nonetheless, two wells that were available for use were identified and provided useful pumping test data. Alta Mesa 2 (161355) and Vista 4 (103045) have overlapping screen intervals and are about 100 feet apart. The well logs at the site show approximately 380 feet of dune sand, underlain by Paso Robles Formation to the maximum well depth of 620 feet (a thickness of 240 feet). The pumping well (Alta Mesa 2) is screened within the Paso Robles Formation from 385 to 435 and 485 to 570 feet. Based upon review of the lithologic and geophysical logs and a pumping well static water level of 297 feet bgs, the upper screen is apparently within an unconfined aquifer, whereas the lower screen is within a confined aquifer. The observation well (Vista 4) is screened across both the Dune Sand and Paso Robles Formation from 80 to 600 feet. The depth to water of about 270 to 280 feet bgs in Vista 4 indicates that the lower 100 feet of Dune Sand is saturated. The pumping well (Alta Mesa 2) is located about 360 southwest of the map trace of the Oceano Fault, and the observation well is located about 260 feet southwest of the fault (Plate 22). The fault, if it is a barrier to groundwater flow, could affect the test results.

Transducers were installed in both wells on May 9, 2014 and pumping for 12 hours was conducted on May 12, 2014. Alta Mesa 2 was pumped at an average rate of 380 gpm, although the substantial pumping rate fluctuations were observed (305 to 560 gpm) due to the nitrate treatment system and/or changing system pressures. After a pumping rate of about 500 gpm over the initial 13 minutes of pumping, the rate declined to about 400 gpm after 60 minutes of pumping. The pumping rate then declined to a range of 375 to 380 gpm between 90 and 120 minutes of pumping. The pumping rate briefly spiked back up to 560 gpm at 150 minutes of pumping, followed by a decline to 380 gpm at 210 minutes of pumping. The pumping rate gradually declined to a low of 305 gpm at 510 minutes of pumping, followed by a gradual rise back up to 370 to 380 gpm by the end of the pumping phase.

Interpretation of recovery data is less dependent on maintaining a constant discharge rate as compared to pumping data (Todd, 1980; Kruseman and de Ridder, 2000). Therefore, given the unavoidable pumping rate fluctuations during this test, the recovery data provided more reliable data and useful confirmation of aquifer parameters calculated from time-drawdown data impacted by pumping rate fluctuations. Interpretation of recovery data is less dependent on maintaining a constant discharge rate as compared to pumping data.

Groundwater level hydrographs and pumping test data analysis plots are provided in Appendix I. The total amount of drawdown measured at the end of 12 hours of pumping was 11.4 feet in the Vista 4 observation well and 50 feet in the Alta Mesa 2 pumping well. Evaluation of Vista 4 observation well data during the pumping phase by the Theis and Cooper-Jacob methods yield T values of 15,200 to 19,800 gpd/ft and an S value of 0.002. Observation Well Vista 4 recovery data analysis showed a T value of 19,700 gpd/ft and a K value of 8 feet/day. The pumping well recovery data analysis yields a T value of 11,000 gpd/ft, and a K value of 6 feet/day. The overall representative aquifer parameters include transmissivity of 15,500 to 19,700 gpd/ft, hydraulic conductivity of 7 to 8 feet/day, and storativity of 0.002 (Table 5). The aquifer parameter values derived from this test should be considered representative of the Paso Robles Formation at this location.

The pumping test data at this site also provided potentially useful information regarding boundary conditions in the site vicinity. In particular, the recovery data show the occurrence of a distinct discharge boundary, which may represent the Oceano Fault. A break in slope on the recovery data plot occurs at about 230 minutes after pumping ceased (a value of about 4.1 in terms of t/t' on the X axis). The change in slope (about double the slope used to calculate the T value) is indicative of a planar no-flow type of boundary on one side of the wells that was encountered within the cone of depression. Normally, this boundary condition would be present on time-drawdown data as well, but the pumping rate fluctuations may be masking the boundary during the pumping phase of the test.

8.2.3.5 City of Grover Beach

Production wells for the City of Grover Beach are located relatively close together in a park area (Plate 22). The proposed pumping test targeted Well 1 (90012), because two other wells (well 2 (90013) and Well 3 (90014) screened within the same zone were available for use as observation wells within 500 feet. In addition, a deeper screened well (Well 4 (22118)) was also located nearby for use in evaluating the connection between the Paso Robles Formation and Careaga sandstone aquifer zones at this location. The standard pumping test procedure for this study was followed using Well 1 as the pumping well from May 18 to May 20, 2014. Wells 1, 2, and 3 are screened in Paso Robles Formation, and Well 4 is screened in the underlying Careaga sandstone.

An added benefit of this test occurred as a result of transducers being installed on May 15 in Wells 2, 3, and 4 – two full days before the start of the Well 1 pumping period. Well 4 was being pumped on a daily cycle from May 15 until the morning of May 18, thereby allowing collection of drawdown and recovery data from the Careaga sandstone aquifer prior to the onset of the three-day testing period for the Paso Robles Formation aquifer (Well 1). Therefore, there were effectively two separate pumping tests conducted on City of Grover Beach wells, and data were analyzed for both tests.

The pumping rate for Well 1 over the 12-hour pumping period stayed within a relatively narrow range of 630 to 640 gpm, with a 12-hour average of 632 gpm. A transducer was unable to be installed in the pumping well (Well 1) and manual sounder measurements were not able to be collected either. Therefore, only airline measurements were available for Well 1, which have limited accuracy and resolution. The static water levels ranged from about 52 to 55 feet below top of casing for the shallow aquifer, which extends to a depth of approximately 175 feet bgs based on geologic and geophysical logs for the well field. The static water level in Well 4 was about 59 feet below top of casing, which represents the deep confined aquifer from 200 to 530 feet bgs. The shallow zone (upper 200 feet of sediments) in this area has been classified as Paso Robles Formation, whereas the deeper zone (200 to 550 feet) has been classified as the Careaga sandstone.

Groundwater level hydrographs and pumping test data analysis plots are provided in Appendix I. The measured drawdowns in the shallow aquifer observation wells ranged from about 0.2 to 0.6 feet at distances of 440 and 170 feet from the pumping well, respectively. The measured drawdown in the pumping well was two feet based on airline measurements. The relatively minimal drawdowns at a pumping rate of 632 gpm are indicative of a highly efficient well pumping from a formation of high K. The small amount of drawdown also may indicate unconfined conditions and/or a vertical recharge to the pumped aquifer (such as occurs with a semi-confined aquifer). Hydrogeologic conditions at the well field suggest the shallow aquifer is unconfined; however, a considerably longer pumping test would likely be needed to further evaluate this based strictly on time-drawdown data.

The time-drawdown data do fit a pattern of a semi-confined aquifer, which may be a result of the thin clay layer interbeds that occur in the predominantly sand, gravel, and cobble sediments comprising the screened interval. Assuming that semi-confined analytical techniques are most appropriate for the available data, the calculated transmissivity values from observation Wells 2 and 3 ranged from 112,000 to 121,000 gpd/ft. These T values divided by an aquifer thickness of 120 feet yield K values of 125 to 135 feet/day. The Cooper-Jacob and Theis Recovery analytical techniques yield transmissivity values of 500,000 to 1,200,000 gpd/ft, which are extremely high values and likely not realistic (i.e., these methods are not applicable). Storativity values from the semi-confined analysis were 0.02 and leakage coefficients were 1.0 to 1.75 – indicative of unconfined aquifer conditions and/or high rates of vertical/lateral leakage.

A distance-drawdown analysis provided an estimated transmissivity of 360,000 gpd/ft, hydraulic conductivity of 400 feet/day, and storativity of 0.10. Average aquifer parameters for this test based on both time-drawdown and distance-drawdown analyses are 240,000 gpd/ft for T, 270 feet/day for K, and 0.05 for S (Table 5). There was no influence on Well 4 water levels from pumping of Well 1 for 12 hours, indicating the two aquifers have little to no hydraulic connection.

In terms of the pumping test conducted on the deep aquifer (Careaga sandstone), the only available pumping test data are from pumping Well 4. Given this was an informal pumping test, no record of pumping rates over time was collected. However, the operator indicated that a typical pumping rate for Well 4 was approximately 530 gpm. Analysis of the available pumping test data indicate a transmissivity value of 27,000 to 32,000 gpd/ft for the deep aquifer, and an associated K value of 11 to 13 feet/day.

8.2.4 Conclusions from Pumping Test Data

Aquifer parameter values, and especially hydraulic conductivity, are available from previous reports, previous (existing) pumping test data, and from pumping test data collected in 2014 as part of this study. A summary of all available hydraulic conductivity data is provided in Table 6. As a note of caution and as previously discussed (Section 5.1), it should be pointed out that data related to full saturated aquifer thickness is not always known; well screen length, or cumulative lengths of screened intervals, are often used as a means of estimating saturated aquifer thickness. However, uncertain use of screened intervals because of limited data in lieu of aquifer thickness in estimating hydraulic conductivity may result in overestimating the hydraulic conductivity value. The highest K values are generally associated with recent alluvium of Santa Maria Valley and Arroyo Grande Plain. Previous reports indicate K values ranging from 100 to 800 feet/day for Santa Maria Valley alluvium, and 27 to 270 feet/day for Arroyo Grande Plain alluvium. Documented K values (from pumping test data reviewed or analyzed for this study) for Paso Robles Formation, beneath the Nipomo Mesa, range from 3 to 47 feet/day and from 115 to 270 feet/day beneath Tri-Cities Mesa. The overall range of K values for Paso Robles Formation is somewhat greater when incorporating reported results from previous studies.

The available data for wells screened exclusively in Careaga sandstone is limited – the reported K range is 5 to 10 feet/day for Nipomo Mesa based on previous studies, and from 12 to 13 feet/day for Tri-Cities Mesa based on previous studies and analysis of pumping test data. Data are also limited for the Squire Member of Pismo Formation, and available pumping test data indicate a K value of 5 feet/day. Limited data for the surficial Dune Sand suggest K values of 20 to 175 feet/day in Nipomo Mesa and 47 feet/day for Tri-Cities Mesa.

Overall, aquifer parameter data from previous studies and pumping test data reviewed/analyzed for this study provide a good data base for future studies (such as groundwater modeling). In addition to K values provided for various geologic units, aquifer pumping test data provided in this report (see Appendices) will be useful for model calibration of both horizontal and vertical hydraulic conductivity values. Three tests conducted for this study in Tri-Cities Mesa included monitoring of deeper or shallow units than were screened in the pumping well. The pumping test response (or lack thereof) in these monitoring wells can be used in the groundwater modeling effort to help calibrate vertical hydraulic conductivity values.

8.3 ALTERNATIVE HYDROGEOLOGIC INTERPRETATION OF PORTION OF TRI-CITIES MESA AREA

Based upon review of surface topography and geology, subsurface geologic cross-sections, existing pumping test data, and pumping tests conducted for this study, an alternative geologic conceptual model for the central portion of the Tri-Cities Mesa may be warranted. Previous studies and well log interpretations have all considered the stratigraphic column in this area to consist of 20 to 60 feet of dune sand, 150 to 200 feet of Paso Robles Formation, and 300 feet or more of Careaga sandstone (or Squire Member of Pismo Formation). Production wells are generally screened in either the shallow Paso Robles Formation aquifer (upper 200 feet), or the deeper Careaga sandstone aquifer.

In the adjacent Nipomo Mesa, Paso Robles Formation is the primary aquifer screened by wells and K values are well documented to range from 2 to 15 feet/day, with some higher values in the 15 to 50 feet/day range. However, K values of the shallow aquifer beneath central Tri-Cities Mesa are consistently much higher than 50 feet/day and generally range from 115 to 270 feet/day. These K values are more characteristic of coarse-grained recent alluvium than they are of the older Paso Robles Formation. In addition, a detailed geologic log at the Grover Beach well field documents the abundance of cobbles (some exceeding 6 inches in diameter) within relatively clean (no fines) sand, gravel, and cobble layers. This geologic layer description is more diagnostic of recent coarse-grained alluvium than it is of Paso Robles Formation.

Review of topographic and surface geology maps show that the lower portion of Arroyo Grande Creek Canyon extends from the hills with Arroyo Grande Creek heading towards the middle of Tri-Cities Mesa. However, the recent dune sands comprising the Mesa cause the creek channel to bend to the south and around the mesa. It is possible that in the geologic past, prior to deposition of the dune sands, the ancestral Arroyo Grande Creek flowed through the area presently occupied by the central portion of the mesa, including the Arroyo Grande and Grover Beach well fields. If this is the case, the upper 200 feet of sediments may contain alluvium from ancestral Arroyo Grande Creek, which better explains the presence of 6-inch diameter cobbles and the associated high hydraulic conductivity values. This hypothesis likely warrants further consideration as additional wells are drilled and logged in the future – more detailed geologic logs would be helpful in this evaluation. Regardless of the name of the formation present in the shallow aquifer beneath Tri-Cities Mesa, a future groundwater modeling effort needs to account for the extremely high transmissivity and hydraulic conductivity values of this layer, which is likely connected to alluvium in the Arroyo Grande Plain.

9.0 EVALUATION OF STREAM INFILTRATION

9.1 INTRODUCTION

Stream infiltration in the study area is primarily limited to Arroyo Grande Creek, and possibly Los Berros Creek (Plate 23). Review of existing studies and the permeable nature of Dune Sand soils suggest runoff and stream infiltration is limited for the Mesa areas, because rainfall tends to infiltrate the permeable soils as opposed to becoming runoff to stream channels. In recent years, the District has been collecting stream stage data (but not flow data) at selected locations along Arroyo Grande and Los Berros creeks. The data were provided just prior to publication of this report, so an extensive review and analysis of the data were not conducted. The full data set are appended to this report as Appendix K.

9.2 PREVIOUS STUDIES

A Hoover Associates study (1985) conducted synoptic surveys on two days in June 1984, one day with “very low” streamflow and another day with approximately 3 cubic feet per second (cfs) recorded at the USGS gauge on Arroyo Grande Creek. Based on the day with higher flows, Hoover estimated that 3.0 cfs infiltrated between the USGS gauge and 22nd Street Bridge (Plate 23). This equated to an average streambed infiltration rate of about 2 acre-feet per day (AFD). Hoover reported the creek reach with highest infiltration rate is between Fred Brieb Bridge and Highway 1 Bridge. Todd (2007) reported that the Hoover study showed net loss of about 200 acre-feet per year (AFY) between the USGS gauge and Traffic Way. Todd also stated that bedrock occurs at USGS gauge such that subsurface flow upstream is forced up into the creek at this point.

Todd (2007) conducted a synoptic survey on April 18, 2006 for Arroyo Grande Creek. Todd measured a streamflow loss of 2.2 cfs between the USGS gauge and the Highway 1 Bridge, and a streamflow gain of 0.5 cfs between the Highway 1 Bridge and 22nd Street Bridge. Thus, the net streamflow loss in the Todd survey between USGS gauge and 22nd Street Bridge was 1.7 cfs (3.4 AFD). Todd suggested that recent rains just prior to their survey may have raised the water table and/or resulted in unaccounted for seepage into the creek that may have caused lower streamflow infiltration rates on the day of the survey. Todd recommended additional synoptic surveys be conducted in late summer/early fall.

DWR (2002) generally estimated Arroyo Grande Creek stream infiltration to be about 10 percent of total inflow, with a range from 300-500 AFY in dry years to 1,600-2,400 AFY in wet years. DWR (1979) states that perennial flow is maintained in Arroyo Grande Creek via natural runoff, underflow from hills, irrigation return flows, and Lopez Dam releases. Todd (2007) reported that District staff had previously estimated up to 5 cfs (9.9 AFD) of streamflow percolation over the study area based upon informal observations; however, this estimate has not been documented.

The limited data available from previous studies regarding the amount of surface water infiltration along Arroyo Grande Creek are summarized in Table 7. The previous estimates of streamflow percolation include Hoover (1985), DWR (2002), Todd (2007), and the District (undocumented). The previous estimates are based on synoptic surveys to measure stream loss between various points on the stream on a given day, and review of available stream gaging records. The previous studies indicate that typical streamflow losses between the USGS gauge and 22nd Street Bridge range from 1.7 to 5 cubic feet per second (cfs); however, stream flow losses (and groundwater basin recharge) would be less than these measured rates at times of low stream discharge (e.g., less than 2 cfs) when the rate of infiltration is limited to the total amount of incoming streamflow.

The estimated average annual stream infiltration amounts by DWR and Todd include consideration of stream infiltration being limited at low flows, whereas the average annual stream infiltration amounts listed in Table 7 for Hoover and the District are based on the measured stream losses being maintained throughout the year. Review of the previous studies indicates the likely range for average annual streamflow infiltration along Arroyo Grande Creek ranges from about 800 to 2,100 AFY with a potential maximum ranging up to 3,600 AFY.

9.3 EVALUATION

The amount of stream infiltration likely varies substantially based on the amount of flow in Arroyo Grande Creek and groundwater levels. The limited available data indicates net streamflow percolation of about 3 cubic feet per second (cfs) in June 1984 with measured streamflow of 3 cfs at the USGS gauge and no flow at the 22nd Street Bridge. A streamflow percolation of 1.7 cfs was measured in April 2006 based on 24.2 cfs at the USGS gauge, a 5.4 cfs contribution to Arroyo Grande Creek from Los Berros Creek, and measured flow of 27.9 cfs at 22nd Street Bridge (24.3+5.4-27.9=1.7 cfs). In addition, another set of measurements in June 1984 indicate very low flow, which indicates minimal streamflow percolation.

The available data do not indicate that higher streamflow equates to higher streamflow percolation, likely because times of higher streamflow also correspond to higher groundwater elevations. There is likely a time of maximum streamflow percolation as both streamflow and groundwater level decline seasonally.

Available USGS stream gauge data after Lopez Dam construction were used to evaluate streamflow percolation. Based upon review of available data related to streamflow and streamflow percolation, the following assumptions were used in the analysis:

1. When streamflow at USGS gauge is 5 cfs or less, streamflow percolation between USGS gauge and 22nd St. Bridge is assumed to be equal to streamflow at USGS gauge.
2. When streamflow at USGS gauge is 10 cfs or more, streamflow percolation between USGS gauge and 22nd St. Bridge is assumed to be equal to 1.7 cfs.

3. When streamflow at USGS gauge is between 5 and 10 cfs, streamflow percolation between USGS gauge and 22nd St. Bridge is assumed to decline linearly from 5 cfs to 1.7 cfs.

The available Arroyo Grande Creek streamflow data from the USGS gauge range from 1939 to 1986. However, the construction of Lopez Dam changed the streamflow pattern downstream of the dam. Thus, only data from Water Year 1970 through 1986 were used in this analysis. The streamflow data used for input to the analysis and the detailed analysis results are provided in Appendix K. The streamflow data used as input were the average daily flows at the gauge for each month and year in the period of record. The overall results are summarized in Table 8. The analysis resulted in an average annual streamflow infiltration of 2,350 AFY, with a range from approximately 1,830 to 2,850 AFY.

Review of the total amount of streamflow vs. the amount of streamflow percolation shows that maximum streamflow percolation tends to occur in low to average water years. The reason for the observed relationship is that when streamflows are higher during wet years the groundwater basin is receiving significant recharge from various sources such as rainfall percolation. The overall greater recharge (from non-streamflow sources) causes higher groundwater elevations to occur in wet years, which serves to reduce streamflow percolation compared to when groundwater levels are lower in normal to dry years. However, when more detailed streamflow data become available from the District monitoring program, additional analyses are warranted to evaluate streamflow infiltration.

9.3.1 Data Gaps

Aside from the need for additional synoptic surveys to be conducted under different water table and streamflow conditions, two specific data gaps have been identified. The first data gap is the need to know how much of the previously estimated streamflow infiltration along Arroyo Grande creek occurs between the USGS gauge and Highway 101. The reason this data is needed is because this creek reach lies outside the boundary of NCMA, and streamflow percolation along this reach is presumably already accounted for in subsurface flow calculations (and thus needs to be subtracted from assumed streamflow infiltration along Arroyo Grande Creek within NCMA boundaries). A second data gap is the need to understand streamflow gain/loss between 22nd Street Bridge and the Pacific Ocean – Todd (2007) states this is a gaining reach of Arroyo Grande Creek. The net streamflow gain between 22nd Street Bridge and the ocean needs to be subtracted from total basin streamflow infiltration.

Future synoptic streamflow surveys should include previous synoptic stations (USGS, Los Berros Creek at Valley Road, Highway 1 Bridge, and 22nd Street Bridge). It is also recommended to add synoptic stations at Highway 101 Bridge, near 3rd Street, and near the Pacific Ocean along Arroyo Grande Creek, and two synoptic stations along Los Berros Creek.

10.0 EVALUATION OF AREAS FOR ENHANCED RECHARGE

10.1 INTRODUCTION

This section briefly assesses potential areas for enhanced recharge. The potential sources of water for enhanced recharge include storm water runoff, recycled water, and surface water. Potential methods that may be used for enhanced recharge are surface infiltration basins (recharge basins, storm water retention/detention basins), dry wells, and injection wells.

10.2 PREVIOUS STUDIES

The cities of Arroyo Grande and Grover Beach capture a portion of rainfall runoff and route it to infiltration basins to provide supplemental groundwater recharge. The City of Arroyo Grande is divided into three drainage zones (A, B, and C). The infiltration basins are located in Drainage Zone A (670 acres and 37% of City surface area), where soils have infiltration rates estimated to be 6 inches/day. Zone B is underlain by fine-grained soils and recharge basins are not effective, and Zone C is located in the hills north of Highway 101 and does not overlie the aquifer. Eight infiltration basins are located in Arroyo Grande, encompassing a total basin area of 145 acres with contributing watershed areas of 752 acres. The City of Grover Beach has one infiltration basin covering 48.5 acres, and with a contributing watershed area of 229 acres (Todd, 2007).

Historic infiltration from the six older Arroyo Grande infiltration basins was estimated at 175 AFY (Todd, 2007). Todd's analysis indicated a low of about 50 AF in a dry year to as much as 775 AF in a wet year. Todd estimates that 15-20% of current runoff is captured by the existing basin system. Todd estimated that the amount of storm water infiltration could be increased up to 1,000 AFY with expansion of the basin system in Arroyo Grande, Grover Beach, and Oceano.

The cities of Arroyo Grande, Grover Beach, Oceano, and Pismo Beach prepared storm water management plans in 2008. Each city anticipated that new retention/detention basins would be associated with new developments to help address local storm runoff water quality issues. These new retention/detention basins may provide additional groundwater recharge (GEI Consultants, 2013). We understand from conversations with NCMA Technical Group members that many small retention/detention basins have been installed for new developments in recent years.

Cannon (2014) recently completed the San Luis Obispo County Regional Recycled Water Strategic Plan. The areas covered in the report included essentially all of NCMA and the Nipomo CSD service area. The draft report addressed the potential for groundwater reuse in these areas along with several other reuse alternatives (e.g., agricultural irrigation, urban reuse, industrial reuse). The two groundwater reuse options evaluated were surface infiltration basins and injection wells.

Nipomo CSD has two wastewater treatment plants (WWTPs) – Blacklake and Southland. Blacklake treated effluent is already used for irrigation at Blacklake Golf Course, and Southland treated effluent is disposed through percolation basins. Southland treated effluent is already accounted for in the NMMA water balance as a groundwater recharge component. The conclusion of the Plan was that no new significant water supply benefit would be obtained through a new Nipomo CSD recycled water project; however, the need for alternative disposal methods in the future may serve as incentive for future development of such a project.

Wastewater treatment facilities in the NCMA include City of Pismo Beach and South San Luis Obispo County Sanitation District (SSLOCSD) treatment facilities. Current treated effluent disposal for both Pismo Beach and SSLOCSD is through an ocean outfall. Groundwater recharge concepts were developed along with landscape irrigation, agricultural irrigation, surface water augmentation, and industrial reuse project concepts (Cannon, 2014).

Potential groundwater replenishment options for NCMA were evaluated by Cleath and included in an appendix to the plan (Cannon, 2014). Cleath stated potential areas for surface recharge are not well defined at this time, in part because the target aquifers for municipal supply wells are at significant depth beneath surficial Dune Sand and/or alluvium. More detailed studies are needed to define areas where surface recharge can effectively migrate vertically downward through the surficial sediments to the underlying municipal well aquifers. With respect to injection wells, Cleath identified several potential locations for such wells that were sited based upon a calculated required setback distance of 2,300 feet. The 2,300 foot distance calculated by Cleath was intended to represent a 12-month residence time in the subsurface based on assumed inputs of K = 20 feet/day, porosity = 0.30, and hydraulic gradient associated with an injection mound of 0.1. Potential injection well locations identified by Cleath included the north side of Tri-Cities Mesa, interspersed among the municipal production wells in the middle of Tri-Cities Mesa, along Arroyo Grande Creek, and along the coast line (to serve as a sea water barrier).

A map of the distribution of soil units across the study area is shown on Plate 24 and the soil unit key is on Plate 25. In the discussion below, it should be noted that soil surveys use the term “permeability” for rate of infiltration. The primary soil type across Nipomo Mesa and Tri-Cities Mesa is Oceano Sand with 0 to 9 percent slopes (Unit 184), and the secondary soil type is Oceano Sand with 9 to 30 percent slopes (Unit 185). These two soil units generally correspond to the occurrence of Older Dune Sand on the geologic map (Plate 6). The Oceano Sand soil units are characterized by rapid permeability (6 to 20 inches per hour) and a Hydrologic Group A designation. Group A soils are characterized by high infiltration rates and low runoff potential, and are generally comprised of well drained sands and/or gravelly sands (USDA, 1984) and would be favorable groundwater recharge areas.

The Younger Dune Sands along the coast on the geologic map are classified primarily as the Dune land soil unit (Unit 134) with a few small areas designated as Psamments and Fluvents wet (Unit 193). The Dune land soil unit consists of sand-sized particles subject to movement by wind and is characterized by very rapid permeability, low surface runoff potential, and would be consistent with Hydrologic Group A (the Soil Survey does not assign it to a specific hydrologic group) and would be favorable groundwater recharge areas. The Psamments and Fluvents soil unit occurs in Dune land areas and consists of loamy sand that commonly contains organic matter. This soil unit is comprised of poorly drained, water logged soils subject to occasional flooding (USDA, 1984) and would not be favorable areas for groundwater recharge.

The most common soil units in the Arroyo Grande Alluvial Plain include Mocho Variant fine sandy loam (Soil Unit 176) in the northwest portion of the plain, Marimel sandy clay loam (Soil Unit 169) in the southwest portion of the plain, and Marimel silty clay loam (Soil Unit 170) in the northeastern portion of the plain. Soil Units 169 and 170 are characterized by moderately slow permeability (0.2 to 0.6 inches/hour), slow runoff, and belong to Hydrologic Groups D and C, respectively. Hydrologic Groups C and D are characterized by slow to very slow infiltration, and high runoff potential depending on slopes. Soil Unit 176 has moderately fast permeability (2 to 20 inches/hour), slow runoff, and belongs to Hydrologic Group A (USDA, 1984), which would be favorable groundwater recharge areas.

The soil groups along the valley bottom of Los Berros Creek in NMMA are Psamments and Fluvents, occasionally flooded (Soil Unit 192) and Still gravelly sandy clay loam (Soil Unit 209). The Psamments and Fluvents soil unit is located in the western portion of Los Berros Creek valley in NMMA and is described above in the Soil Unit 193 description. The Still gravelly sandy clay loam soil unit belongs to Hydrologic Group B, and is characterized by a moderate infiltration rate and slow runoff (USDA, 1984).

10.3 EVALUATION

10.3.1 NMMA Soil and Geologic Conditions

The major soil unit in Nipomo Mesa is the Oceano Sand, which has a relatively high infiltration rate and low runoff potential. Geologic cross-sections completed for this study (Plates 8 through 14) show most areas of Nipomo Mesa south of the Santa Maria River Fault, with 200 to 300 feet of surficial Dune Sand and production wells screened at depths below 300 feet. Depths to regional groundwater (i.e., not including perched water) are typically in excess of 250 feet across Nipomo Mesa. Various studies conducted by Cleath (e.g.,1996), Fugro (e.g., 2008), and others indicate that Dune Sands at many locations include one or more thin clay layers that may create perched groundwater tables at depths considerably shallower than the regional water table. These thin clay layers do not appear to be regionally continuous.

The geologic formation immediately below the Dune Sand across most of NMMA is Paso Robles Formation. Thicknesses are quite variable but typically in the range from 100 to 300 feet, and the majority of wells are screened either entirely or partially within this formation. Geologic cross-sections constructed for this study show that the upper portion of the Paso Robles Formation is often comprised of clayey sediments, thereby creating another potential surface for perched groundwater. Wells screened in Paso Robles Formation are typically screened below the upper clayey sediments of the formation. However, as shown on Plates 8 through 14, recharge to the Older Dune Sands could migrate horizontally into the Santa Maria Valley alluvium. Water recharged into the Older Dune Sands as shown on Plates 11 through 14 could recharge the Paso Robles Formation.

10.3.2 NCMA Soil and Geologic Conditions

The major soil unit in the Tri-Cities Mesa is the Oceano Sand, which has a relatively high infiltration rate and low runoff potential. Geologic cross-sections completed for this study (Plates 15 and 16) show most areas of Tri-Cities Mesa to be underlain with 20 to 60 feet of surficial Dune Sand and production wells screened at depths below 100 feet. Depths to regional groundwater are typically from 20 to 80 feet across Tri-Cities Mesa. Geologic cross-sections and review of well logs for this study indicate clay layers are prevalent along the coast, but pinch out inland to create a range of confined to unconfined conditions in the Paso Robles Formation aquifer. These unconfined areas have potential for artificial recharge projects (Plates 7 and 24).

The geologic formation immediately below the Dune Sand across NCMA is Paso Robles Formation. Thicknesses are quite variable but typically in the range from 100 to 300 feet, and several wells are screened either entirely or partially within this formation. Geologic cross-sections constructed for this study show that the upper portion of the Paso Robles Formation is relatively coarse-grained in the central inland area, thereby creating potentially good pathways for vertical migration of water and, based on 2014 aquifer tests, have some interconnection with the underlying Careaga sandstone aquifer. In coastal areas and the southern portion of Tri-Cities Mesa the upper Paso Robles Formation has more clayey sediments that likely restrict potential vertical migration of surface recharge waters to the aquifers screened in production wells.

The Arroyo Grande Plain portion of NCMA is characterized by three major soil types, only one of which is considered to have good infiltration rates (northwest portion of the plain). Limited well log data in this area make it difficult to evaluate the occurrence or absence of clay layers in the subsurface above the screened interval of typical production wells.

10.3.3 Recharge Basins

Based upon the assessment of soils and geologic conditions described above, it is likely that use of surface recharge basins to effectively recharge production aquifers is limited to the inland central part of Tri-Cities Mesa (located within the cities of Arroyo Grande and Grover Beach). This is because of the presence of clay layers in the Dune Sand and/or upper Paso Robles Formation across NMMA, in coastal areas of NCMA, and in the southern part of Tri-Cities Mesa. These clay layers tend to either create perched groundwater conditions (if present in the unsaturated zone) or impede vertical migration of recharge water for clay layers within the saturated zone. Thus, the area of suitable soils (and vadose zone) for effective use of recharge basins is generally limited to the sandy soils of the central Tri-Cities Mesa area (Plates 7 and 24), which corresponds to an urban area occupied by the cities of Arroyo Grande and Grover Beach. However, the urban development of this area greatly restricts the amount of available land for infiltration basins.

It is likely, based on inspection of well logs and cross sections extending into the Santa Maria Valley south of the study area, that sites favorable for recharge exist at the base of the Nipomo Mesa. Although some of the recharged water may be lost to the Santa Maria Valley Management Area, there may be some benefit to the NMMA, upgradient of the pumping depression that exists in the central portion of the region, given groundwater flow directions that exist in the area between the Santa Maria River and the pumping depression.

10.3.4 Dry Wells and Injection Wells

The difference between dry wells and injection wells is that dry wells only extend into the vadose zone above the water table, whereas injection wells are screened below the water table in the saturated zone. One major advantage of wells over infiltration basins is that considerably less space is required for these facilities, which is an important consideration in urban areas. Another advantage of wells is that recharge water can be placed below the impeding clay layers that may restrict vertical downward flow of water from recharge basins. A disadvantage of wells is that a significant level of water treatment is required when using either dry wells or injection wells both to meet regulatory requirements and to minimize clogging of wells.

Dry wells are likely of limited advantage over surface infiltration basins where clay layers are present near the water table and/or just above the production well screen intervals, because vertical migration of recharge water from dry wells to production well screen zones will still be impeded in these areas. In areas where such clay layers are not present or are of limited thickness and lateral extent (e.g., central Tri-Cities Mesa), surface infiltration basins have the advantage of less strict water quality requirements while likely still allowing a similar potential for vertical migration to the production aquifer afforded by dry wells in this area. In this case, the only advantage of dry wells over recharge basins is that less area is required for the facilities.

Injection wells have a major advantage over recharge basins and dry wells in areas where clay layers are prevalent above production screen intervals, because they allow for recharge water to be directly injected into the production aquifer zone. Thus, the recharge water becomes readily available for extraction by pumping wells. Another advantage of injection wells over recharge basins is that considerably less land is required for well facilities versus infiltration basin facilities. However, these advantages for injection wells are balanced against a major disadvantage of much stricter requirements for water quality and treatment of the recharge water prior to injection, higher operation and maintenance costs, as well as requirements for residence time in the aquifer prior to extraction of the recharge water. Many potential locations exist for injection wells because siting of the wells is not limited/restricted by the presence of clay layers; thus, most locations are suitable for injection wells from a hydrogeologic standpoint. However, it would be important to maximize injection rates for each well to derive the greatest water supply benefit per unit cost; therefore, it is important to site injection wells in areas of higher specific capacity (e.g., southwest of Santa Maria River and Oceano faults on Nipomo Mesa) and in geologic formations with higher specific capacities (e.g., Paso Robles Formation preferred over Careaga sandstone in Tri-Cities Mesa area). The Black Lake Canyon area may also prove to be a suitable target area because wells drilled along the bottom of the canyon (see Plates 12, 13, and 14) would not need to be drilled as deep as other parts of the area to encounter the Paso Robles Formation.

10.3.5 Sources of Water

The potential sources of water for enhanced recharge include storm water runoff, recycled water, and surface water. The only existing source of water developed for enhanced recharge is storm water runoff in the Tri-Cities Mesa. It is estimated that 15-20% of storm water runoff within the area of permeable soils in the Tri-Cities Mesa area of Arroyo Grande and Grover Beach is captured and recharged by the existing infiltration basin system. There is potential to utilize more storm water in this region for enhanced recharge via recharge basins; however, the large undeveloped areas necessary for development of recharge basins are difficult to find in this highly developed urban area. Storm water is difficult to utilize for injection wells because it requires capture, storage, and treatment prior to injection. Given the presence of clay layers in the vadose zone and/or saturated zone above production well screens, the available storm water in other areas likely has limited potential benefit to production aquifers if used for enhanced recharge via recharge basins.

A second potential source of new water is recycled water. A recent draft report prepared by Cannon (2014) documented the amounts of available recycled water, current level of treatment, and potential reuse options. In general, the most common reuse of recycled water is for irrigation (in-lieu conjunctive use management). However, utilization of highly treated recycled water for enhanced recharge has been successful in some areas (e.g., Orange

County, California). While the use of recycled water for enhanced recharge via any method poses some regulatory challenges, those obstacles are much greater for use with injection wells than for recharge basins. As discussed previously in this section, the portion of the study area where recharge basins would provide significant benefit to production aquifers are likely limited to the central portion of the Tri-Cities Mesa and portions of the Nipomo Mesa. New areas developed as recharge basins in this area might face less stringent regulatory requirements if they are able to use storm water runoff as the source of water during the wet season. However, an optimum use of recycled water in the cities of Arroyo Grande and Grover Beach might be for recharge in new and/or existing infiltration recharge basins during the dry season.

A third potential source of new water is surface water. Surface water could be derived from streams flowing into the study area (e.g., Arroyo Grande Creek, Los Berros Creek), or imported water. With respect to streams flowing into the area, water would primarily be available in the wet season during high flow events. Short duration high flow events require infrastructure for capture, storage, and infiltration of the water, thereby limiting the enhanced recharge methods to recharge basins. A source of imported water may allow for more uniform flow of water throughout the year, and provides more flexibility in terms of potential methods of enhanced recharge that may be utilized.

Overall, recharge basins will work best when located further inland over semi-confined to unconfined aquifers, whereas injection wells will work best when located near the coast in confined aquifer conditions. Recharge basins would be best supplied by capturing storm water runoff, whereas injection wells would be best supplied with recycled water from local treatment plants. This type of recharge scenario would allow for aerially dispersed recharge at the inland, upgradient side of the major production zones, and specific aquifer focused recharge along the coast to prevent seawater intrusion.

11.0 EVALUATION OF OFFSHORE AQUIFER AND SEAWATER INTRUSION

11.1 INTRODUCTION

The potential for sea water intrusion in the study area has been an ongoing concern dating back to the 1950’s. Many of the studies conducted by DWR in the region were the result of concerns related to seawater intrusion. The threat of sea water intrusion is a major limiting factor on development of the groundwater basin.

11.2 PREVIOUS STUDIES

According the DWR (1958), groundwater flow in NCMA area (as of 1954) was generally towards the ocean, although a pumping depression was noted in the area north of Oceano since 1945. However, the report stated that groundwater elevations were still above sea level and sea water intrusion likely had not occurred. The report indicated this cone of depression occurred within the Paso Robles Formation, which is less permeable than alluvium in the basin. It was believed that the area west of the pumping depression had a discontinuous clay layer that allowed deep percolation from the Older Dune Sands into Paso Robles Formation that helped maintain a seaward hydraulic gradient. Groundwater level fluctuations during the 1933 to 1954 period indicated that while groundwater levels may decline significantly at times, the Arroyo Grande Basin tends to refill during wet seasons – resulting in wide fluctuations in water levels.

Groundwater contours also indicated flow from Nipomo Mesa to the Arroyo Grande Basin at this time (DWR, 1958).

The DWR (1970) study of seawater intrusion in the Pismo-Guadalupe area documents results of a field investigation conducted in the 1960's due to suspected seawater intrusion in the study area, including installation of 32 piezometers. The field work completed for the investigation established a coastal monitoring well network through drilling and installation of several nested monitoring wells, five of which are still monitored today. The overall study objective was to evaluate the extent and rate of seawater intrusion via three tasks: 1) establish a coastal monitoring system; 2) characterize hydrogeologic and water quality conditions in the basin; and 3) evaluate the present and future potential extent of sea water intrusion. The study also included an assessment of probable offshore aquifer conditions.

The seafloor adjacent to the study area slopes very gently such that the ocean is only 1,100 to 1,400 feet deep at 20 miles off the coast. Evaluation of hydrogeologic conditions suggested that the production aquifers may extend several miles offshore, and it is likely fresh water is stored offshore in these aquifers. Groundwater level data available at the time of the study suggested that water levels fluctuated seasonally and annually with climatic conditions, but were generally stable over the long term (no net decline) in the Nipomo Mesa and Tri-Cities areas.

The overall conclusions of the DWR (1970) study were: 1) shallow groundwater in the upper 100 feet of sediments north of Arroyo Grande Creek contain chlorides at 100 to 1,630 parts per million (ppm), but the elevated concentrations were attributed to sources other than sea water intrusion; 2) with the exception noted above, the major aquifers at the coast contain fresh water with chloride concentrations of 20 to 70 ppm; 3) groundwater in inland wells ranged from 30 to 190 ppm chloride, but elevated concentrations were attributed to excess irrigation water percolation and treated effluent percolation; 4) hydrogeologic conditions indicate storage of a considerable amount of fresh water in offshore aquifers, but the potential for sea water intrusion exists in the Paso Robles Formation and Careaga sandstone aquifers if the hydraulic gradient is reversed; and 5) groundwater levels in the Arroyo Grande and Nipomo Mesa areas fluctuate with climatic conditions but did not show net declines.

The DWR (1979) report documents drilling of two exploratory boreholes/nested wells (shown on Plate 26) to depths of 850 and 1,000 feet near the coast (PSBO-1 or 90019 and PSBO-2 or 90020). These boreholes showed discrete aquifer zones near the coast that are less well defined inland. Based on available onshore geologic data and offshore seismic profiles, projection of coastal aquifers offshore showed two aquifer systems that measure 9 miles along the beach and 12 miles oceanward. The study defined an upper aquifer as being 190 feet thick and the lower aquifer that was 430 feet thick near the coast.

DWR (2002) concluded that aquifers in NMMA and NCMA extend offshore and are in hydraulic communication with the onshore portion of the aquifers. Thus, a reversal of the hydraulic gradient from offshore to onshore would result in seawater intrusion of the inland portion of the basin and ultimately into municipal, agricultural, and domestic production wells. They concluded that the offshore versus onshore direction of the hydraulic gradient may change depending on climatic conditions (i.e., dry conditions may initiate seawater intrusion that is subsequently reversed during average to wet years). DWR concluded that inadequate data exist to characterize the configuration of aquifers offshore and the location of the fresh water – salt water interface. Therefore, an early detection monitoring program was necessary to facilitate protection of the groundwater basin. DWR recommended the seawater intrusion monitoring program include mitigation actions that could be implemented in the event that seawater intrusion is detected in monitoring wells. Groundwater quality samples were collected in 1996 from seven nested coastal monitoring wells as part of their evaluation of sea water intrusion. Analytical results showed no indication of seawater intrusion at that time along the coast west of the NCMA and NMMA (DWR, 2002).

Papadopulos (2004) stated that the aquifer system is continuous offshore. Groundwater samples collected as of the time of their study did not indicate seawater intrusion. However, there was concern about exposure of Careaga sandstone as a conduit for seawater intrusion – especially given slightly elevated chloride concentrations in two coastal monitoring wells screened in that formation. Groundwater modeling indicated there may be significant lag times for seawater intrusion to occur from inland pumping depressions depending on the location of the salt water/fresh water interface.

Todd (2007) conducted a water balance study for NCMA, which included a component for subsurface outflow to the ocean. It was estimated that the average annual subsurface outflow to the ocean was about 3,000 AFY over the study period from 1986 to 2004. The calculated 3,000 AFY of outflow was sufficient to prevent seawater intrusion; however, the minimum amount of subsurface outflow needed to prevent seawater intrusion is not known. Todd's calculations assume steady-state conditions (i.e., the same conditions are maintained one year after another) – it is considerably more difficult to evaluate the effect of the more transient conditions that actually occur with annual variations in recharge and pumping. A numerical model is likely required to address these transient effects.

Elevated chloride and TDS concentrations were reported for NCMA sentry wells 30N02 and 30N03 in 2009 (Todd, 2010) when chloride concentrations increased in August 2009 and October 2009 from normal levels of 50 to 70 mg/L to as high as 190 mg/L in 30N03 and 600 mg/L in 30N02. Concurrently, TDS concentrations increased in 30N02 and 30N03 from a normal range of approximately 1,000 mg/L to as high as 2,080 mg/L in 30N02 in October 2009. In response to the concern of seawater intrusion, the NCMA municipal water agencies reduced groundwater pumping from in excess of 6,000 AFY in 2008 and prior years to approximately 4,000 AFY in 2010 and 2011. The reduction in groundwater pumping was compensated by increased use of State Project surface water and reduced overall water demands during 2010 and 2011. The concentrations of chloride and TDS in sentry wells 30N02 and 30N03 subsequently returned to pre-2009 levels.

The NCMA 2013 Annual Report (Fugro, 2014) documents the historic groundwater level data pertaining to seawater intrusion monitoring. Four coastal sentry wells with nested completions are located within about 2,000 feet of the coastline, and another nested completion is located about 4,000 feet inland. Groundwater levels in the four nested wells nearest the coastline have fluctuated over time dating back to 1967. The wells typically fluctuate in an elevation range from +4 to +10 feet above mean sea level, with occasional fluctuations above or below this range. Water level fluctuations below this range occurred between 2007 and 2009, during a time when precipitation was well below average. Groundwater levels at sentry wells subsequently recovered since 2009 to within their historic ranges.

Due to concerns about potential for seawater intrusion in the 2007 to 2009 time period, the NCMA implemented a quarterly water quality monitoring program for the sentry wells and Oceano CSD observation wells. In addition, the agencies in the NCMA voluntarily reduced groundwater pumping, implemented conservation measures, and have been working towards development of additional surface water supplies.

The NCMA has developed a deep well index for coastal monitoring of groundwater levels as an indication of risk for seawater intrusion. The three wells in the index are 32S/12E-24B3 (with a screened interval 270-435 feet below ground surface (bgs)), 32S/13E-30F3 (305-372 feet bgs), and 32S/13E-30N2 (175-255 feet bgs), located along the coastline west of the cities of Pismo Beach, Grover Beach, and Oceano. It has been suggested that an average water level elevation of the three deep sentry wells of 7.5 feet above mean sea level (MSL) is the minimum elevation to maintain over an extended time period to minimize the potential for seawater intrusion. Groundwater levels were below the deep well index (minimum desired level) from October 2007 to August 2009, and a spike in chloride and sodium concentrations were observed in Well 32S/13E-30N3 (60-135 feet bgs) in late 2009. NCMA coastal groundwater levels recovered to above the minimum threshold level during 2010 to 2012, but again declined below 7.5 feet MSL from June to December 2013 (Fugro, 2014), and have continued to remain below the deep well index throughout the first six months of 2014. The NCMA supplements their monitoring program with periodic monthly water level measurements and groundwater sampling, such as in the Spring 2014, to improve the monitoring program during the severe dry conditions (e.g., over the 2013 to 2014 time period).

The NMMA conducts a monitoring program that includes groundwater level and groundwater quality data. In contrast to the degraded water quality and potential seawater intrusion event of October 2009 in the 30N02 sentry well in NCMA, consistent long-term water levels and water quality persisted in NMMA coastal well 12C, at least up until the current drought conditions. The most recent annual report (NMMA Technical Group, 2014) indicated that the inland region represented by the NMMA Key Wells Index is experiencing Potentially Severe Water Shortage Conditions (i.e., the normalized groundwater elevation derived from measurements in several wells is below 31.5 feet above mean sea level). Spring 2013 groundwater elevations, as represented by the Key Wells Index, showed a sharp decline from 2012 levels. However, it is important to note that coastal water quality was substantially better than the threshold for Potentially Severe Water Shortage Conditions (based on consistent chloride concentrations between approximately 60 and 90 mg/L), and inland groundwater quality was relatively unchanged in 2013.

11.2.1 Geologic Conditions

Although continuity of lithologic units (e.g., clay layers) and geologic formations extending offshore are not well defined, our review of data (including from previous studies) and geologic cross-sections developed for this study suggest that onshore geologic formations likely continue offshore for several miles. An interface (i.e., contact) between freshwater and salt water exists between the coastline and some unknown distance offshore. The fresh water/salt water interface may be at different locations for the various aquifers separated by substantial clay layers, depending on the amount of recharge, pumping, and subsurface outflow associated with each aquifer. The fact that the locations of these fresh water/salt water interfaces (in the various aquifers) are unknown is not meant to imply a minimal threat of seawater intrusion. It should be assumed that the interface is near the shoreline, and groundwater levels need to be maintained at elevations sufficient to allow adequate offshore flow of freshwater to prevent seawater intrusion.

Available data suggest aquifers providing potable groundwater to NCMA and NMMA are subject to seawater intrusion if hydraulic gradients are reversed for a sufficient period of time (i.e., no geologic barriers to seawater intrusion are known to exist). Seawater intrusion can occur laterally through subsea geologic unit outcrops on the ocean floor and/or through vertical migration through overlying layers. Geologic conditions along the study area coastline and offshore (i.e., continuation of aquifers westward beneath the ocean floor until they pinch out or outcrop on the ocean floor) indicate that it is necessary to maintain a certain amount of subsurface outflow towards the ocean to prevent seawater intrusion.

11.3 EVALUATION

Although offshore geologic data are limited, it is likely that geologic formations present along the coastline and inland continue offshore beneath the ocean floor. There are no documented geologic features that would serve to help restrict the potential for seawater intrusion (e.g., faulting or folding of geologic formations at the coastline or just offshore). Previous studies suggest aquifers present in these geologic formations likely continue offshore for up to several miles before intersecting the shallow slope of the ocean floor. However, vertical pathways for seawater to migrate through the ocean floor and into the aquifers likely exist, and such vertical movement of seawater may occur depending on hydraulic gradients. Thus, it is critical that groundwater levels onshore be maintained at high enough elevations to prevent the vertical and lateral migration of seawater inland across the coastline.

An evaluation of seawater intrusion for NCMA and NMMA is primarily contingent upon an assessment of groundwater elevations and groundwater gradients – particularly near the coast. In addition, historic groundwater quality data during times of lower groundwater elevations may be useful in evaluating seawater intrusion. An important factor to consider in this overall analysis was mentioned by Papadopulos (2004) regarding the lag time that may be associated with lowered groundwater elevations onshore and appearance of saline water at inland water supply wells. It should be noted that Papadopulos evaluated seawater intrusion lag times for Nipomo Mesa, where production wells and pumping depressions are further inland than in NCMA. Thus, it should not be assumed that the significant lag times (several years) shown in modeling results for Nipomo Mesa are applicable to NCMA.

Groundwater level fluctuations in recent years have been correlated with climatic conditions and basin groundwater pumping. A notable decline in groundwater levels along the coast occurred in the 2007 to 2009 period related to consecutive years of below normal rainfall, followed by recovery of water levels during a high rainfall year (Fugro, 2014). In particular, water level declines during 2007 to 2009 were noted in wells 30F3 (screened 305-372 feet bgs), 30N2 (175-255 feet bgs), OCSD Silver (395-435 and 470-510 feet bgs), and OCSD Yellow (625-645 feet bgs). As described under the Previous Studies section of this report, the NCMA municipal water agencies reduced groundwater pumping and increased surface water use during 2010 and 2011 to help mitigate groundwater level declines. Although groundwater levels subsequently recovered during 2010 and 2011, notable groundwater level declines began to occur again in some wells by late 2013 and into 2014.

The NMMA has designated eight key wells to track overall groundwater elevations across Nipomo Mesa. In addition, NMMA tracks water level and water quality data from nested coastal monitoring wells 12C and 36L to help evaluate water shortage conditions for NMMA. The period of record for the key wells extends back to the 1960s or 1970s for five of the nine wells, and at least back to the late 1990s for all key wells. Several key wells were at or near historic lows in 2013, likely related, at least in part, to the extremely dry climatic conditions since fall of 2012. NMMA groundwater contour maps for spring and fall 2013 generally show groundwater flow towards the coast, although insufficient data points are available in the western portion of NMMA to document flow directions near the coast. A large pumping depression was present in 2013 (and has been recognized in previous years by NMMA) in the west central portion of Nipomo Mesa, and included some wells with groundwater elevations slightly below sea level. As described below, recent groundwater quality data for the NMMA area do not indicate the presence of sea water intrusion.

Recent groundwater quality data collected in the NMMA area includes one coastal monitoring well cluster (11N/36W-12C1, 2, 3) and several inland wells. Chloride concentrations since 2007 in monitoring well cluster 12C have remained generally consistent from year to year with overall concentrations ranging from about 40 to 50 milligrams per liter (mg/l) in well 12C2 (screened 450 to 460 feet bgs) to 90 to 100 mg/l in well 12C3 (screened 720 to 730 feet bgs). Chloride and TDS concentrations at inland well locations were reported to be relatively unchanged in 2013 compared to previous years (NMMA Technical Group, 2014). Although data points for water quality data collection are limited within the NMMA, especially near the coast, available data show no indication of seawater intrusion as of 2013 even though groundwater elevations at some wells have declined slightly below sea level.

The NCMA coastal sentry well network is also monitored closely for groundwater quality changes – especially rising chloride and TDS levels that may be indicative of sea water intrusion. Chloride/TDS spikes were noted in late 2009 in wells 30N3 (60-135 feet bgs) and OCSD Blue (190-210 and 245-265 feet bgs) The chloride/TDS spikes in 30N3 and OCSD Blue were one time measurements in late 2009, and returned to normal levels by the next sampling event in 2010. Thus, the relationship of elevated chloride/TDS levels and seawater intrusion is not yet clear. However, it should be noted that NCMA municipal water agencies acted quickly to reduce groundwater pumping, and this action likely helped to mitigate the elevated chloride/TDS concentrations.

Review of groundwater level and groundwater chemistry data indicate that water level declines are more prevalent in deeper screened wells, and spikes in chloride/TDS more prevalent in shallower screened wells. Additional data are being collected for the NCMA groundwater monitoring program, and will need to be reviewed in future studies to better understand how susceptible the various aquifers may be to seawater intrusion. The current extremely dry conditions since the beginning of 2013 and associated water level declines may provide greater insight on potential seawater intrusion pathways. However, based on data collected to date, it is clear that it will be important to maintain groundwater elevations a sufficient distance above sea level to avoid seawater intrusion in the future.

Based on review of available data and under existing pumping conditions, it appears that the current drought has not resulted in seawater intrusion. However, an extended multiple year drought has not occurred under current pumping conditions, and it remains to be seen if such a drought will lead to problems with seawater intrusion in the NCMA and/or NMMA. In addition, if long-term overdraft were to occur in the study area (independent of shorter term dry climatic conditions) the most likely detrimental effect would be the occurrence of seawater intrusion and resulting inability to pump potable groundwater from certain existing production wells.

12.0 INSTALLATION OF PERMANENT PRESSURE TRANSDUCERS

This section briefly summarizes the rationale for well selection, types of transducers installed, and initial programming of the four pressure transducers installed in wells as part of this basin characterization study. A brief TM was initially prepared (June 18, 2014) to document existing monitoring wells with permanent transducers already installed (Appendix L), and to obtain input from the District and Steering Committee on selection of an additional four wells for transducer installation which were to be purchased and installed as part of this project. Appendix L includes a list of wells that were evaluated for potential transducer installation as well as a list of wells with previously installed transducers (note that the table of information included in the TM in Appendix L has been updated as Table 9 of this report). The list of potential new instrumentation was developed on the basis of direct discussions and input from the NCMA and NMMA technical groups.

12.1 WELL SELECTION

Based on review of existing transducer locations, a review of 2013 NCMA and NMMA annual reports, and direct discussions with NCMA and NMMA TG members, coastal monitoring is considered the highest priority due to increasing risk of seawater intrusion from declining groundwater levels. Secondary priority is monitoring the groundwater flow relationships between management areas. Existing well locations with transducers installed are summarized in Table 9 and locations shown on Plate 26. Eight potential candidate wells, with 10 unique screen intervals and transducer settings, were evaluated for new permanent transducer installations, including 32S/13E-30N03 (60-135 feet bgs); 12N/35W-32 blue (190-210 and 245-265 feet bgs); 12N/35W-32 silver (395-435 and 470-510 feet bgs); 12N/36W-36L01 (227 to 237 and 535-545 feet bgs) ; 11N/34W-19Q01 (screen unknown); 11N/35W-22M01 (430-680 feet bgs); 11N/35W-23G01 (400-460 feet bgs); and 11N/36W-12C01 (280-290 and 450-460 feet bgs). All well locations are summarized in Table 9 and shown on Plate 26.

On the basis of both verbal and written responses from District staff and the NCMA and NMMA technical groups, the need to enhance the coastal monitoring network was clearly a priority. As a result, transducers were installed in the following two monitoring wells and associated horizons:

- 12N/36W-36L01 – screened interval of 227-237 feet bgs.
- 12N/36W-36L01 – screened interval of 535-545 feet bgs.
- 11N/36W-12C01 – screened interval of 280-290 feet bgs.

- 11N/36W-12C01 – screened interval of 450-460 feet bgs.

Well 12N/36W-36L is the Oceano Dunes well, represented as well 90019 on Plate 26. Well 11N/36W-12C is represented as well 90020 on Plate 26.

12.2 INSTALLATION AND PROGRAMMING

The installed transducers record water levels, electrical conductivity, and temperature, with a reading and monitoring frequency at 4 hour intervals. The transducers were set in the 12N/36W-36L monitoring wells in April 2015, and set in Well 11N/36W-12C in October 2015.

13.0 CLIMATE CHANGE

Consistent with California state guidelines for Integrated Regional Water Management (IRWM) planning, Climate Change Analysis is now considered a critical component in the planning and implementation of water resources management projects and programs. The 2014 IRWM Guidelines require that IRWM Plans address both adaptation to the effects of climate change and mitigation of greenhouse gas (GHG) emissions resulting the potential effect of climate change and GHG on the region to identify and prioritize the Region’s vulnerabilities to the effects of climate change.

A Climate Change section is a requirement of the IRWM Plan grant process, and is developed from the San Luis Obispo County IRWM Plan. The Climate Change section, prepared for this report by GEI Consultants and presented in full in Appendix M, focuses on the Santa Maria Groundwater Basin (or Santa Maria Basin Region), which is a portion of the South County Sub-Region of the IRWM Plan. In the process of evaluating climate change for the Santa Maria Basin Region (Region), a Vulnerability Assessment Checklist has been modified to consider GHG emissions between possible project alternatives occurring specifically in the Santa Maria Basin Region. The checklist of prioritized vulnerabilities assists in the ranking and selection process of project alternatives. As with any climate change analysis, a large component of the Region’s implementation of adaption is through data management and monitoring to provide a continuous analysis of climate change as it takes place in the future.

The purpose of this Climate Change analysis is to:

1. **Educate the reader on the contributing factors and measurements of climate change** – a brief introduction to define the terminology used in the section and how each contributes to the understanding of climate change
1. **Describe how Climate Change Analysis is performed** – a discussion of the global models and downscaled data used in the analysis performed in the section’s Climate Change Analysis
2. **Summarize the climate change results** – a summary of the Climate Change Analysis results
3. **Present a ranking of vulnerabilities** – a rating and explanation of vulnerabilities stemming from a thorough vulnerability assessment

The scientific study for this section is derived from both the Climate Change Analysis for the San Luis Obispo County IRWM Region and for the Santa Barbara County IRWM Region, and from various climate change related websites.

The Climate Change Analysis assumes mid-century (2050) carbon production conditions, and runs those conditions through 40 years of monthly hydrology and 20 years of daily hydrology to develop a statistical average of the various climate variables. In this way, the model results are presented so the mid-century results of climate variables are representative of an average over a hydrologic period of record to account for the naturally occurring dry- and wet-period hydrology.

The table, below, provides results of the Climate Change Analysis using monthly data aggregated to seasonal time periods for the mid-century (2050) point in time. The table illustrates the change in average seasonal amounts for each of the key climate variables utilized in the analysis.

Variable	**Change in Variables**				
	Medium Warming Scenario				
	Winter	**Spring**	**Summer**	**Fall**	**Annual**
Precipitation (see note)	7.0%	-27.5%	-32.5%	0.9%	-5.02%
Maximum Temp	6.6%	4.6%	6.1%	6.0%	5.81%
Minimum Temp	23.2%	14.1%	11.2%	18.8%	15.40%
Wind Speed	0.2%	-1.2%	-0.8%	0.7%	-0.32%
Evapotranspiration	-1.8%	3.8%	7.1%	6.0%	4.90%
Runoff	12.8%	-33.7%	-4.4%	1.7%	-8.78%

Note: Percentage amounts also provide the level of sensitivity of the current average amount to the model change (i.e., current small value amounts of rainfall in spring are more sensitive to change than larger values in winter.)

In the table above, the cells with green backgrounds indicate increases of 3 percent change for current seasonal average or more; red backgrounds indicate decreases of 3 percent or more; and white backgrounds indicate no significant change. The table values provide a sense of the order of magnitude of change projected in 2050 as a result of climate change.

The full analysis is presented in Appendix M.

14.0 SUMMARY

This report presents the results of several subtasks conducted for the Santa Maria Basin Characterization project. The subtasks included review of previous studies, compilation of databases, geologic cross-sections, aquifer pumping tests, streamflow infiltration, enhanced recharge areas, seawater intrusion, and selection of wells for permanent transducer installation. The geologic cross-sections were based on the well log database developed for this study. The pumping tests were conducted in coordination with NCMA and NMMA agencies to obtain aquifer parameters. The other subtasks were based on previous studies and data collected during the course of this project.

14.1 PREVIOUS STUDIES

A number of previous hydrogeology studies have been conducted by the NCMA, NMMA, DWR, USGS, consultants, and others. These existing studies have contributed to development of a greater understanding of hydrogeologic conditions in the SMBC study area. In addition, extensive databases of key hydrogeologic data (e.g., groundwater levels, water quality, water demands) have been compiled and continue to be updated on an annual basis for each management areas. This report provided detailed summaries of several previous studies, the data and results of which were applied to subsequent tasks in the overall SMBC study.

14.2 ONGOING DATA COLLECTION PROGRAMS

The NMMA and NCMA have ongoing data collection programs for groundwater levels, groundwater quality, water demands, and other hydrologic data. These data are compiled on an annual basis, databases are updated, and results are summarized in annual reports. Each annual report presents key data and describes recent and longer term trends in groundwater levels, groundwater quality, and other data sets. Points of emphasis in both management areas include monitoring for seawater intrusion (based on coastal groundwater elevations, maintaining a seaward hydraulic gradient, and chloride/TDS concentrations), and monitoring of groundwater elevations associated with inland pumping depressions.

14.3 DATABASES

Two primary databases were developed as a result of the SMBC study: a lithology database, and a specific capacity/pumping test database. The lithology database consists of water well and oil well logs that could be located relatively accurately. Each log was plotted in Google Earth and transferred to GIS. A lithologic symbol system was used to characterize lithologic layers described on each log and entered into an Excel database. The lithology database includes the well log number, top and bottom of each lithologic layer, a lithologic layer symbol, supplemental lithologic layer description notes, color, presence of shells, and DWR assigned T/R/S.

The specific capacity/pumping test database includes wells for which specific capacity or pumping test data are available. The database includes a number of column entries for each well, including well log number, test date, pumping rate, drawdown, specific capacity, duration of pumping, estimated transmissivity (based on conversion of specific capacity or calculated directly from time-drawdown data), screen length, estimated K, T, and S values, and formation screened.

Other important databases (e.g., groundwater levels, groundwater quality) have been developed and are maintained by the respective Technical Groups for each Management Area (i.e., NCMA and NMMA).

14.4 DATA GAPS

The distribution of wells associated with the two primary databases developed for the SMBC study was reviewed to identify data gaps. In general, lithologic data, specific capacity/pumping test data, and geophysical logs are lacking in the Arroyo Grande Plain and in coastal areas. Specific capacity/pumping test data are also sparse in the area surrounding the upper reaches of Black Lake Canyon and in the northwestern portion of Nipomo Mesa north of

Santa Maria River Fault. Geophysical logs compiled for this study are lacking in the same areas where lithologic logs are sparse and generally throughout the entire northern half of Nipomo Mesa.

14.5 GEOLOGY AND GEOLOGIC CROSS-SECTIONS

A total of thirteen geologic cross-sections were constructed across the NMMA and NCMA. The cross-sections are based on the lithologies recorded in the well log database compiled for this study, and depict the interpreted geologic formation contacts, well screen intervals, faults and associated offsets, and possible correlations of fine and coarse-grained units within the geologic formations.

In the NCMA area, Paso Robles Formation is present beneath 20 to 60 feet of Dune Sand sediments beneath Tri-Cities Mesa. The Paso Robles Formation is typically 100 to 300 feet thick in this area and underlain by Careaga sandstone. Production well screen intervals are typically screened exclusively in one formation or the other in Tri-Cities Mesa. The Arroyo Grande Plain has up to 140 feet of alluvium underlain by Paso Robles Formation and/or Careaga sandstone. Distinct aquifer zones separated by relatively continuous clay layers are present along the coast in the Paso Robles Formation, but these clay layers pinch out and/or become discontinuous inland.

In the NMMA area, there is typically 200 to 300 feet of Dune Sand underlain by Paso Robles Formation and Careaga sandstone. Paso Robles Formation generally is thicker near the coast and becomes thinner inland as it crosses each respective fault zone. The Careaga sandstone is variable and often undefined in thickness (because well logs commonly are not deep enough to define the base of the formation), but generally the top of Careaga sandstone is deeper near the coast and becomes shallower inland and across each fault zone. Although not explicitly depicted on cross sections (e.g., Plates 11 and 12), clay layers are present within the Dune Sand deposits in the southern portion of the Nipomo Mesa, giving rise to a relatively shallow aquifer of potentially limited regional extent (see Sections 7.2.2, 8.1.1, and 10.3.1 of this report).

14.6 PUMPING TESTS

Six pumping tests were conducted with the cooperation of five different agencies across NMMA and NCMA including: City of Arroyo Grande, Oceano CSD, City of Grover Beach, Nipomo CSD, and Golden State Water Company; additional tests were proposed but could not be performed due to logistical issues (e.g., inability to shut down wells to allow for recovery ahead of pumping test, inability to pump a well continuously for 8 to 12 hours). Each test included one or more monitoring wells near the pumping well. Of the four tests conducted in NCMA (two for City of Grover Beach), two tests were conducted with pumping wells screened in Paso Robles Formation and two tests were conducted with pumping wells screened in the deeper Careaga sandstone. Both tests conducted in NMMA utilized pumping wells screened in the Paso Robles Formation. The overall results of the pumping test program conducted in the Spring of 2014 indicate Paso Robles Formation transmissivity values in the NCMA of 120,000 to 240,000 gpd/ft, Careaga sandstone transmissivity values in the NCMA of 21,500 to 29,500 gpd/ft, and Paso Robles Formation transmissivity values in the NMMA of 15,500 to 45,000 gpd/ft.

Hydraulic conductivity values reported in previous studies were compiled and documented in this report. In addition, previous pumping test data were reviewed, analyzed, and summarized for this report. Overall, this report provides a comprehensive summary of existing and new pumping test data, and provides a good basis for future development of a Salt/Nutrient Management Plan and a numerical groundwater model.

14.7 STREAM INFILTRATION

Previous studies related to stream infiltration are described and summarized in this report. Based on the limited record of synoptic streamflow studies documented in previous studies, general assumptions were developed to conduct an analysis of available Arroyo Grande Creek streamflow data. The USGS stream gauge on Arroyo Grande Creek was maintained by USGS between 1939 and 1986, but our analysis was limited to 1970 to 1986 in order to correspond to construction of Lopez Dam in the late 1960's. The results of our analysis showed streamflow infiltration along Arroyo Grande Creek ranging from approximately 1,800 to 2,900 AFY, with an overall average of 2,353 AFY. These results agree well with previous analyses by Hoover (1985) and Todd (2007). Stream bed infiltration (recharge) along Arroyo Grande Creek is estimated to be between 15% to 20%, indicating 2,000 to 2,400 AFY of runoff could be available for recharge.

14.8 RECHARGE

The City of Arroyo Grande has eight storm water infiltration basins covering an area of 145 acres, and City of Grover Beach has one basin with an area of 48.5 acres. The use of recharge basins for enhanced recharge that has substantial benefits to production aquifers is likely limited to the central portion of Tri-Cities Mesa in the cities of Arroyo Grande and Grover Beach. In other areas, clay layers in the vadose zone or upper portion of the saturated zone likely impede the direct vertical migration of water to the production zone. Injection wells are potentially feasible in terms of delivering recharge water directly to the production zone throughout the NMMA and NCMA; however, the episodic nature of potential water sources such as storm water runoff or surface water from streams may not be particularly amenable to use of injection wells. In addition, injection wells have more stringent requirements for water quality and significant treatment of source water would likely be needed prior to injection. Highly treated recycled water is a potential source of water for enhanced recharge, given it is a steady source of supply. However, it may be more challenging to utilize for groundwater recharge than it is for irrigation applications due to regulatory requirements related to residence time and setback distances from production wells.

14.9 OFFSHORE AQUIFERS AND SEAWATER INTRUSION

Previous studies in the NCMA and NMMA areas were largely conducted out of concern for potential sea water intrusion. The most significant detrimental effect should overpumping of the groundwater basin occur would be seawater intrusion, because it is likely that onshore aquifers continue a significant distance offshore beneath the ocean floor. Thus, the primary means of preventing seawater intrusion is to maintain sufficient offshore flow of groundwater to keep the fresh water/salt water interface at or seaward of the coastline. In order to maintain sufficient offshore flow of groundwater, groundwater elevations must be maintained a sufficient distance above mean sea level and westward groundwater flow directions must be maintained.

Previous studies and data indicate that groundwater levels may fluctuate significantly related to climatic conditions. A period of dry years from 2007-2009 resulted in notable groundwater level declines in some coastal observation wells, and temporary spikes in chloride/TDS concentrations in a limited number of coastal observation wells. Groundwater management actions undertaken by the municipal water suppliers in the NCMA during this time helped to mitigate the effects of seawater intrusion.

Past experience has shown that a coastal monitoring well network of sufficient well density is critical to long-term management of seawater intrusion in the NMMA and NCMA. The NCMA generally has a good coastal (sentry) well monitoring network both in terms of geographic well distribution and vertical distribution of screen zones at the well clusters. The NCMA has increased the frequency of sentry well monitoring from semi-annual to quarterly, with periodic monthly monitoring events during critical dry conditions such as occurred in 2014. The NMMA coastal monitoring well network could benefit from additional coastal (sentry) monitoring wells to provide better geographic and vertical coverage of potential seawater intrusion pathways to the south of existing coastal monitoring wells.

14.10 INSTALLATION OF PERMANENT PRESSURE TRANSDUCERS

Several monitoring wells within the NCMA area have permanent transducers installed to collect water levels, electrical conductivity, and temperature measurements. The scope of work for this study included the purchase and installation of four additional permanent transducers. Two clustered coastal monitoring wells, each with two distinct screened-interval depths, were selected for transducer installation. Two transducers were installed in 12N/36W-36L01 and 36L02 on April 15, 2015, and two transducers were installed in 11N/36W-12C01 and 12C02 in October 2015.

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TABLES

Table 1a. Specific Capacity Data - Data from Cities, Water Agencies, and Golf Courses

Log No.	Well T/R/S	Date Drilled	Test Date	RE	Q	SWL	PWL	DD	Q/s	Duration (Min)	Est. T	Screen Length	Est. K	Time-DD data?	Formation Screened/Zone
51612	11N/35W-9K5	3/30/1979	4/12/1979	173	1,500	149	210	61	24.6	?	49,180	355	19	No	Paso Robles/3
276929	11N/35W-10G5	7/27/1988	6/27/1989	301	350	297	366	69	5.1	?	10,145	140	10	Partial	Paso Robles/2
171358	11N/35W-10J2	8/20/1985	8/27/1985	317	400	300	382	82	4.9	350	9,756	240	5	Limited	Paso Robles/Careaga/2
336387	11N/35W-10L1	10/21/1992	?	263	500	276	357	81	6.2	143	12,346	300	6	Limited	Paso Robles/3
182644	11N/35W-11J3	2/10/1986	3/1/1988	389	125	347	419	72	1.7	300	3,472	75	6	Limited	Careaga/2
158739	11N/35W-13G1	2/22/1985	2/28/1985	346	200	281	382	101	2.0	480	3,960	90	6	No	Paso Robles and Carega/2
222813	11N/35W-10G4	5/3/1984	5/19/1984	319	350	300	345	45	7.8	4,320	15,556	220	9	No	Paso Robles/2
221031	11N/34W-19E1	12/14/1967	12/2/1982	307	218	257	259	2	109.0	?	218,000	120	243	No	?/2
NA	11N/34W-19L3	5/8/1967	3/5/1980	303	240	221	234	13	18.5	?	36,923	271	18	No	?/2
90024	11N/34W-20	1/24/2000	10/17/2007	300	33	39.4	55.9	16.5	2.0	2,880	4,000	40	13	Yes	?/1
90025	11N/34W-20	1/27/2000	10/22/2007	300	92	44.4	84.3	39.9	2.3	1,440	4,612	80	8	Yes	?/1
156769	11N/35W-4	6/10/1986	?	Location?	60	104	134	30	2.0	?	4,000	120	4	No	Location Uncertain
90005	12N/35W-33	8/8/1983	?	291	75	?	?	142	0.5	?	1,056	30	5	No	Paso Robles/2
290834	11N/35W-5B1	9/26/1989	?	292	150	221	320	99	1.5	240	3,030	60	7	No	Paso Robles/2
395064	11N/35W-5	3/1/1993	3/9/1993	247	100	224	250	26	3.8	240	7,692	80	13	No	Paso Robles/2
906322	11N/35W-5	9/3/2004	4/27/2005	109	105	101	139	38	2.8	330	5,526	60	12	Limited	Paso Robles/3
511080	11N/35W-4	12/1/1997	12/18/1997	293	60	273	299.1	26.1	2.3	1,440	4,598	50	12	Yes	Paso Robles/2
511078	11N/35W-4	12/19/1997	1/5/1998	231	55	212.3	285.3	73	0.8	665	1,507	50	4	Yes	Paso Robles/2
511086	11N/35W-4	1/7/1998	1/9/1998	267	100	254	300.6	46.6	2.1	1,140	4,292	80	7	Yes	Paso Robles/2
511087	11N/35W-4	12/31/1997	1/12/1998	248	55	228.2	297.4	69.2	0.8	1,200	1,590	46	5	Yes	Paso Robles/2
402088	11N/35W-16J	12/3/1993	12/15/1993	279	1,000	246	286	40	25.0	1,440	50,000	300	22	Yes	Paso Robles/3
490963	11N/35W-15D	6/13/1994	7/7/1994	246	1,200	244	295	51	23.5	1,440	47,059	240	26	Yes	Paso Robles/3
490919	11N/35W-15R	7/1/1994	7/21/1994	242	1,400	237	295	58	24.1	1,440	48,276	210	31	Yes	Paso Robles/3
490922	11N/35W-22M	7/13/1994	8/4/1994	184	1,400	171	251	80	17.5	1,440	35,000	250	19	Yes	Paso Robles/3
182660	11N/35W-24A1	4/28/1988	10/19/1989	328	132	261.5	292	30.5	4.3	?	8,656	185	6	No	Paso Robles/3
127249	11N/35W-24J1	7/3/1980	9/2/1980	320	444	272.5	294.5	22	20.2	?	40,364	235	23	No	Paso Robles/3
161355	11N/35W-24L2	4/16/1985	10/22/1992	349	265	328.5	351	22.5	11.8	?	23,511	135	23	No	Paso Robles/3
352734	11N/35W-24L3	6/27/1991	8/23/2006	311	202	317	370.1	53.1	3.8	?	7,608	80	13	No	Paso Robles/3
78836	32S/13E-19Q2	3/29/1973	1973	?	675	25	295	270	2.5	2,340	5,000	350	2	No	Paso Robles/Careaga/1
78836	32S/13E-19Q2	3/29/1973	11/14/1989	?	539	80	122	42	12.8	?	25,667	350	10	No	Paso Robles/Careaga/1
90023	32S/13E-19Q2	3/29/1973	3/5/2013	65	549	20.19	177	156.81	3.5	240	7,002	295	3	Yes	Paso Robles/Careaga/1
174229	32S/13E-19B	12/18/1985	12/30/1985	31	177	14.1	63.4	49.3	3.6	1,413	7,181	190	5	Yes	Pismo/1
174325	32S/13E-18Q	1/10/1986	1/10/1986	64	250	50.4	93.6	43.2	5.8	1,440	11,574	260	6	Yes	Pismo/1
		1990	12/21/1992	?	680	28	79	51	13.3	?	26,667	?	?	No	Careaga/1
NA	No Well Log	1990	3/4/2013	Location?	854	14.42	94.5	80.08	10.7	240	21,329	170	17	Yes	Careaga/1
NA	No Well Log		1/9/2014	86	320	76	80	4	80.0	?	160,000	?	?	No	Paso Robles/1
90008	?	8/11/1954	1/9/2014	87	400	82	89	7	57.1	?	114,286	119	128	No	Paso Robles/1
90026	?	7/9/1964	1/9/2014	85	402	76	82	6	67.0	?	134,000	140	128	No	Paso Robles/1
90009	32S/13E-29F1	3/9/1967	1/9/2014	74	971	64	71	7	138.7	?	277,429	125	297	No	Paso Robles/1
90010	?	12/10/1981	1/9/2014	86	674	82	181	99	6.8	?	13,616	235	8	No	Careaga/1
339665	?	12/17/1990	1/9/2014	87	479	82	108	26	18.4	?	36,846	94	52	No	Paso Robles/1
40-0651	32S/13E-32D3	5/15/1952	1/22/2014	89	304	79.5	90	10.5	29.0	?	57,905	14	553	No	Paso Robles/1
51670	32S/13E-32D11	11/9/1979	1/22/2014	?	380	87	255	168	2.3	?	4,524	207	3	No	Careaga/1
219080	32S/13E-31A	6/12/1984	1/22/2014	32	912	43	119	76	12.0	?	24,000	140	23	No	Careaga/1
22118	32S/13E-29E7	10/25/1978	1978	64	1,025	50	135	85	12.1	120	24,118	270	12	Yes	Careaga/1

Notes: See bottom of Table 1b for explanations

Table 1b. Specific Capacity Data - Data from DWR Water Well Drillers Reports

Log No.	Well T/R/S	Date Drilled	Test Date	RE	Q	SWL	PWL	DD	Q/s	Duration (Min)	Est. T	Screen Length	Est. K	Time-DD data?	Formation Screened/Zone
40-0909	11N/34W-18	3/5/1976	?	331	40	185	200	15	2.7	4,320	5,333	60	12	No	Paso Robles/2
401545	11N/34W-18	7/8/1992	7/28/1992	358	60	290	307	17	3.5	2,400	7,059	90	10	No	Paso Robles/Careaga/2
763353	11N/34W-19E2	4/24/2002	?	307	900	252	266	14	64.3	480	128,571	180	95	No	Paso Robles/Careaga/2
40-0826	11N/34W-19L1	3/19/1962	?	299	600	236	304	68	8.8	?	17,647	275	9	No	Paso Robles/Careaga/2
289187	11N/34W-19L4	1989	?	298	500	220	234	14	35.7	3,780	71,429	200	48	No	Paso Robles/Careaga/2
1082555	11N/34W-20	1/19/2009	1/22/2009	317	7	244	251	7	1.0	720	2,000	100	3	No	Paso Robles/Careaga/2
505486	11N/34W-20	1/12/2001	1/12/2001	311	10	71	280	209	0.05	?	96	120	0.1	No	Tert. Undiv./1
38350	11N/34W-20E2	12/4/1958	?	321	30	235	244	9	3.3	?	6,667	14	64	No	Paso Robles/2
538880	11N/34W-21	8/5/2000	8/22/2000	370	100	295	343	48	2.1	2,880	4,167	80	7	No	Paso Robles/Careaga/2
538355	11N/34W-21	9/29/1998	9/29/1998	322	80	209	360	151	0.5	?	1,060	80	2	No	Careaga/2
1090797	11N/34W-27	3/2/2007	3/8/2007	298	3	265	330	65	0.05	240	92	120	0.1	No	Tert. Undiv./1
1098046	11N/34W-29	2/17/2007	?	286	770	270	319	49	15.7	480	31,429	125	34	No	Paso Robles/Careaga/2
1082554	11N/34W-29	11/8/2008	11/2/2008	303	650	250	337	87	7.5	1,440	14,943	160	12	No	Paso Robles/Careaga/2
1082553	11N/34W-29	11/29/2008	9/10/2008	323	600	255	350	95	6.3	1,440	12,632	160	11	No	Paso Robles/Careaga/2
1098071	11N/34W-29	5/12/2008	5/1/2008	166	600	91	110	19	31.6	480	63,158	220	38	No	Paso Robles/Careaga/2
748810	11N/34W-35	3/12/2004	3/15/2004	213	30	81	104	23	1.3	240	2,609	135	3	No	?(Santa Maria Valley)/2
159144	11N/35W-2	12/5/1978	?	419	4	?	?	60	0.07	120	133	45	0.4	No	Sisquoc/1
143717	11N/35W-2	8/11/1980	?	434	4	80	177	97	0.04	360	72	100	0.1	No	Sisquoc/1
1085530	11N/35W-2	3/25/2006	3/25/2006	394	2	320	393	73	0.02	240	49	140	0.05	No	Sisquoc/1
491800	11N/35W-4	7/18/1991	7/19/1991	365	20	309	427	118	0.2	240	339	200	0.2	No	Paso Robles/2
139094	11N/35W-4	3/30/1982	?	195	90	202	235	33	2.7	240	5,455	156	5	No	Paso Robles/3
77808	11N/35W-5	12/14/1971	?	256	410	256	336	80	5.1	240	10,250	90	15	No	Paso Robles/2
77809	11N/35W-5	10/4/1971	?	72	314	220	300	80	3.9	240	7,850	135	8	No	Paso Robles/3
961854	11N/35W-5J	5/18/2012	5/16/2012	148	100	136	224	88	1.1	1,440	2,273	170	2	No	Paso Robles/3
None	11N/35W-7A1	5/19/1951	?	79	570	75	165	90	6.3	?	12,667	31	55	No	Paso Robles/Careaga/3
None	11N/35W-7A1	5/19/1951	?	79	600	75	275	200	3.0	?	6,000	31	26	No	Paso Robles/Careaga/3
5946	11N/35W-7R1	2/1/1954	?	87/112	1,500	55	109	54	27.8	?	55,556	133	56	No	Paso Robles/Careaga/3
907653	11N/35W-8	11/29/2004	12/15/2004	90	500	73	211	138	3.6	480	7,246	250	4	No	Paso Robles/3
223663	11N/35W-8	3/20/1989	?	172	10	209	239	30	0.3	240	667	40	2	No	Paso Robles/3
715654	11N/35W-8	8/16/2002	8/26/2002	268	30	256	266	10	3.0	240	6,000	80	10	No	Paso Robles/3
715663	11N/35W-8	8/16/2002	8/22/2002	265	30	266	280	14	2.1	480	4,286	80	7	No	Paso Robles/3
715655	11N/35W-8	8/16/2002	8/23/2002	266	30	257	270	13	2.3	240	4,615	100	6	No	Paso Robles/3
763499	11N/35W-9	2/25/2005	2/28/2005	179	10	145	149	4	2.5	480	5,000	100	7	No	Paso Robles/3
763500	11N/35W-9	2/28/2005	3/2/2005	163	50	137	147	10	5.0	240	10,000	100	13	No	Paso Robles/3
1090810	11N/35W-9	11/18/2006	12/11/2006	218	972	201	282	81	12.0	540	24,000	160	20	No	Paso Robles/Careaga (?)/3
1090811	11N/35W-9	11/4/2006	11/24/2006	201	800	237	281	44	18.2	300	36,364	140	35	No	Paso Robles (?)/3
1090226	11N/35W-9	12/6/2008	12/28/2008	188	600	189	270	81	7.4	240	14,815	200	10	No	Paso Robles (?)/3
1085512	11N/35W-10	5/31/2006	5/31/2006	280	250	223	286	63	4.0	240	7,937	180	6	No	Paso Robles/Careaga/2
907667	11N/35W-10	9/28/2005	10/4/2005	283	229	287	314.7	28	8.3	240	16,534	120	18	No	Paso Robles/Careaga/2
336363	11N/35W-11	6/29/1991	?	124	30	121	130	9	3.3	480	6,667	80	11	No	Paso Robles/3
763495	11N/35W-11	1/21/2005	1/21/2005	346	30	294	310	16	1.9	240	3,750	120	4	No	Paso Robles/2
139247	11N/35W-12	3/30/1984	?	394	11	104	201	97	0.11	240	227	137	0.2	No	Sisquoc (?)/1
1090807	11N/35W-13	12/1/2006	12/6/2006	321	15	160	254	94	0.16	240	319	180	0.2	No	Paso Robles/2
1089651	11N/35W-13	11/23/2007	11/27/2007	307	300	238	287	49	6.1	480	12,245	200	8	No	Paso Robles/Careaga (?)/2
786263	11N/35W-14	5/21/2004	5/20/2004	292	150	261	310	49	3.1	480	6,122	100	8	No	Paso Robles/Careaga (?)/2
1085548	11N/35W-14	1/23/2006	2/6/2006	311	30	237	290	53	0.6	240	1,132	120	1.3	No	Paso Robles/2
1085549	11N/35W-14	1/3/2006	2/6/2006	?	28	186	302	116	0.2	240	483	100	0.6	No	Paso Robles/2
34272	11N/35W-17	9/13/1969	?	92	270	?	?	132	2.0	2,880	4,091	145	4	No	?(Santa Maria Valley)/3
104151	11N/35W-22	10/11/1965	?	101	980	?	?	176	5.6	240	11,136	170	9	No	?(Santa Maria Valley)/3
1098051	11N/35W-23	1/0/1900	7/15/2007	289	700	280	340	60	11.7	1,440	23,333	260	12	No	Paso Robles/3
1097672	11N/35W-23	10/21/2006	10/19/2006	304	23	257	324	67	0.3	240	687	140	0.7	No	Paso Robles/3
1090806	11N/35W-23	11/28/2006	11/27/2006	355	30	276	299	23	1.3	240	2,609	80	4	No	Paso Robles/3
1097661	11N/35W-24	9/23/2006	9/27/2006	344	20	321	330	9	2.2	240	4,444	60	10	No	Paso Robles/3
103045	11N/35W-24L1	12/23/1976	?	348	527	276	374	98	5.4	3,750	10,755	226	6	No	Dune Sand/Paso Robles/3
1098062	11N/35W-25	6/5/2008	6/1/2008	135	1,500	80	89	9	166.7	720	333,333	200	223	No	?(Santa Maria Valley)/3
961855	11N/35W-25	3/1/2012	3/1/2012	?	1,600	65	97	32	50.0	240	100,000	180	74	No	?(Santa Maria Valley)/3
802734	11N/35W-26	8/7/2002	?	121	2,012	64	103	39	51.6	420	103,179	130	106	No	?(Santa Maria Valley)/3

Table 1b. Specific Capacity Data - Data from DWR Water Well Drillers Reports (Con't).

Log No.	Well T/R/S	Date Drilled	Test Date	RE	Q	SWL	PWL	DD	Q/s	Duration (Min)	Est. T	Screen Length	Est. K	Time-DD data?	Formation Screened/Zone
78140	11N/35W-27E1	2/26/1974	?	?	10	173	200	27	0.4	?	741	55	2	No (bail test)	Tca(?)/Tms(?)/1
961853	11N/35W-34	5/10/2012	5/2/2012	?	1,600	56	73	17	94.1	720	188,235	200	126	No	?(Santa Maria Valley)/3
40-1823	32S/13E-20N1	11/5/1950	?	95	50	68	73	5	10.0	300	20,000	18	149	No	Paso Robles/1
5774	32S/13E-28E1	1/22/1951	1/22/1951	112	25	93	98	5	5.0	120	10,000	40	33	No	Paso Robles/1
5775	32S/13E-28P3	12/30/1950	12/27/1950	112	700	99	169	70	10.0	3,000	20,000	130	21	No	Paso Robles/Careaga/1
90011	32S/13E-29B2	1/15/1957	?	73	60	69	76	7	8.6	?	17,143	27	85	No	Paso Robles/1
17801	32S/13E-29C3	6/19/1954	?	50	950	79	89	10	95.0	630	190,000	60	423	No	Paso Robles/1
39474	32S/13E-29F2	7/14/1967	?	72	1,020	63	143	80	12.8	1,080	25,500	51	67	No	Paso Robles/1
90009	32S/13E-29F1	Oct. 1964	?	74	2,050	65	97	32	64.1	240	128,125	125	137	No	Paso Robles/1
90012	32S/13E-29E1	9/18/1951	9/26/1951	60	1,400	50	62	12	116.7	?	233,333	144	217	No	Paso Robles/1
90013	32S/13E-29E2	9/21/1951	9/29/1951	61	1,400	50	62	12	116.7	?	233,333	141	221	No	Paso Robles/1
90014	32S/13E-29E3	5/19/1959	5/26/1959	64	2,100	58	81	23	91.3	?	182,609	120	203	No	Paso Robles/1
90017	32S/13E-30K5	1933	?	30	287	?	?	11	25.2	?	50,351	?	?	No	Paso Robles/1
90018	32S/13E-30K6	?	?	31	611	?	?	9.5	64.3	?	128,632	90	191	No	Paso Robles/1
50900	32S/13E-30K14	5/23/2006	?	49	1,500	?	?	60	25.0	840	50,000	102	66	No	Paso Robles/1
101595	32S/13E-30K16	8/5/1965	?	30	1,600	23	80	57	28.1	240	56,140	70	107	No	Paso Robles/1
31910	32S/13E-30R13	4/1/1966	?	51	1,200	36	61	25	48.0	240	96,000	80	160	No	Paso Robles/1
38509	32S/13E-32D9	2/20/1960	?	85	480	61	128	67	7.2	1,890	14,328	17	113	No	Paso Robles/1
223346	32S/13E-33M	6/9/1987	?	48	20	19	86	67	0.3	240	597	40	2	No	Alluvium/Paso Robles/1
77824	32S/13E-33	12/14/1971	?	257	410	256	376	120	3.4	240	6,833	90	10	No	Paso Robles(?)/Careaga (?)/2
792436	32S/13E-35N	1/27/2003	1/30/2003	182	35	17	32	15	2.3	240	4,667	180	3	No	?/1
792463	32S/13E-35	10/12/2004	10/6/2004	232	500	23	130	107	4.7	720	9,346	200	6	No	?/1
1085551	32S/13E-36	12/18/2005	12/29/2005	332	500	94	212	118	4.2	4,320	8,475	100	11	No	?/0

Notes:
Zone 1 = between Wilmar Avenue Fault and Santa Maria River Fault
Zone 2 = between Santa Maria River Fault and Oceano Fault
Zone 3 = between Oceano Fault and Pacific Ocean
T/R/S = Township/Range/Section
RE = Reference (Land Surface) Elevation (feet MSL)
Q = Pumping Rate (gpm)
SWL = Depth (feet) to Static Water Level;
PWL = Depth (feet) to Pumping Water Level
DD = Drawdown (feet)
Q/s = Specific Capacity (gpm/foot)
Est. T = Estimated Transmissivity (gpd/ft) based on conversion (x 2000) from Specific Capacity; see Sections 5.1, 5.3, and 8.2 of this report
Est. K = Estimated Hydraulic Conductivity (feet/day) based on T divided by Screen Length (feet); see Sections 5.1, 5.3, and 8.2 of this report for discussion of appropriate use of screen length and aquifer thickness

Summary of Specific Capacity Data

Q/s	No. Samples	T	K (mean)	Formation Screened/Zone
1.3	1	2,609	3	?(Santa Maria Valley)/2
62	6	123,329	45	?(Santa Maria Valley)/3
1.3	17	2,642	4	Paso Robles/2
8.1	24	16,237	8	Paso Robles/3
1.1	2	2,266	3	Careaga/2
NA	0	NA	NA	Careaga/3
12	17	24,495	12	Paso Robles/Careaga/2
5.4	1	10,755	6	Dune Sand/Paso Robles/3
12	4	24,556	35	Paso Robles/Careaga/3
0.06	4	120	0.14	Sisquoc/1
0.05	2	94	0.10	Tert. Undiv./1
34.1	20	68,241	109	Paso Robles/1
7.5	5	15,362	10	Careaga/1
7.9	2	15,847	10	Paso Robles/Careaga/1

Table 2. Top Elevations of Geologic Formations for Cross-Sections

Cross-Section	Zone	Elevation of Top QTpr (Feet MSL)	Thickness of QTpr (Feet)	Elevation of Top Tca (Feet MSL)	Thickness of Tca (Feet)	Elevation of Top Tms (Feet MSL)
A-A'	1	NP	NP	200 to 270	10 to 20	180 to 260
B-B'	1	170 to 310	50 to 140	80 to 180	40 to 50	50 to 130
C-C'	1	170 to 320	40 to 160	80 to 220	30 to 80	20 to 200
D-D'	1	170 to 370	90 to 180	-10 to 230	20 to 60	-50 to 200
E-E'	1	210 to 370	160 to 210	NP	NP	10 to 170
F-F'	1	90 to 260	100 to 260	NP	NP	-20 to -10
G-G'	1	50 to 260	> 100	<-100 to -80	> 190	NA
I-I'	1	70 to 110	120 to >250	-40 and lower	> 40	NA
A-A'	2	40 to 200	80 to 150	-160 to 120	> 80	NA
B-B'	2	20 to 100	120 to 200	<-280 to 10	40 to 50	<-280 to -40
C-C'	2	0 to 160	230 to 300	-300 to -120	< 70	NA
D-D'	2	10 to 170	> 240	NA	NA	NA
E-E'	2	60 to 210	180 to 310	-250 to 30	190 to 300	-440 to -280
F-F'	2	20 to 230	140 to 250	-130 to -10	100 to >120	<-260 to -130
G-G'	2	-10 to -90	> 170	NA	NA	NA
J-J'	2	-60 to 130	120 to 330	<-200 to -80	160+	NA
K-K'	2	-30 to 180	110 to 260	-200 to 40	30 to >150+	<-300 to -70
D-D'	3	-100 to 30	> 320	NA	NA	NA
E-E'	3	-40 to 60	470 to 630	-650 to -470	170 to 200	-840 to -650
F-F'	3	-180 to 20	> 380	NA	NA	NA
G-G'	3	-150 to -10	230 to 430	-650 to -250	> 50 to 240	-930 to >-720
H-H'	1 (TCM)	0 to 90	110 to 280	-290 to -30	320 to 380+	-620 to -500
I-I'	1 (TCM)	10 to 30	50 to 250	-230 to -40	> 200	-670 +/-
L-L'	3 (Coastal)	-50 to 0	130 to 390	-400 to -180	200 to 380	-560 to -740
M-M'	3 (Coastal)	-130 to 30	380 to 520	-650 to -400	200 to 290+	<-900 to -600

Legend:
NA = Not Available; NE = Not Estimated; NP = Not Present ; TCM=Tri Cities Mesa; QTpr = Paso Robles Formation; Tca = Careaga sandstone; Tms = Sisquoc Formation

Table 3. Hydraulic Conductivity Values from Existing Studies (feet/day)

Study	Qds (NM)	Qds (TCM)	Qal (SMV)	Qal (AGP)	QTpr (SMV)	QTpr (NM)	QTpr (TCM-AGP)	QTpr (All Areas)	Tca (All Areas)	Tpps
NMMA (NMMA, 2010)					13 to 52	2 to 15				
NCMA (Todd, 2007)		47		27			13		7	7
Worts, 1951						9			9	
Cleath, 1996						5 to 50				
LSCE, 2000	175⁽²⁾		270 to 600			2 to 15			9.5	
LSCE, Model⁽¹⁾			100 to 200			20 to 30			5 to 10	
DWR, 1970				110 to 400				70 to 230	<13 to 67	
DWR, 2002			270 to 800	95 to 270		<1 to 70	15 to 360			3 to 15
Overall Range	175	47	100 to 800	27 to 270		<1 to 70	13 to 360		5 to 10	3 to 15

Legend:

Qds = Dune Sand; Qal = Alluvium; QTpr = Paso Robles Formation; Tca = Careaga sandstone; Tpps = Pismo Formation;
NM = Nipomo Mesa; TCM = Tri-Cities Mesa; SMV = Santa Maria Valley; AGP = Arroyo Grande Plain

Footnote:

1. These K values are based on a calibrated model and are not directly derived from pumping tests or lab tests.
2. This is an assumed value and is not based on specific capacity or pumping test data.

Table 4. Existing Aquifer Pumping Test Results

Test Well	Well Log ID	Test Date	PW or OW	Unit	T (gpd/ft)	K (ft/d)	S	Comments
PB Well 5	90023	3/5/13	PW	QTpr/Tca	15,500	5	NA	Zone 1
PB Well 23	NA	3/4/13	PW	Tca	31,000	12	NA	Zone 1
PB Well 9	174229	12/30/85 and 7/13/05	PW	Tpps	7,500	5	NA	Zone 1
PB Well 10	174235	1/21/86 and 7/26/05	PW/OW	Tpps	11,500	5	0.0015	Zone 1
GB Well 4	22118	10/31/78	PW/OW	Tca	30,000	13	NA	Zone 1
Woodlands Well 1	962000	12/15/93	PW/OW	QTpr	70,000	31	0.002	Zone 3
Woodlands Dawn Rd.	490963	7/7/94	PW	QTpr	85,000	37	NA	Zone 3
Woodlands Mesa Rd.	490919	7/21/94	PW	QTpr	76,000	47	NA	Zone 3
Woodlands Homestead	490922	8/4/94	PW	QTpr	27,000	14	NA	Zone 3
CR Well 4	511080	12/04/97	PW	QTpr	5,000	11	NA	Zone 2
CR Well 5	511078	1/5/98	PW	QTpr	5,800	10	NA	Zone 2
CR Well 6	511086	1/7/98	PW	QTpr	6,300	10	NA	Zone 2
CR Well 7	511087	1/8/98	PW	QTpr	1,000	3	NA	Zone 2
NCSD Bev 2	171358	8/27/85	PW	QTpr/Tca	17,800	9	NA	Zone 2
NCSD WWTP MW-1	90024	10/17/07	PW	Qds		22	NA	Zone 1
NCSD WWTP MW-3	90025	10/19/07	PW	Qds		20	NA	Zone 1

Legend:
PB = Pismo Beach; GB = Grover Beach; CR Cypress Ridge; NCSD = Nipomo Community Services District; PW = Pumping Well; OW = Observation Well;
T = Transmissivity; K = Hydraulic Conductivity; S = Storativity; Qds = Dune Sand; QTpr = Paso Robles Formation; Tca = Careaga sandstone; Tpps = Pismo Formation; ; NA = Not Available or Not Applicable; PW/OW = Pumping test utilized one or more observation wells, but only the pumping well is listed in the left most column.

Table 5. Aquifer Pumping Test Results

Test Well	Area	PW or OW	Unit	T (gpd/ft)	K (ft/d)	S	Comments
AG Well 8	Zone 1	PW	QTpr	30,000	29	N/A	Unconfined aquifer conditions
(339665) AG Well 8		OW	QTpr	123,000	117	0.002	OW 3 top of screen is 36 feet shallow than PW 8
AG Well 8		Dist-DD	QTpr	117,000	112	0.02	
AG Well 8		N/A	QTpr	**120,000**	**115**	**0.01**	**Overall Representative Values**
OCSD Well 8	Zone 1	PW	Tca	26,000	13	NA	Semi-confined to confined aquifer conditions
(219080) OCSD Well 8		OW	Tca	17,500	9	0.003	
OCSD Well 8		N/A	Tca	**21,500**	**11**	**0.003**	**Overall Representative Values**
GB Well 1	Zone 1	OW	QTpr	117,000	130	0.02	Unconfined aquifer conditions
(90012) GB Well 1		Dist-DD	QTpr	360,000	400	0.10	
GB Well 1		N/A	QTpr	**240,000**	**270**	**0.05**	**Overall Representative Values Average of Observation Well and Distance-Drawdown Analyses**
GB Well 4 (22118)	Zone 1	PW	Tca	**29,500**	**12**	**N/A**	Semi-confined to confined aquifer conditions
NCSD BL 4	Zone 2	PW	QTpr	18,000	11	N/A	Unconfined aquifer conditions
(276929) NCSD BL 4		OW	QTpr	70,000	41	0.02	OW BL 3 bottom of screen is 30 feet deeper than PW BL 4
NCSD BL 4		N/A	QTpr	**45,000**	**26**	**0.02**	**Average of Pumping and Observation Wells Overall Representative Values**
GSWC AM 2	Zone 3	PW	QTpr	11,000	6	N/A	Semi-confined to confined aquifer conditions
(161355) GSWC AM 2		OW	QTpr	20,000	8	0.002	OW Vista 4 screen is 30 feet deeper and 100 feet shallower than PW AM2 screen
GSWC AM 2		N/A	QTpr	**15,500**	**7**	**0.002**	**Overall Representative Values**

Legend:
AG = Arroyo Grande; OCSD = Oceano Community Services District; GB = Grover Beach; NCSD = Nipomo Community Services District; GSWC = Golden State Water Company; PW = Pumping Well time-drawdown data used to calculate T/K values; OW = Observation Well time-drawdown data used to calculate T/K/S values; Dist-DD = Distance-Drawdown data used to calculate T/K/S values; T = Transmissivity; K = Hydraulic Conductivity; S = Storativity; QTpr = Paso Robles Formation; Tca = Careaga sandstone;
; NA = Not Available or Not Applicable

Table 6. Summary of Hydraulic Conductivity Values (feet/day)

Unit	Zone	Previous Studies	Existing Data	2014 Data	Overall Range
Qal	SMV	100-800	--	--	100-800
Qal	AGP	27-270	--	--	27-270
Qds	NMMA	175	20-22	--	20-175
Qds	NCMA	47	--	--	47
QTpr	Zone2	--	3-11	26	3-26
QTpr	Zone 3	--	14-47	7	7-47
QTpr	All Zones	<1-70	--	--	<1-70
QTpr	NCMA	13-360	--	115-270	13-270
QTpr/Tca	Zone 2	--	9	--	9
QTpr/Tca	NCMA	--	5	--	5
Tca	All Zones	5-10	--	--	5-10
Tca	NCMA	7	12-13	11-12	7-13
Tpps	NCMA	--	5	--	5

Legend:
Qds = Dune Sand; Qal = Alluvium; QTpr = Paso Robles Formation; Tca = Careaga sandstone; Tpps = Pismo Formation; NCMA = Northern Cities Management Area; NMMA = Nipomo Mesa Management Area; SMV = Santa Maria Valley; AGP = Arroyo Grande Plain

Table 7. Previous Arroyo Grande Creek Streamflow Infiltration Estimates

Reference	Measured Stream Loss (cfs)	Estimated Average Annual Stream Infiltration (AFY)
Hoover (1985)	3 (June 1984)	2,100
DWR (2002)	NA	800
Todd (2007)	1.7 (April 2006)	2,017
District (undocumented)	5	3,600

Table 8. Streamflow Infiltration Analysis

Reference	Calculated Average Annual Stream Infiltration (cfs)	Calculated Average Annual Stream Infiltration (AFY)
Minimum	2.6	1,830
Maximum	3.9	2,853
Average	3.2	2,353

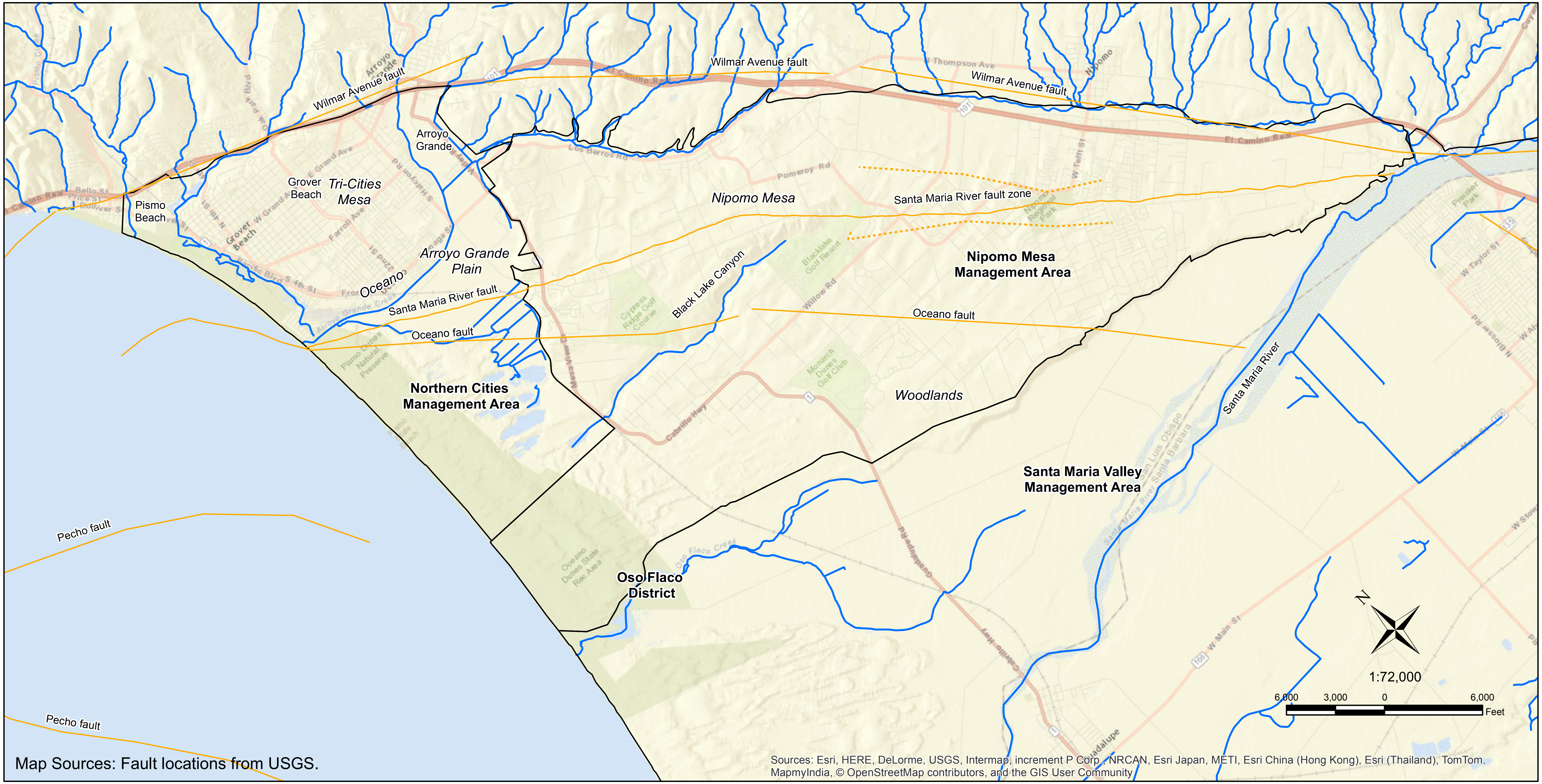
Table 9. Wells with Existing Transducers and Potential New Transducer Installations

Wells with Transducers	Management Area	Well Log No.	Screen (feet bgs)	Other Wells in Cluster/Screen Intervals (feet bgs)
32S/12E-24B01	NCMA	90021 (POO-1)	48-65	B2 = 120-145, B3 = 270-435
32S/12E-24B03	NCMA	90021 (POO-1)	270-435	B1 = 48-65, B2 = 120-145
32S/13E-30F03	NCMA	90015 (POO-3)	305-372	F1 = 15-30, 40-55; F2 = 75-100
32S/13E--30N02	NCMA	90016 (POO-4)	175-255	N1 = 15-40; N3 = 60-135
11N/35W-23G01 (1)	NMMA	1083178 (Co. MW-5)	400-460	None
11N/36W-12C01 (2)	NMMA	90020(PSBO-2)	280-290	C2 = 450-460; C3 = 720-730
11N/36W-12C01 (2)	NMMA	90020(PSBO-2)	280-290	C2 = 450-460; C3 = 720-730
12N/35W-32C03	NCMA/NMMA	961625 (Co. MW-3)	90-170	None
12N/36W-36L01 (4)	NCMA	90019 (PSBO-1)	227-237	L2 = 535-545
12N/36W-36L02 (5)	NCMA	90019 (PSBO-1)	535-545	L1 = 227-237

Potential New Locations	Management Area	Well Log No.	Screen (feet bgs)	Other Wells in Cluster/Screen Intervals (feet bgs)	Surface Elevation (Feet MSL)	Depth to Water (feet bgs)	Transducer Depth (below water level)
32S/13E-30N03	NCMA	90016 (POO-4)	60-135	N1 = 15-40; N2 = 175-255	14	5-10	55-60
11N/34W-19Q01	NMMA	Unknown (Division Rd.)	Unknown	Unknown	?	?	?
11N/35W-22M01	NMMA	490922 (Woodlands Homestead)	430-680	None	184	171 (in 1994)	264
12N/35W-32	NCMA	221036 (OCSD MW Blue)	190-210, 245-265	Green = 100-133, Silver = 395-510, Yellow = 625-645	32	13-31	164-182
12N/35W-32	NCMA	221036 (OCSD MW Silver)	395-435, 470-510	Green = 110-130, Blue = 190-265, Yellow = 625-645	32	13-31	369-387

Notes: (1) Transducer installed in December 2013 by SMVMA
(2) Transducer installed in October 2015 as part of Santa Maria Basin Characterization study
(3) Transducer installed in October 2015 as part of Santa Maria Basin Characterization study
(4) Transducer installed in April 2015 as part of Santa Maria Basin Characterization study
(5) Transducer installed in April 2015 as part of Santa Maria Basin Characterization study

PLATES



Map Sources: Fault locations from USGS.

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

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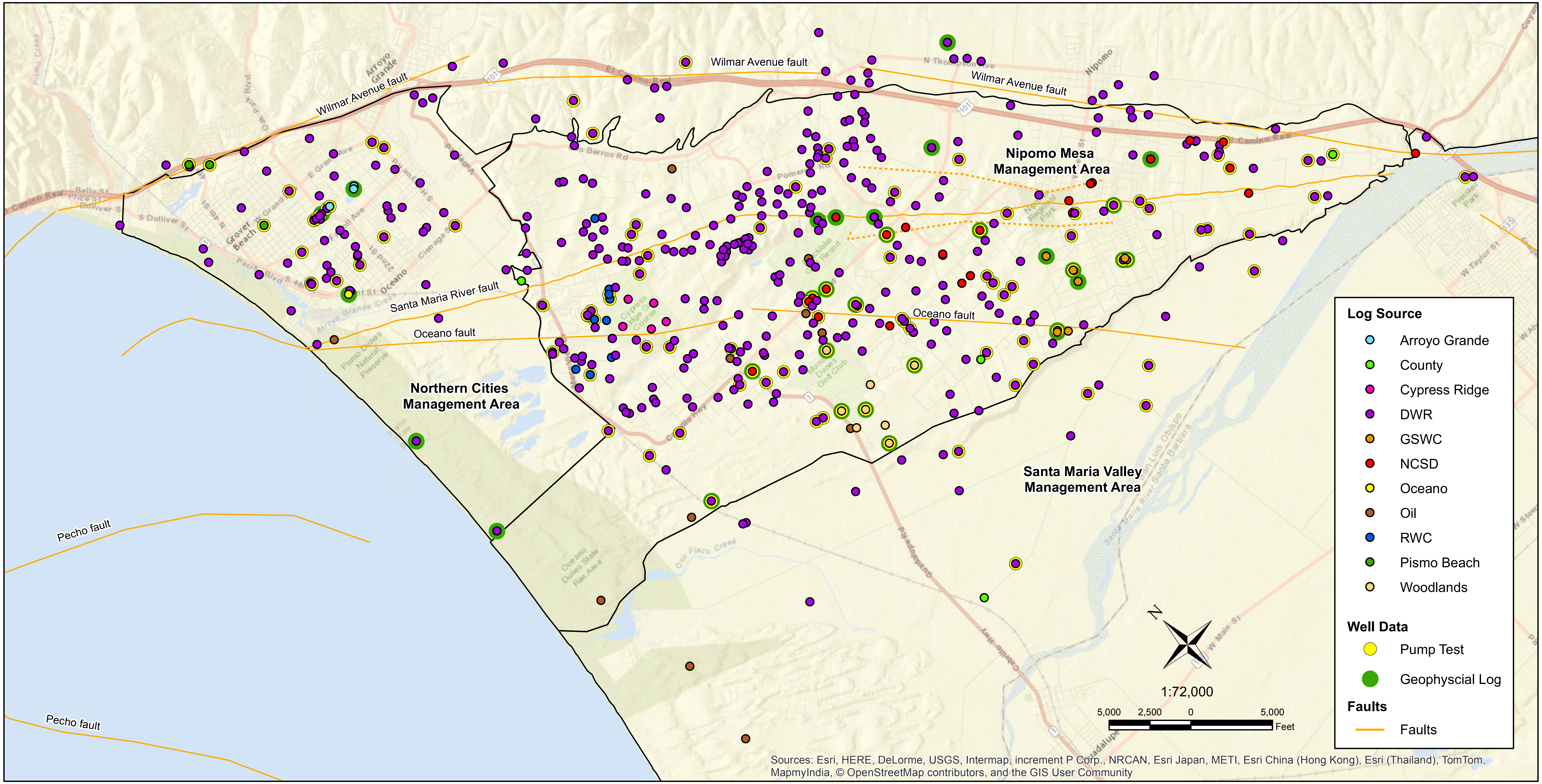
STUDY AREA LOCATION MAP
Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 1



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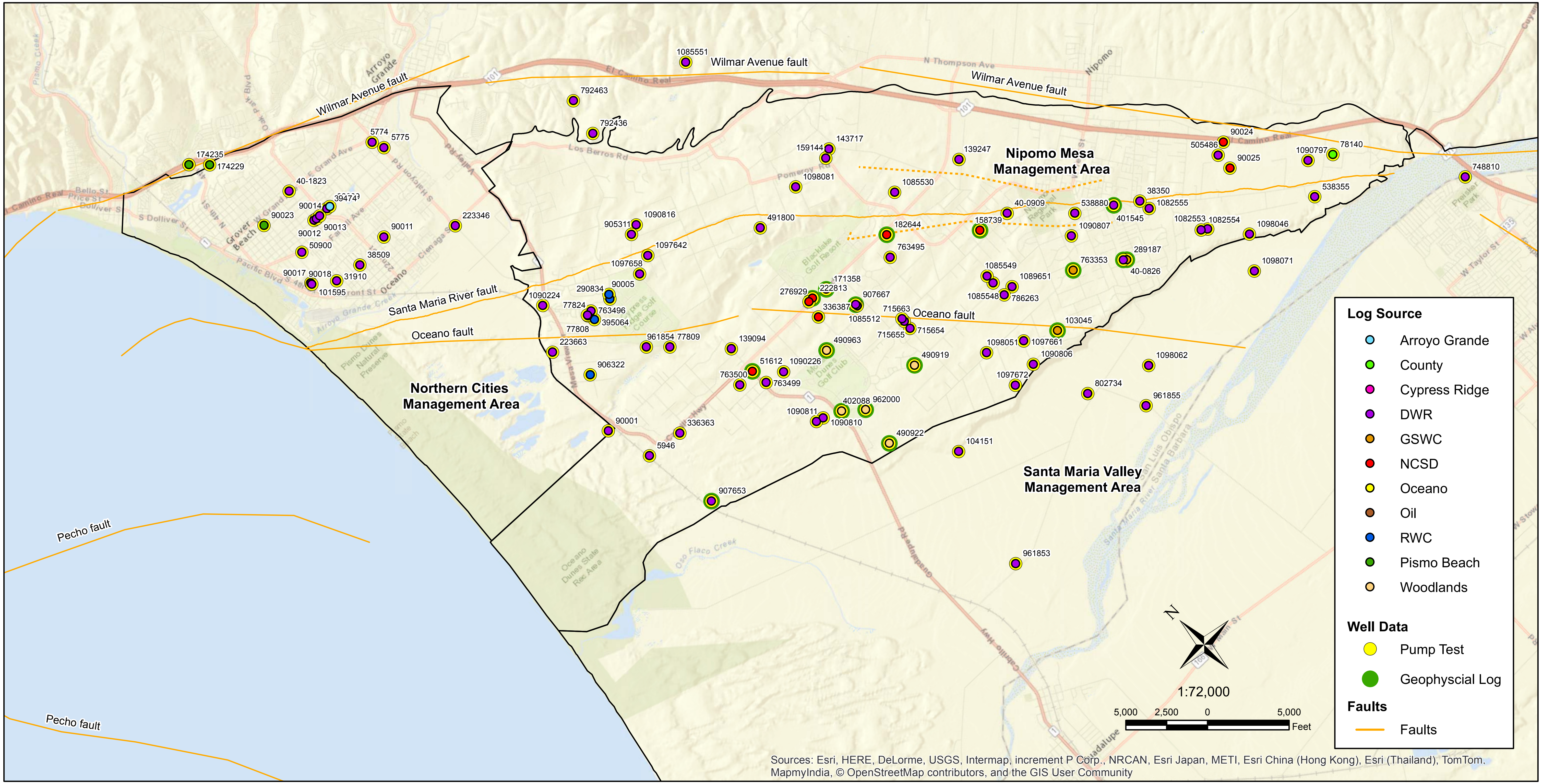
REGIONAL WELL LOCATION MAP
Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 2



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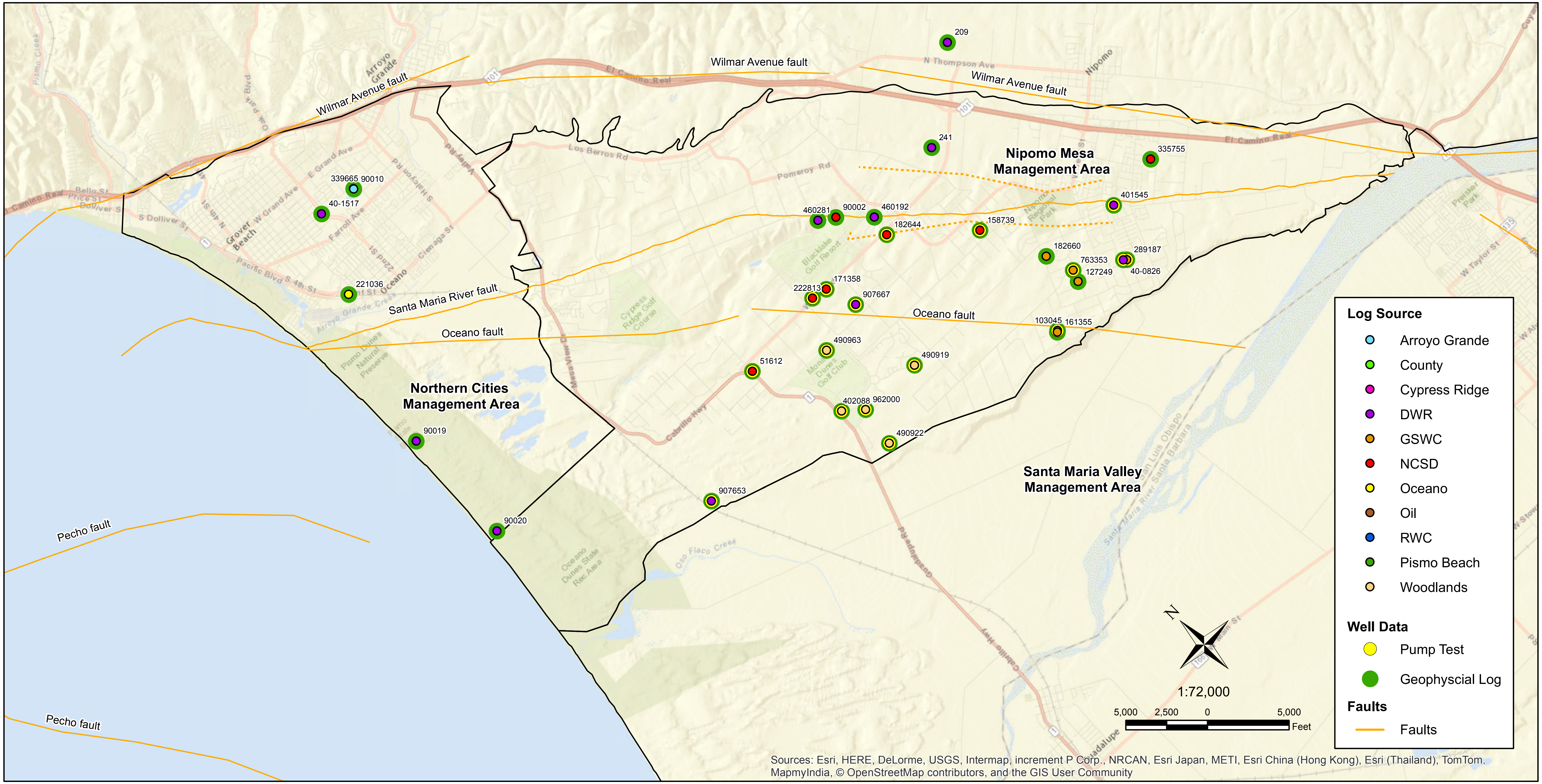
MAP OF WATER WELL LOCATIONS WITH AQUIFER TEST DATA

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 3



Log Source
- ● Arroyo Grande
- ● County
- ● Cypress Ridge
- ● DWR
- ● GSWC
- ● NCSD
- ● Oceano
- ● Oil
- ● RWC
- ● Pismo Beach
- ● Woodlands

Well Data
- ● Pump Test
- ● Geophyscial Log

Faults
- — Faults

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

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MAP OF WATER WELL LOCATIONS WITH GEOPHYSICAL LOG DATA

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 4

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

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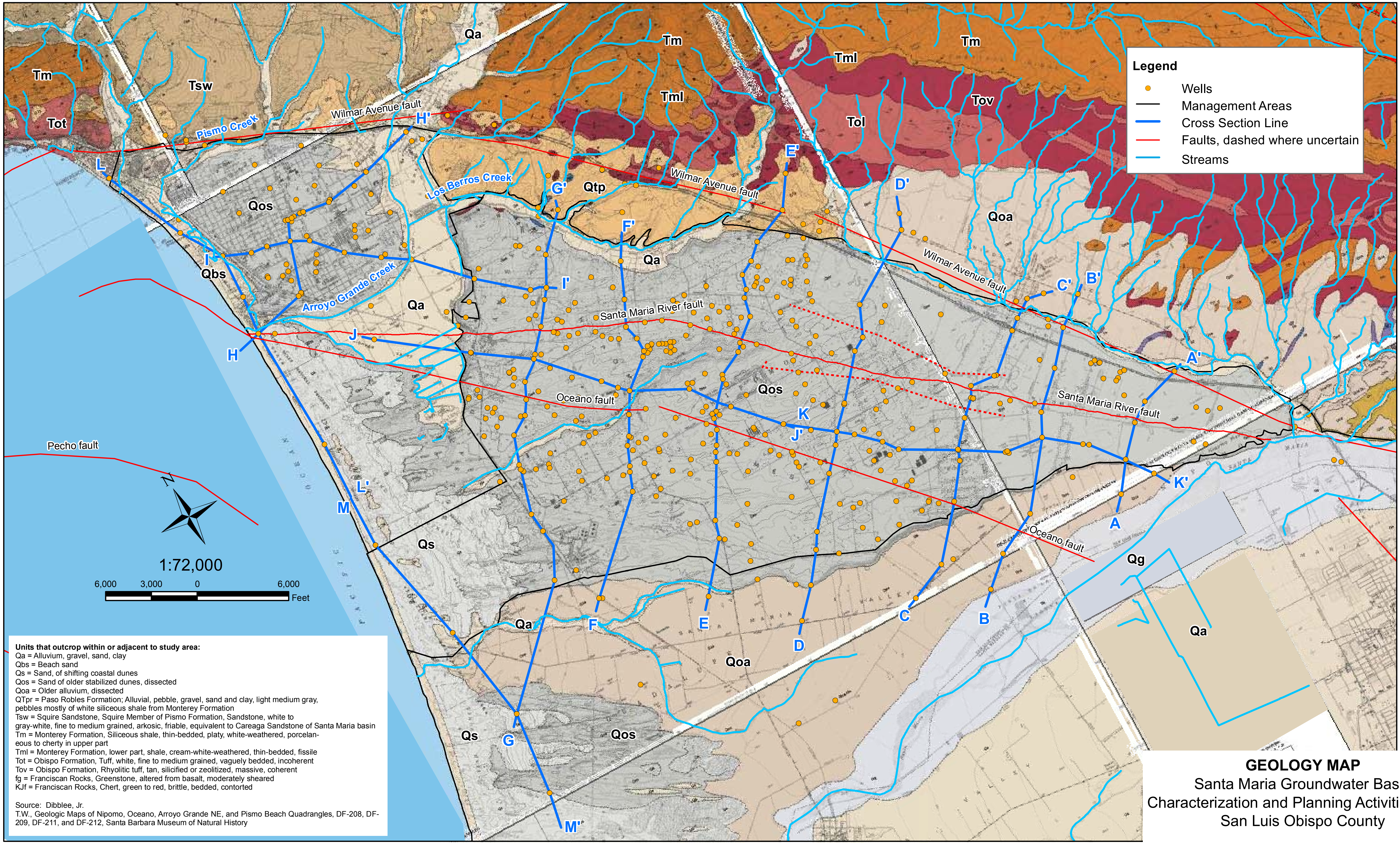
MAP OF OIL WELL LOCATIONS

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 5



Legend

- ● Wells
- Management Areas
- Cross Section Line
- Faults, dashed where uncertain
- Streams

Units that outcrop within or adjacent to study area:
Qa = Alluvium, gravel, sand, clay
Qbs = Beach sand
Qs = Sand, of shifting coastal dunes
Qos = Sand of older stabilized dunes, dissected
Qoa = Older alluvium, dissected
QTpr = Paso Robles Formation; Alluvial, pebble, gravel, sand and clay, light medium gray, pebbles mostly of white siliceous shale from Monterey Formation
Tsw = Squire Sandstone, Squire Member of Pismo Formation, Sandstone, white to gray-white, fine to medium grained, arkosic, friable, equivalent to Careaga Sandstone of Santa Maria basin
Tm = Monterey Formation, Siliceous shale, thin-bedded, platy, white-weathered, porcelaneous to cherty in upper part
Tml = Monterey Formation, lower part, shale, cream-white-weathered, thin-bedded, fissile
Tot = Obispo Formation, Tuff, white, fine to medium grained, vaguely bedded, incoherent
Tov = Obispo Formation, Rhyolitic tuff, tan, silicified or zeolitized, massive, coherent
fg = Franciscan Rocks, Greenstone, altered from basalt, moderately sheared
KJf = Franciscan Rocks, Chert, green to red, brittle, bedded, contorted

Source: Dibblee, Jr.
T.W., Geologic Maps of Nipomo, Oceano, Arroyo Grande NE, and Pismo Beach Quadrangles, DF-208, DF-209, DF-211, and DF-212, Santa Barbara Museum of Natural History

GEOLOGY MAP
Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

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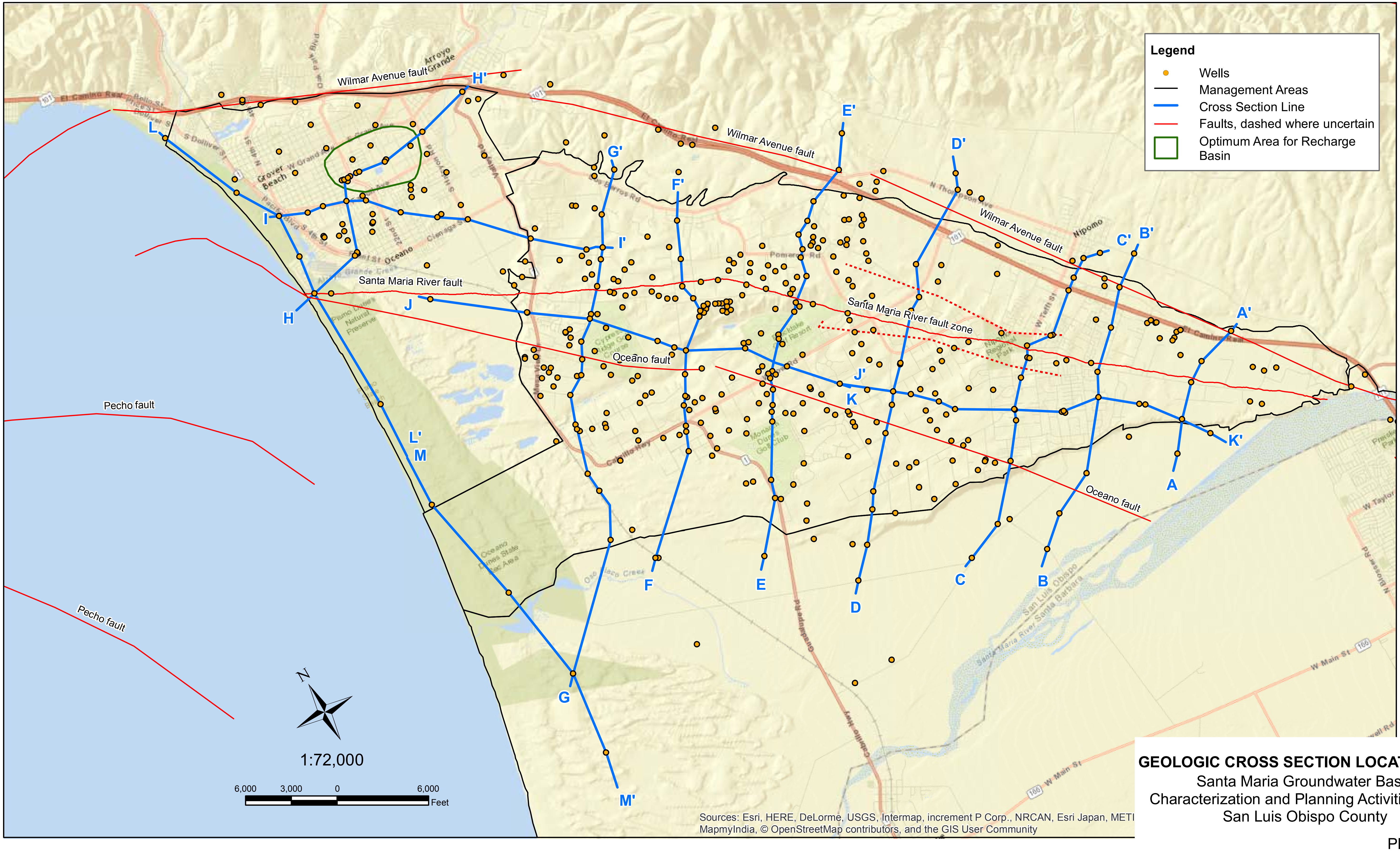

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GEOLOGIC CROSS SECTION LOCATION MAP

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 7

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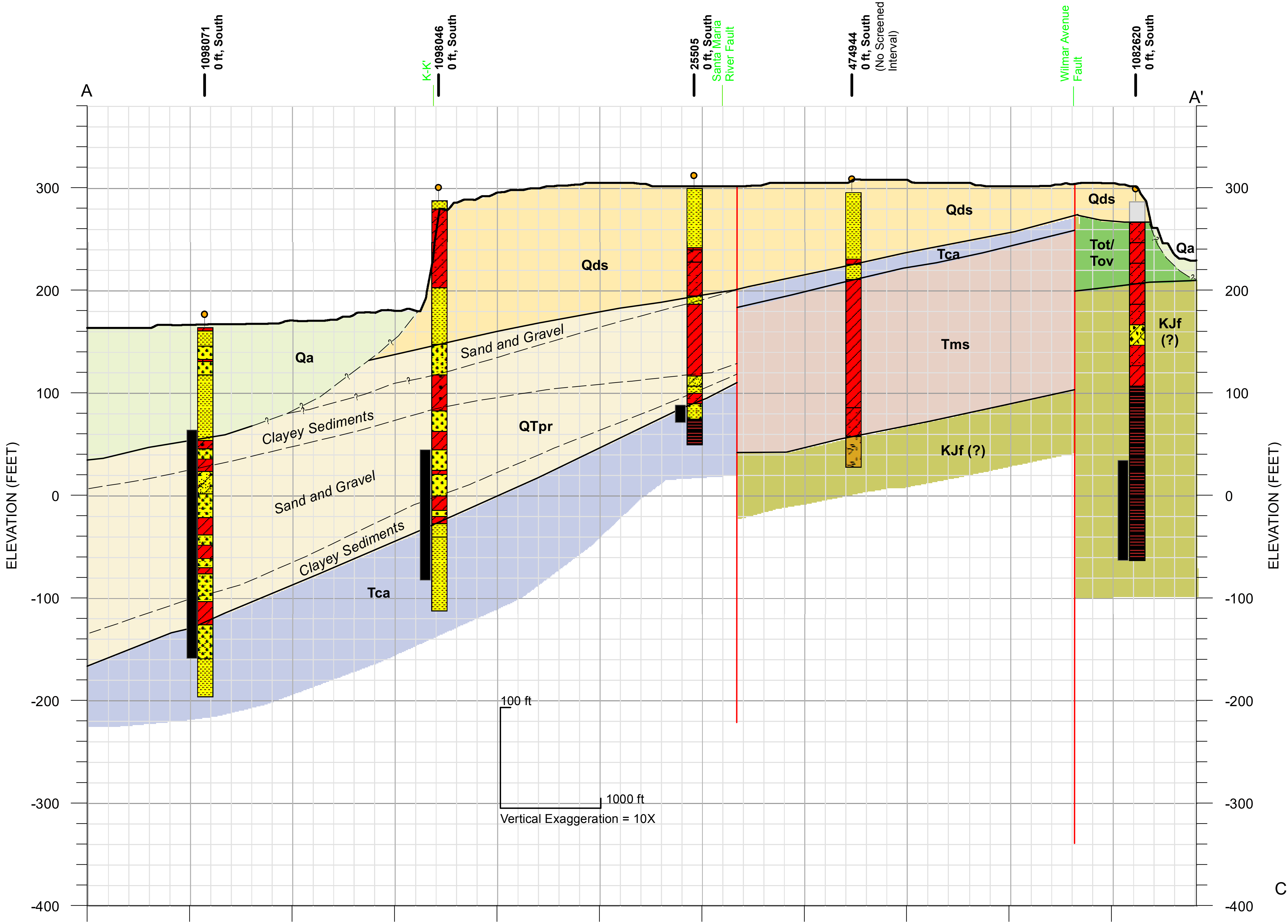

GEOLOGIC CROSS SECTION A-A'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 8

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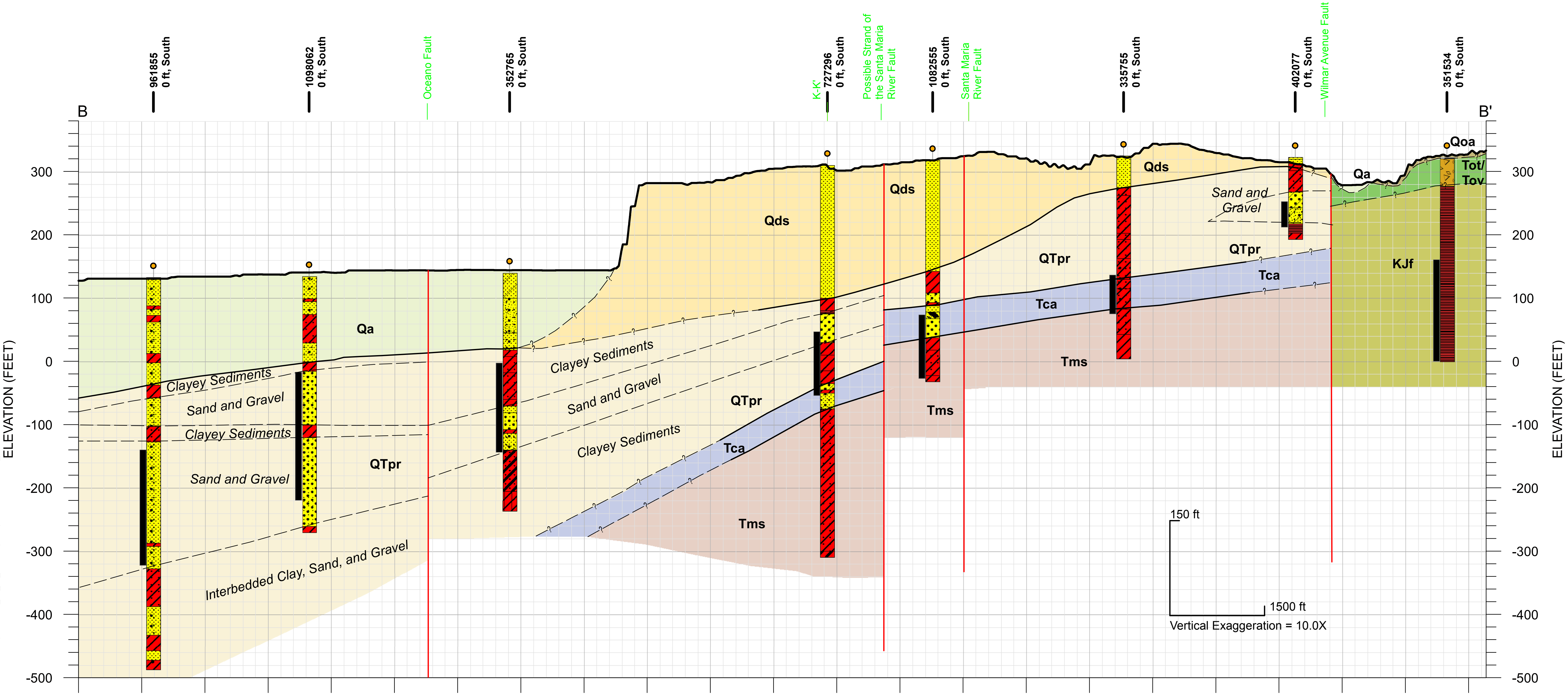

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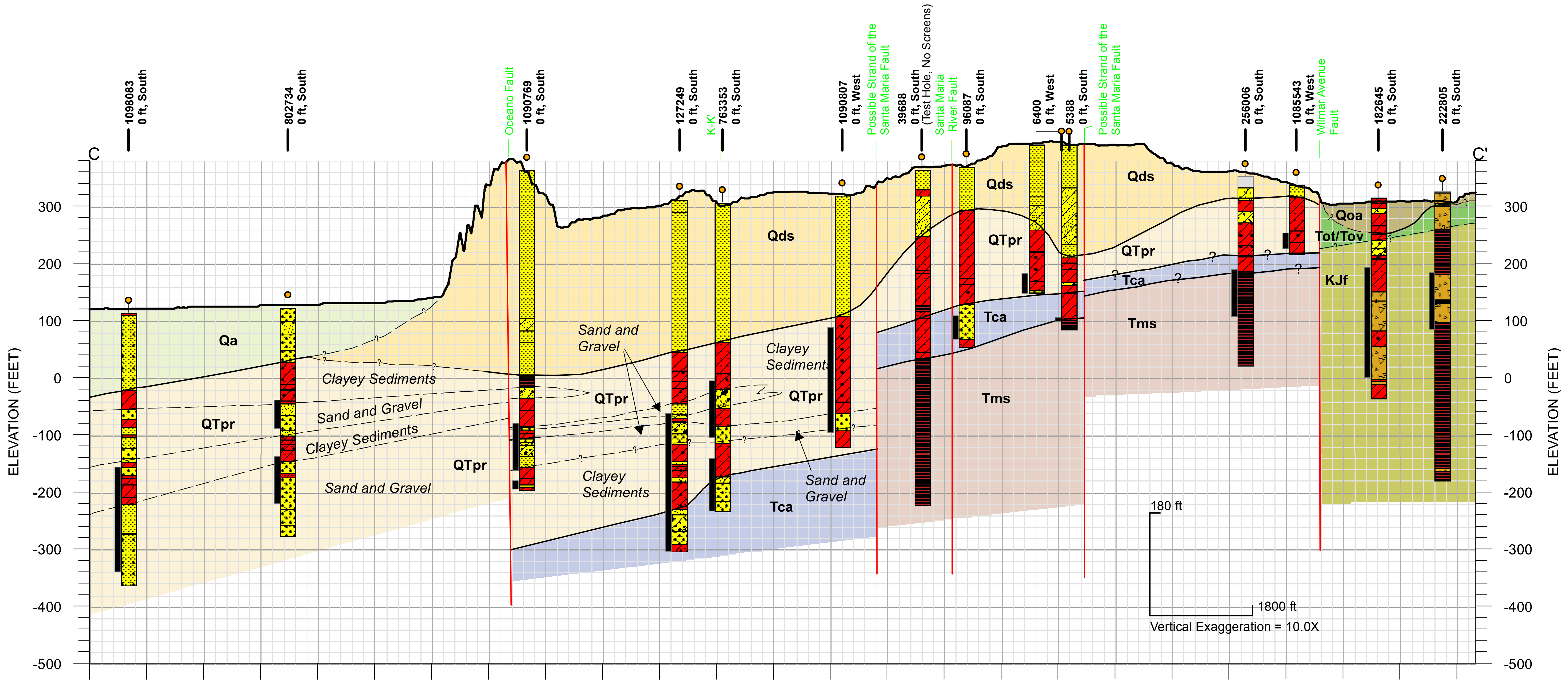
GEOLOGIC CROSS SECTION B-B'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 9



GEOLOGIC CROSS SECTION C-C'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 10

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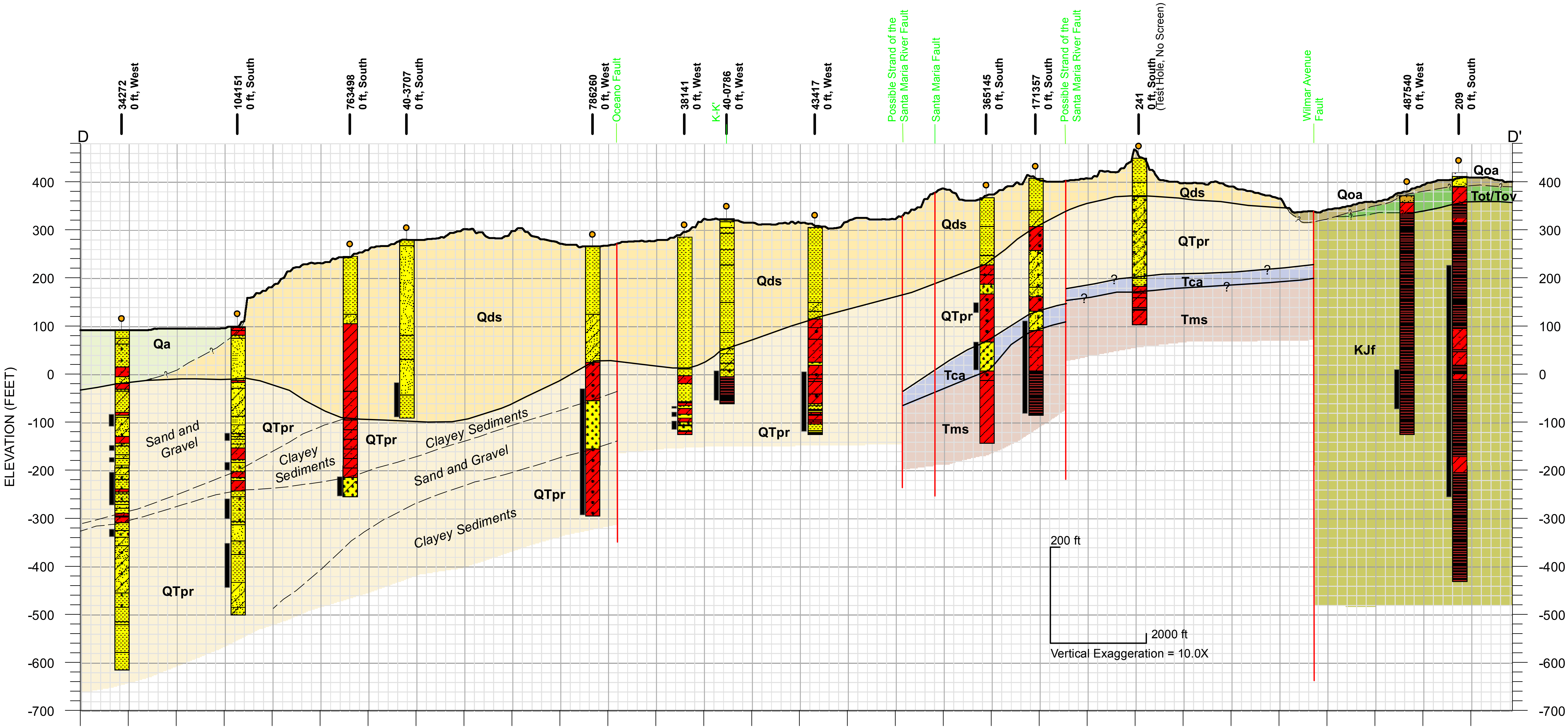

GEOLOGIC CROSS SECTION D-D'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 11

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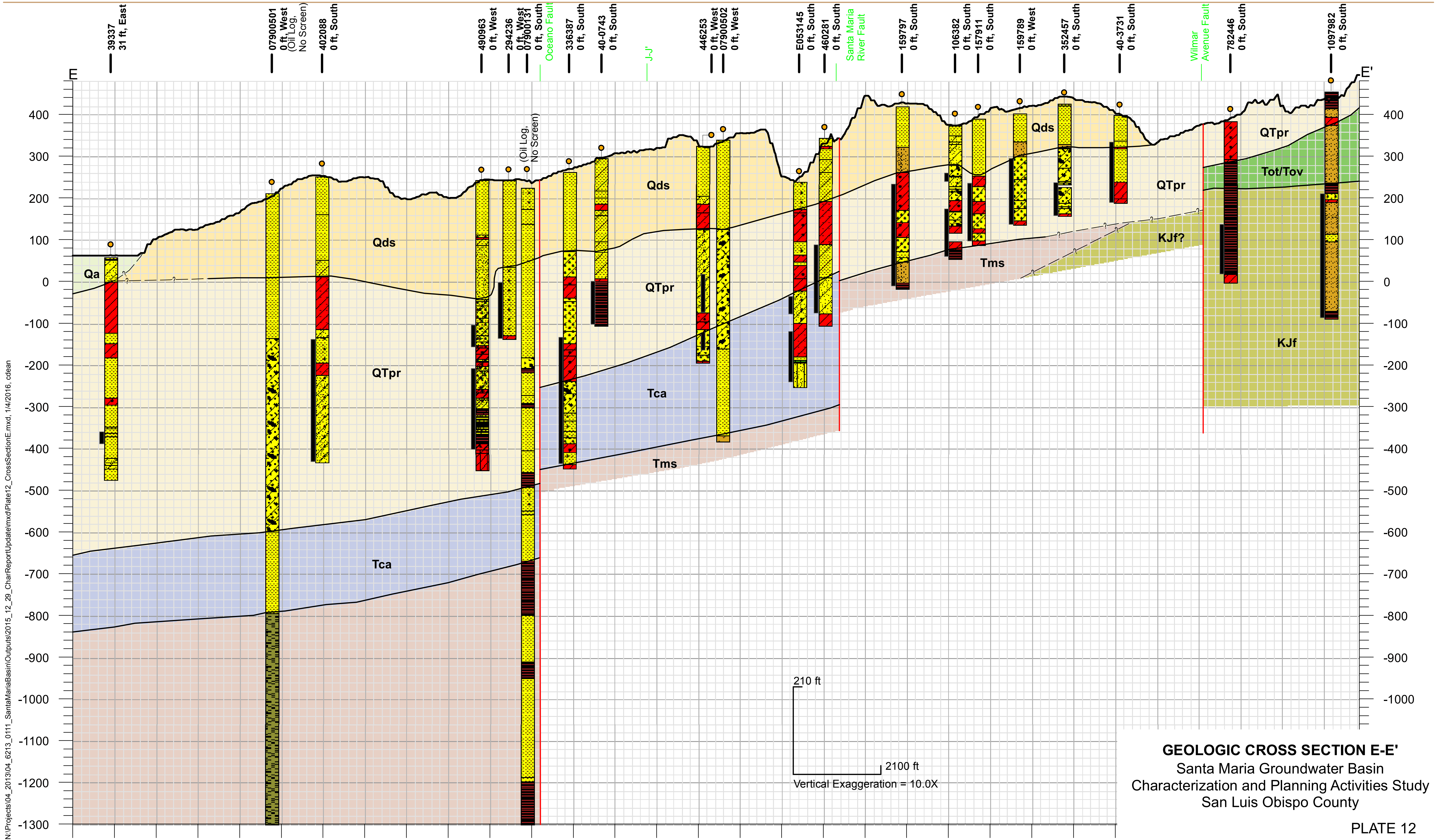

GEOLOGIC CROSS SECTION E-E'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 12

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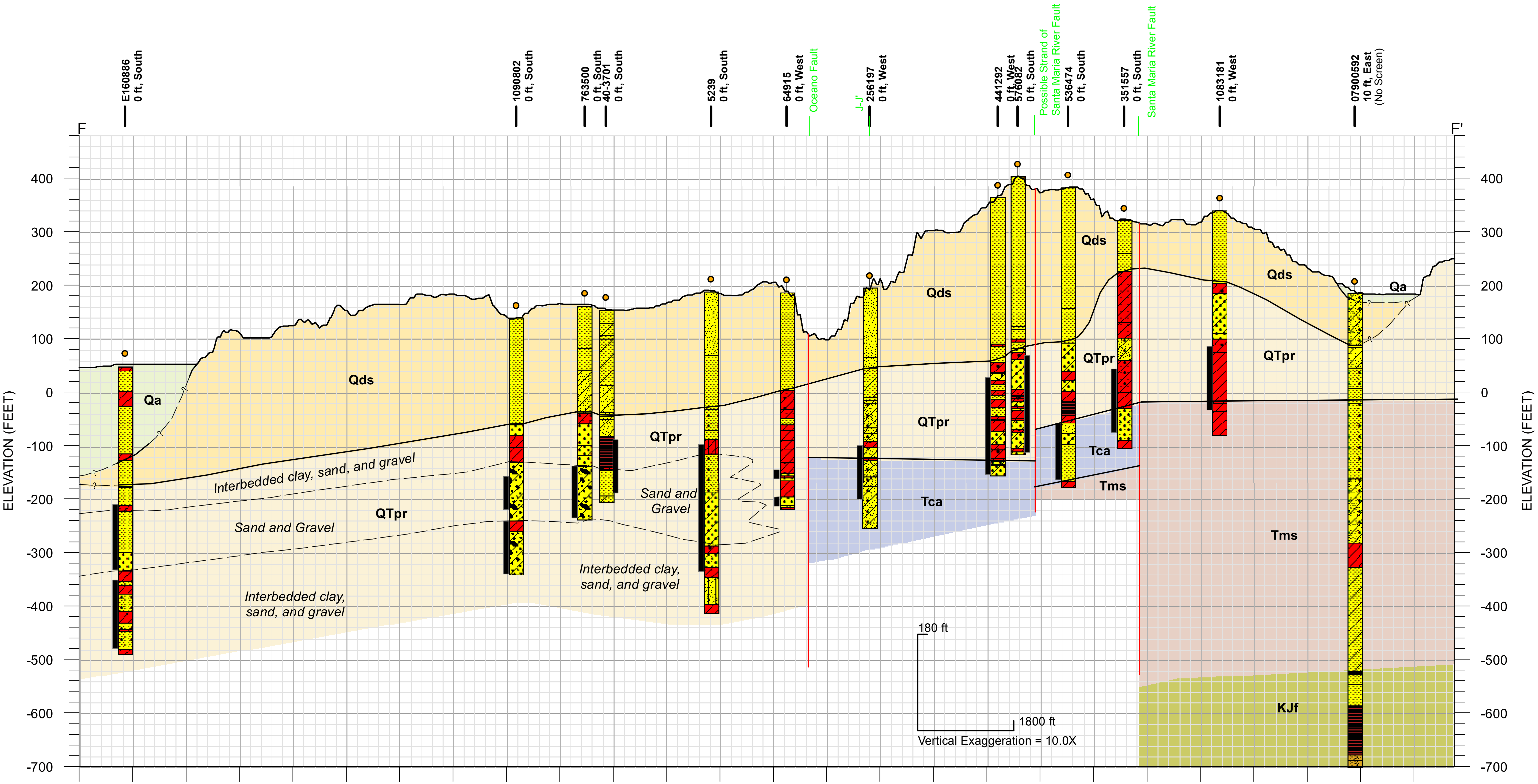

GEOLOGIC CROSS SECTION F-F'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 13

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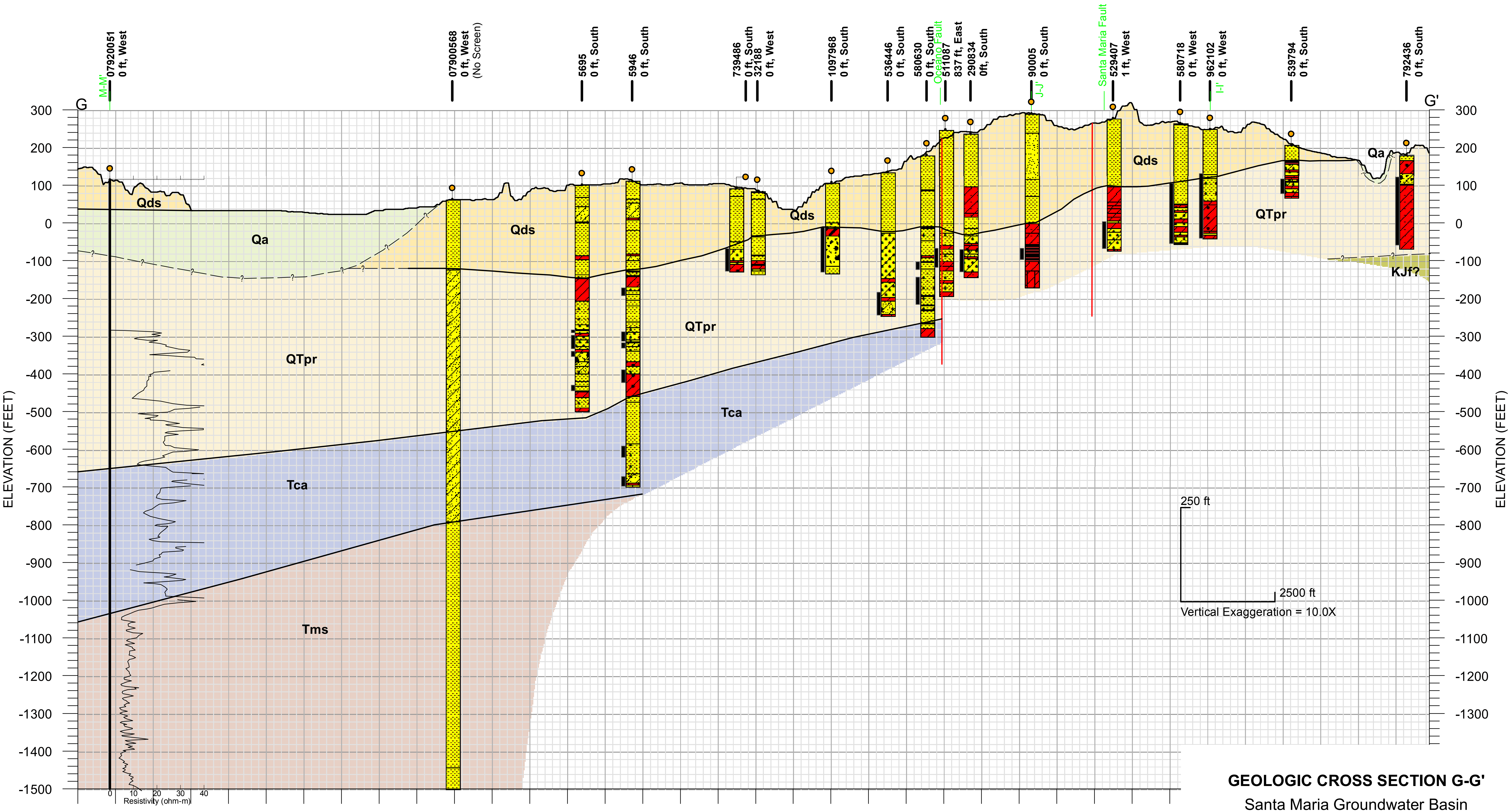

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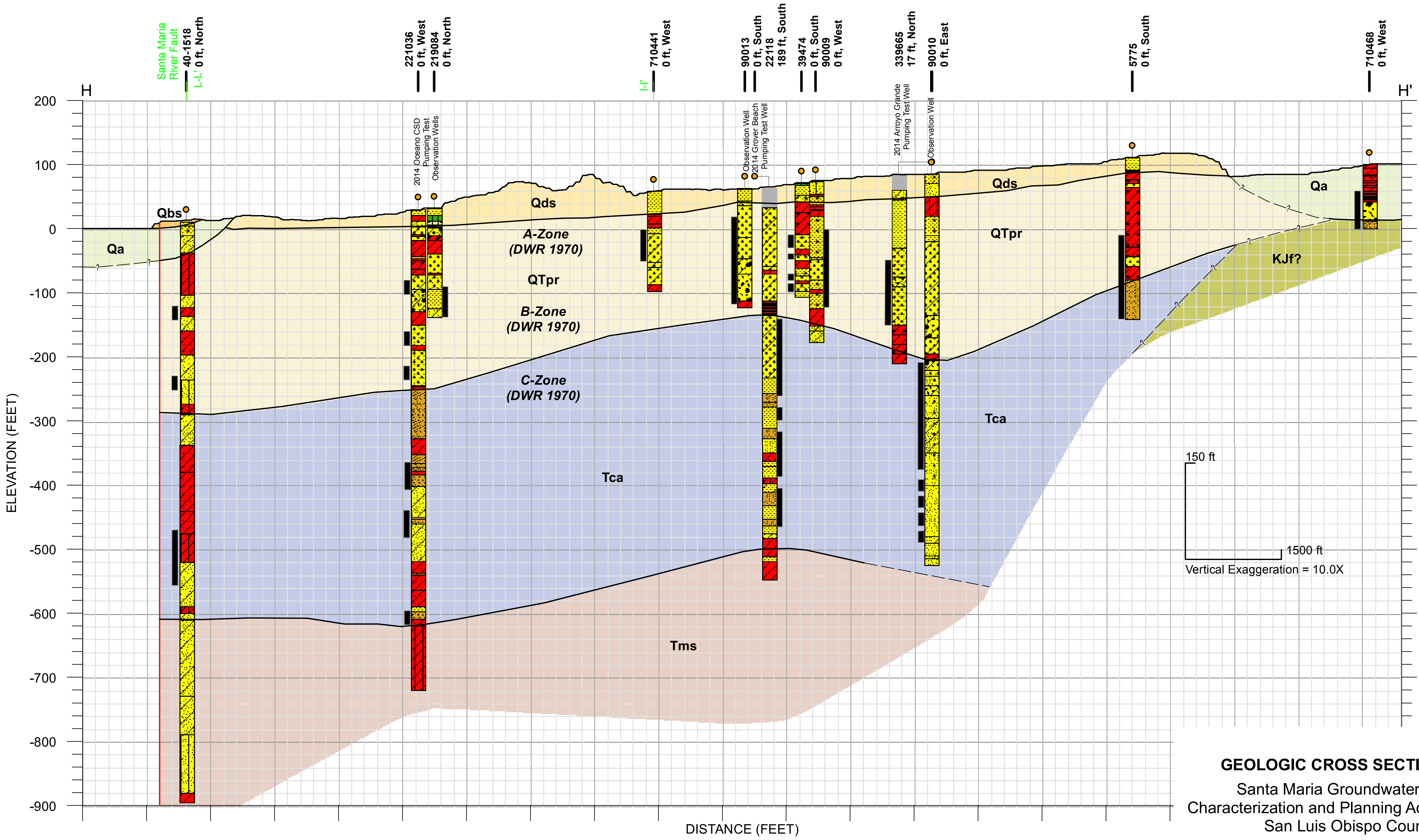
GEOLOGIC CROSS SECTION G-G'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 14



GEOLOGIC CROSS SECTION H-H'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 15

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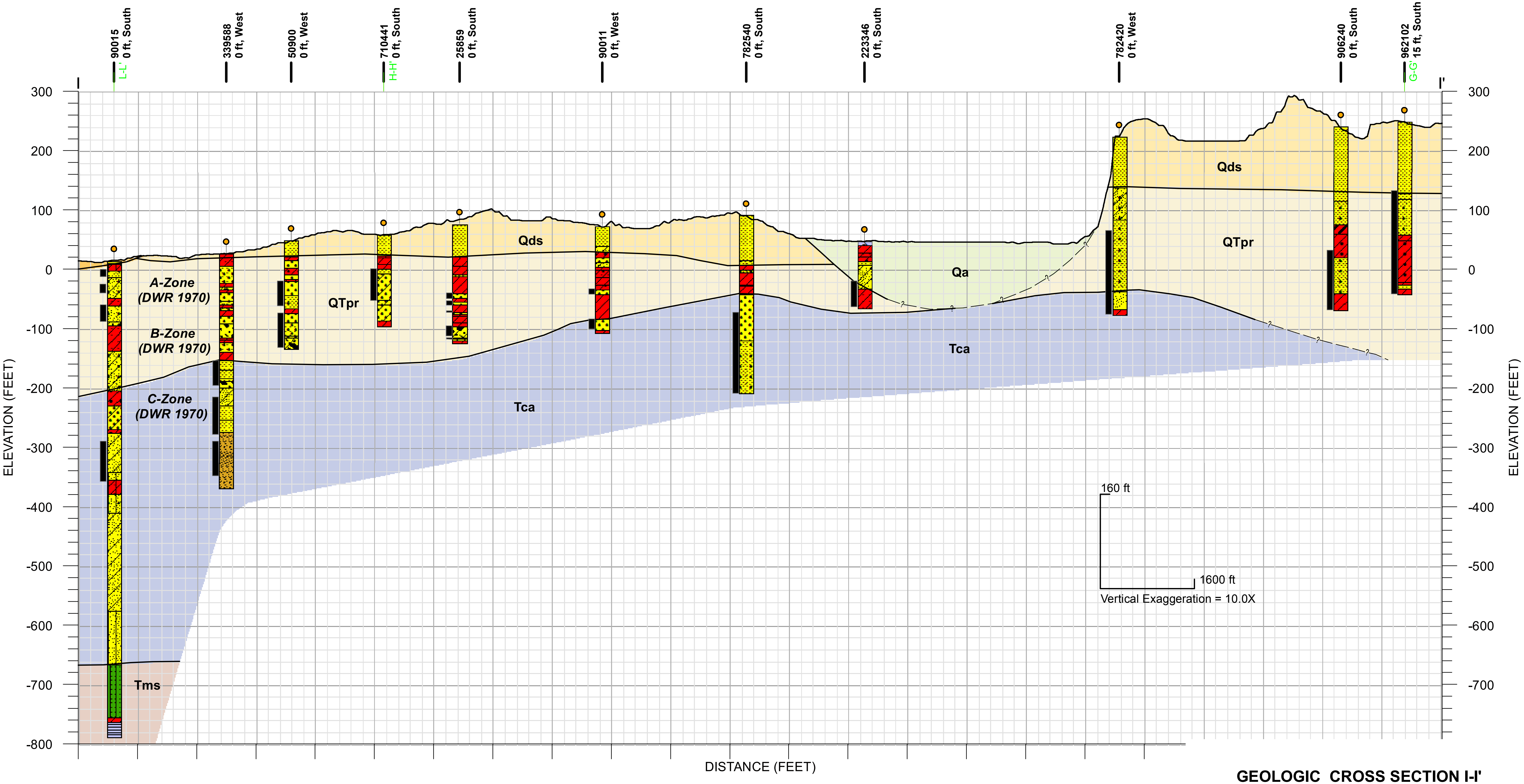

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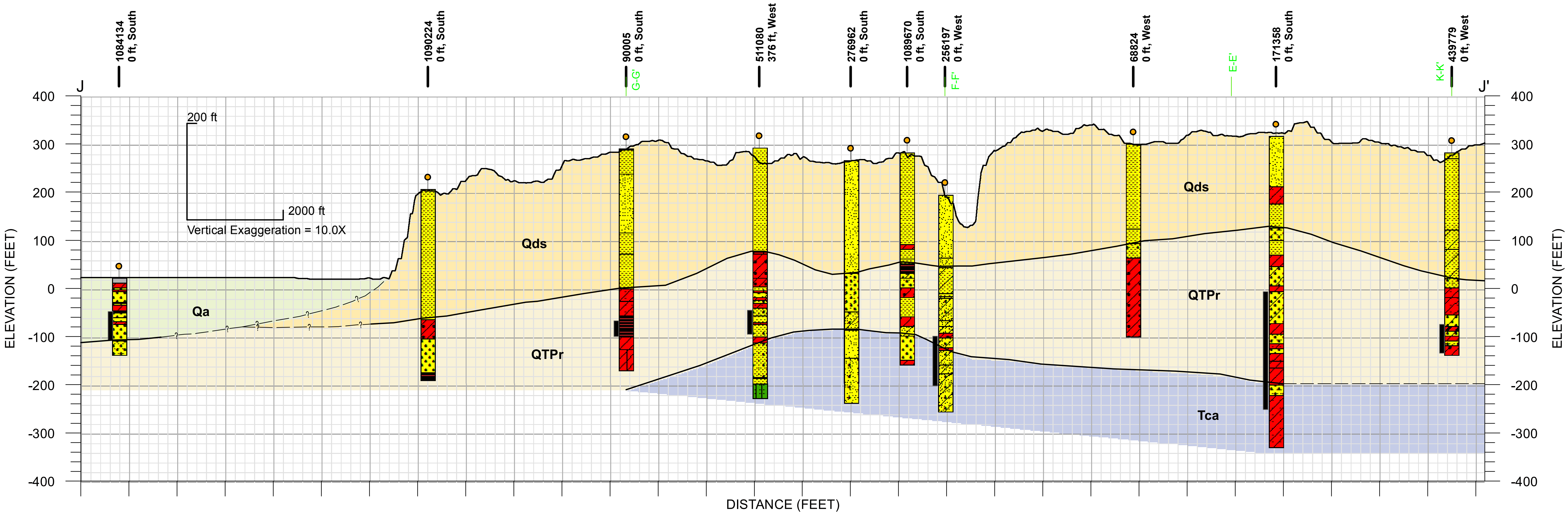
GEOLOGIC CROSS SECTION I-I'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 16



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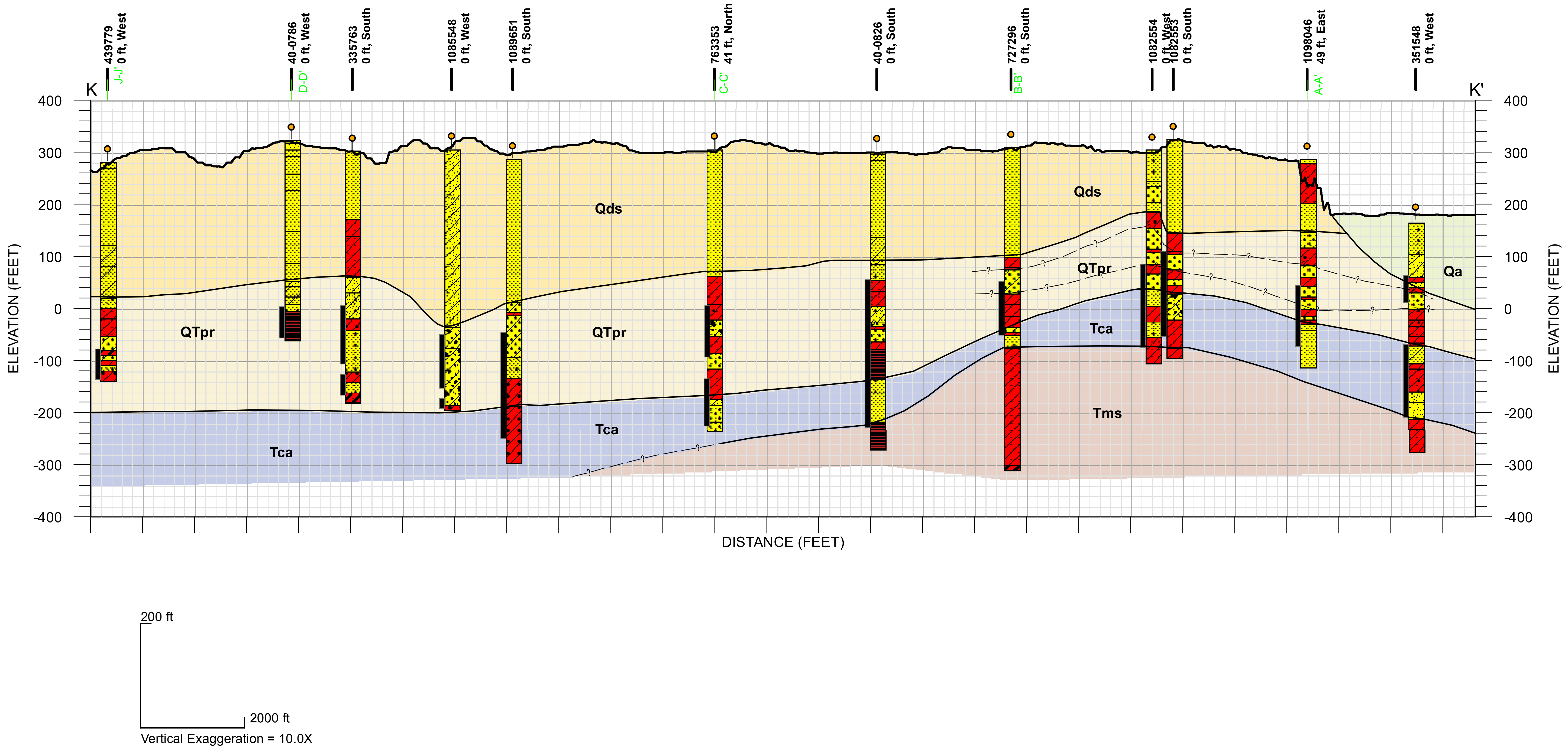
GEOLOGIC CROSS SECTION J-J'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 17



GEOLOGIC CROSS SECTION K-K'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 18

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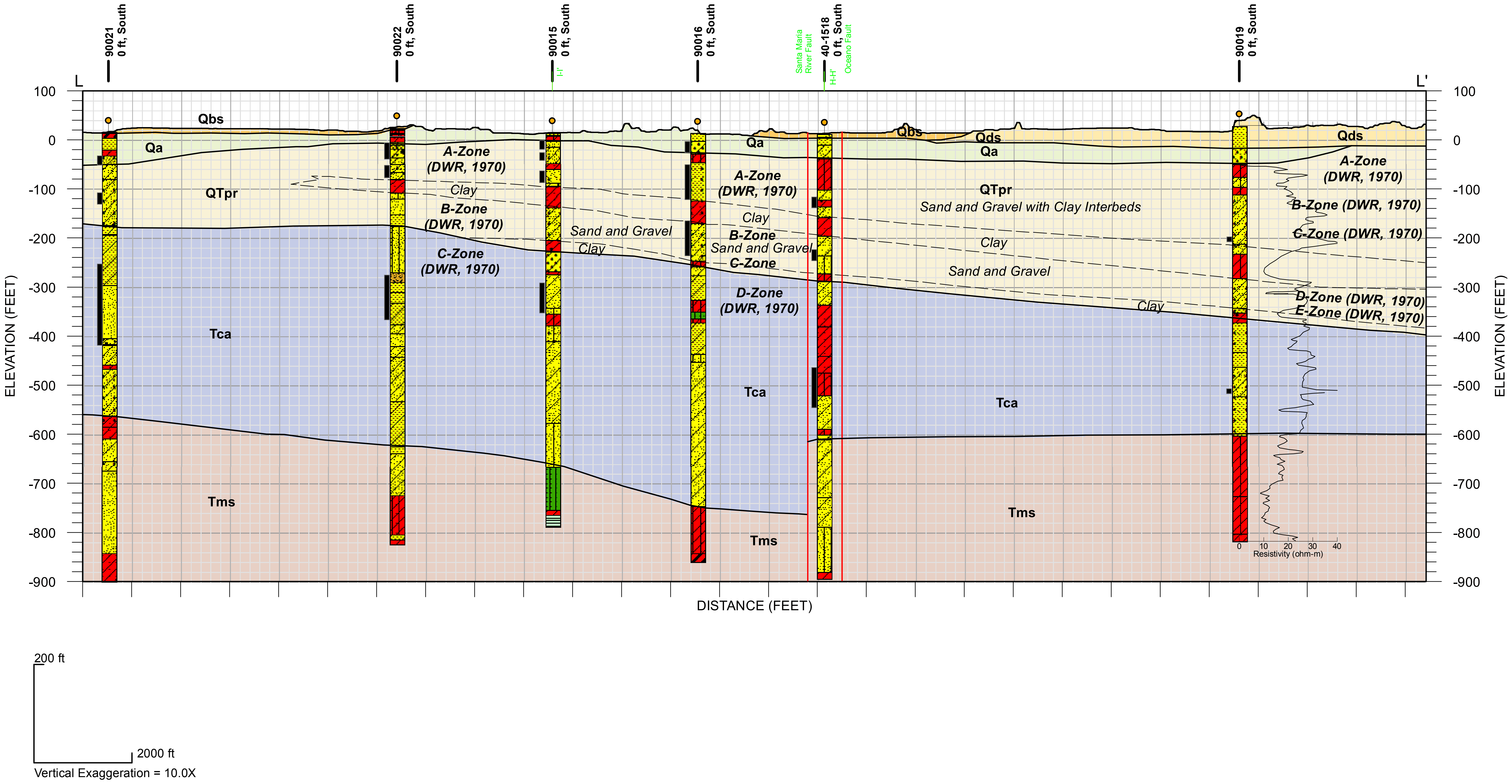
County of San Luis Obispo
Project No. 04.62130111



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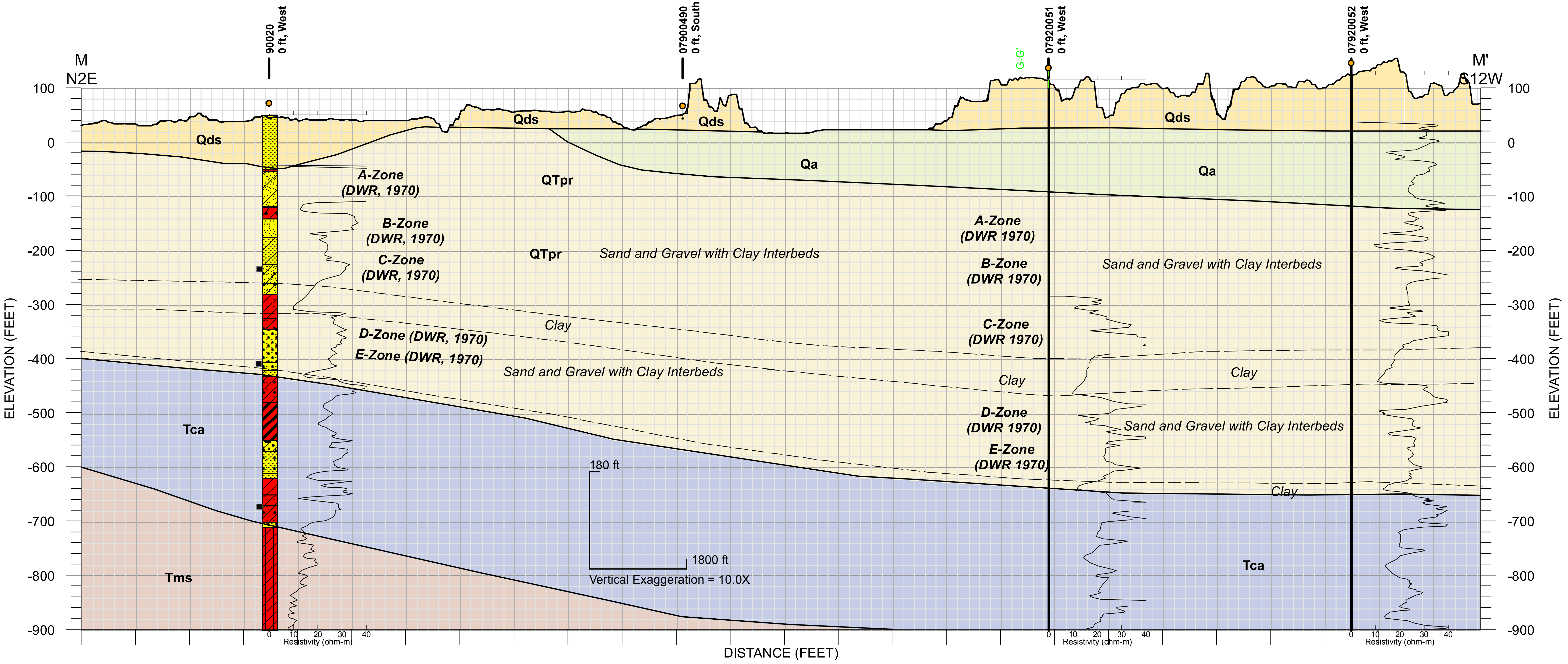
GEOLOGIC CROSS SECTION L-L'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 19



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GEOLOGIC CROSS SECTION M-M'

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 20

Boring Legend

- ▨ Lean CLAY (CL)
- ▨ Silty CLAY (CL-ML)
- ▨ Silty CLAY with Sand (CL-ML)
- ▨ Lean CLAY with Sand (CL)
- ▨ Sandy Lean Clay (CL)
- ▨ Sandy, Gravelly Lean CLAY (CL)
- ▨ Gravelly Lean CLAY (CL)
- ▨ Fat CLAY (CH)
- ▨ Sandy Fat CLAY (CH)
- ▥ Silt (ML)
- ▥ Sandy SILT (ML)
- ▥ Gravelly SILT (ML)
- ▩ Poorly-Graded SAND (SP)
- ▨ Poorly-Graded SAND with Clay (SP-SC)
- ▩ Poorly-Graded SAND with Silt (SP-SM)
- ▩ Gravelly Poorly-Graded SAND (SP)
- ▩ Well-Graded SAND (SW)
- ▨ Well-Graded SAND with Clay (SW-SC)
- ▩ Well-Graded SAND with Silt (SW-SM)
- ▩ Gravelly Well-Graded SAND (SW)
- ▨ Clayey SAND (SC)
- ▨ Clayey to Silty SAND (SC-SM)
- ▨ Gravelly, Clayey SAND (SC)
- ▩ Silty SAND (SM)
- ▩ Gravelly Silty SAND (SM)
- ▩ Poorly-Graded GRAVEL (GP)
- ▩ Poorly-Graded GRAVEL with Clay (GP-GC)
- ▩ Sandy GRAVEL (GP)
- ▩ Well-Graded GRAVEL (GW)
- ▩ Well-Graded GRAVEL with Clay (GW-GC)
- ▨ Clayey GRAVEL (GC)
- ▨ Sandy, Clayey GRAVEL (GC)
- ▤ SHALE
- ▤ MUDSTONE
- ▩ SANDSTONE
- ▤ SANDSTONE to SILTSTONE
- ▩ ROCK Fragments

Geologic Units

- 🟧 Qbs - Beach Sand
- 🟨 Qds - Dune Sand
- 🟩 Qa - Alluvium
- 🟫 Qoa - Older Alluvium
- 🟨 QTpr - Paso Robles Formation
- 🟦 Tca - Careaga Sandstone
- 🟫 Tms - Sisquoc Formation
- 🟩 Tot/Tov- Obispo Formation
- 🟩 KJf - Franciscan Formation

- ——— Formation Contact
- — — — Lithologic Contact within Formation
- ——— Faults
- ▮ Screened Zone

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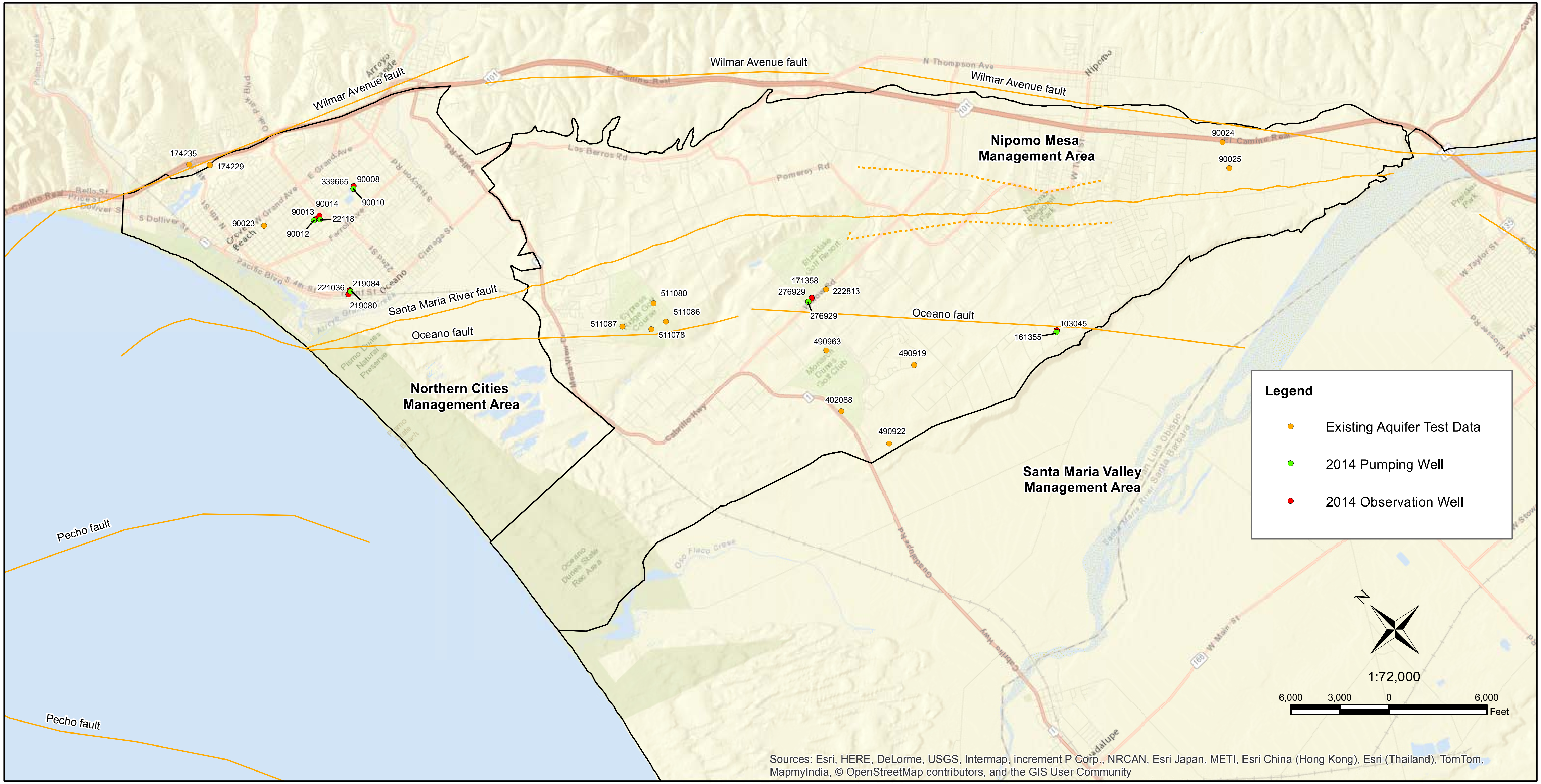
CROSS SECTION KEY
Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 21



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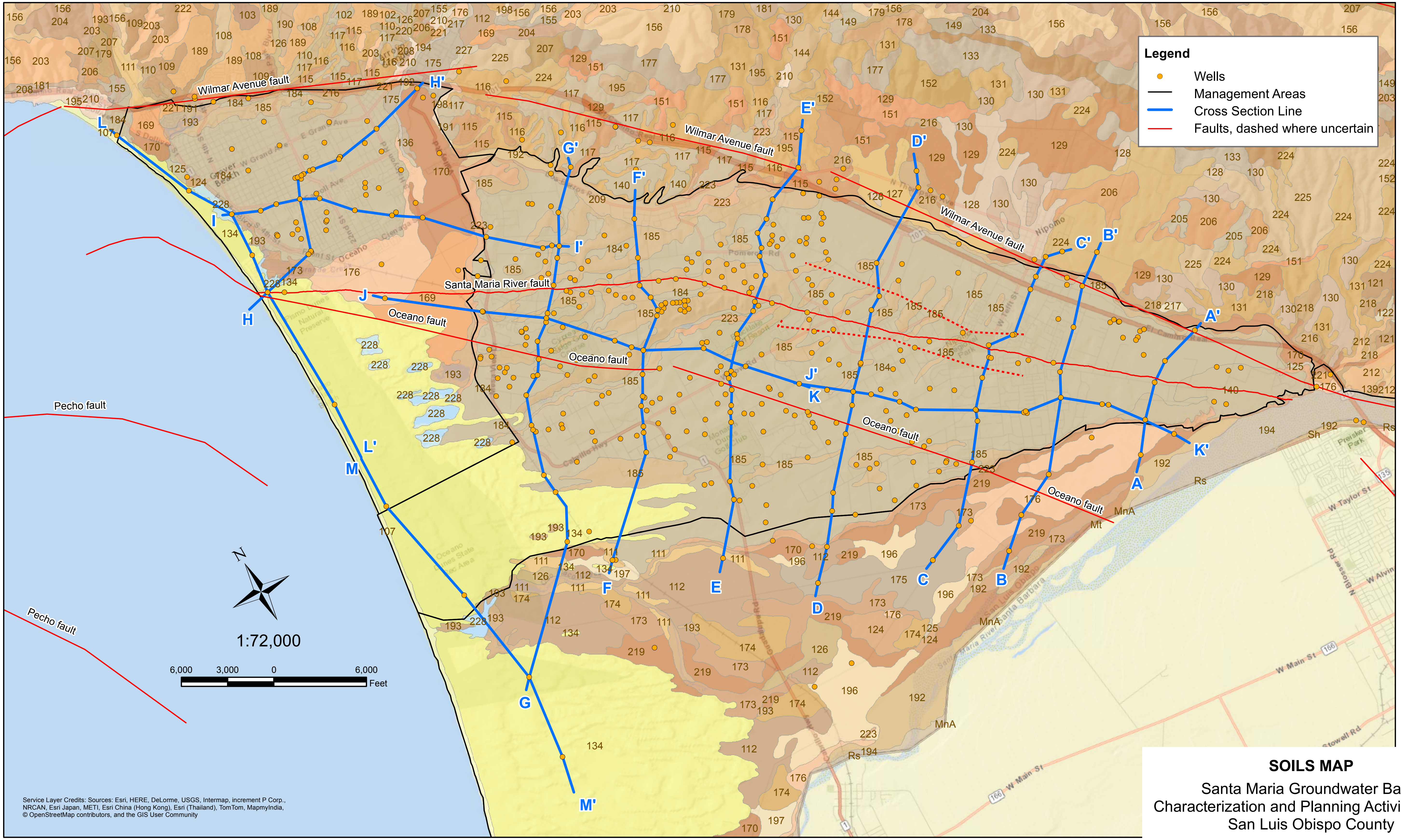
2014 PUMPING TEST LOCATIONS
Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 22

N:\Projects\04_2013\04_6213_0111_SantaMariaBasin\Outputs\2015_12_29_CharReportUpdate\mxd\Plate23_StreamGauges.mxd, 1/4/2016, cdean

STREAM GAUGE AND SYNOPTIC LOCATIONS

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County



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SOILS MAP

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 24

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107	Beaches
109	Briones-Pismo loamy sands, 9 to 30 percent slopes, HSG-B
112	Camarillo loam, drained, HSG-C
111	Camarillo sandy loam, HSG-C
116	Chamise shaly loam, 15 to 30 percent slopes, HSG-C
115	Chamise shaly loam, 9 to 15 percent slopes, HSG-C
117	Chamise shaly sandy clay loam, 5 to 9 percent slopes, HSG-C
CnB	Coastal beaches
124	Corralitos sand, 0 to 2 percent slopes, HSG-A
125	Corralitos sand, 2 to 15 percent slopes, HSG-A
126	Corralitos variant loamy sand, HSG-C
127	Cropley clay, 0 to 2 percent slopes, HSG-D
129	Diablo clay, 5 to 9 percent slopes, HSG-D
134	Dune land
136	Elder sandy loam, 5 to 9 percent slopes, HSG-B
139	Elder sandy loam, occasionally flooded, 2 to 9 percent slopes, HSG-B
140	Garey sandy loam, 2 to 9 percent slopes, HSG-C
169	Marimel sandy clay loam, occasionally flooded, HSG-D
170	Marimel silty clay loam, drained, HSG-C
Mh	Marsh
MnA	Metz loamy sand, 0 to 2 percent slopes
173	Mocho fine sandy loam, HSG-B
174	Mocho loam, HSG-B
Mt	Mocho sandy loam, sandy substratum, overflow
175	Mocho silty clay loam, HSG-B
176	Mocho variant fine sandy loam, HSG-A
184	Oceano sand, 0 to 9 percent slopes, HSG-A
OcD3	Oceano sand, 2 to 15 percent slopes, severely eroded
185	Oceano sand, 9 to 30 percent slopes, HSG-A
189	Pismo loamy sand, 9 to 30 percent slopes, HSG-D
191	Pismo-Tierra complex, 9 to 15 percent slopes, HSG-D
192	Psamments and Fluvents, occasionally flooded
193	Psamments and Fluvents, wet
194/Rs	Riverwash
196	Salinas loam, 0 to 2 percent slopes, HSG-C
197	Salinas silty clay loam, 0 to 2 percent slopes, HSG-C
198	Salinas silty clay loam, 2 to 9 percent slopes, HSG-C
Sh	Sandy alluvial land
Sk	Sandy alluvial land, wet
StC	Sorrento sandy loam, 2 to 9 percent slopes
209	Still gravelly sandy clay loam, 0 to 2 percent slopes, HSG-B
214	Suey silt loam, 15 to 30 percent slopes, HSG-B
212	Suey silt loam, 2 to 9 percent slopes, HSG-B
218	Tierra loam, 15 to 30 percent slopes, HSG-D
216	Tierra sandy loam, 2 to 9 percent slopes, HSG-D
219	Tujunga loamy sand, 0 to 2 percent slopes, HSG-A
228	Water
221	Xererts-Xerolls-Urban land complex, 0 to 15 percent slopes
223	Xerorthents, escarpment
224	Zaca clay, 9 to 15 percent slopes, HSG-D
HSG	Hydrologic Soil Group

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SOILS MAP KEY

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

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EXISTING AND CANDIDATE WELLS FOR TRANSDUCER INSTALLATION

Santa Maria Groundwater Basin
Characterization and Planning Activities Study
San Luis Obispo County

PLATE 26

APPENDICES