The following protocols can be incorporated into a GSP's monitoring protocols for collecting groundwater quality data. More detailed sampling procedures and protocols are included in the standards and guidance documents listed at the end of this BMP.

In general, the use of existing water quality data within the basin should be done to the greatest extent possible if it achieves the DQOs for the GSP. In some cases it may be necessary to collect additional water quality data to support monitoring programs or evaluate specific projects. The USGS National Field Manual for the Collection of Water Quality Data (Wilde, 2005) can be used as a guide for the collection of reliable data. **Figure 5** illustrates a typical groundwater quality sampling setup.

Figure 5 – Typical Groundwater Quality Sampling Event December 2016 Groundwater Monitoring Protocols, Standards, and Sites BM

All analyses should be performed by a laboratory certified under the State Environmental Laboratory Accreditation Program or by a certified technician when applicable. The specific analytical methods are beyond the scope of this BMP, but should be commiserate with other programs evaluating water quality within the basin for comparative purposes.

Groundwater quality sampling protocols should ensure that:

- Groundwater quality data are taken from the correct location
- Groundwater quality data are accurate and reproducible
- Groundwater quality data represent conditions that inform appropriate basin management and are consistent with the DQOs
- All salient information is recorded to normalize, if necessary, and compare data
- Data are handled in a way that ensures data integrity

The following points are general guidance in addition to the techniques presented in the previously mentioned USGS National Field Manual for the Collection of Water Quality Data.

Standardized protocols include the following:

- Prior to sampling, the sampler must contact the laboratory to schedule laboratory time, obtain appropriate sample containers, and clarify any sample holding times or sample preservation requirements.
- To the greatest extent possible, the sampler should use the GPS locator in the SJREC GSA's DMS to ensure location accuracy. Each well used for groundwater quality monitoring must have a unique identifier. This identifier must appear on the well housing or the well casing to avoid confusion.
- In the case of wells with dedicated pumps, samples should be collected at or near the wellhead. Samples should not be collected from storage tanks, at the end of long pipe runs, or after any water treatment.
- The sampler should clean the sampling port and/or sampling equipment and the sampling port and/or sampling equipment must be free of any contaminants. The sampler must decontaminate sampling equipment between sampling locations or wells to avoid cross-contamination between samples.
- The groundwater elevation in the well should be measured following appropriate protocols described above in the groundwater level measuring protocols.
- For any well not equipped with low-flow or passive sampling equipment, an adequate volume of water should be purged from the well to ensure that the groundwater sample is representative of ambient groundwater and not stagnant water in the well casing. Purging three well casing volumes is generally considered adequate. Professional judgment should be used to determine the proper configuration of the sampling equipment with respect to well construction such that a representative ambient groundwater sample is collected. If pumping causes a well to be evacuated (go dry), document the condition and allow well to recover to within 90% of original level prior to sampling. Professional judgment should be exercised as to whether the sample will meet the DQOs and adjusted as necessary.
- Field parameters of pH, electrical conductivity, and temperature should be collected for each sample. Field parameters should be evaluated during the purging of the well and should stabilize prior to sampling. Measurements of pH should only be measured in the field, lab pH analysis are typically unachievable due to short hold times. Other parameters, such as oxidation-reduction potential (ORP), dissolved oxygen (DO) (in situ measurements preferable), or turbidity, may also be useful for meeting DQOs of GSP and assessing purge conditions. Where applicable, field instruments should be calibrated daily and evaluated for drift throughout the day.
- Sample containers should be labeled prior to sample collection. The sample label must include: sample ID (often well ID), sample date and time, sample personnel, sample location, preservative used, and analytes and analytical method.
- If possible, samples should be collected under laminar flow conditions.
- Samples should be collected according to appropriate standards such as those listed in the Standard Methods for the Examination of Water and Wastewater, USGS National Field Manual for the Collection of Water Quality Data, or other appropriate guidance. The specific sample collection procedure should reflect the type of analysis to be performed and DQOs.
- All samples requiring preservation must be preserved as soon as practically possible, ideally at the time of sample collection. Ensure that samples are appropriately filtered as recommended for the specific analyte. Entrained solids can be dissolved by preservative leading to inconsistent

results of dissolve analytes. Specifically, samples to be analyzed for metals should be field-filtered prior to preservation; do not collect an unfiltered sample in a preserved container.

- Samples should be chilled and maintained per recommendation to prevent degradation of the sample. The laboratory's Quality Assurance Management Plan should detail appropriate chilling and shipping requirements.
- Samples must be shipped under chain of custody documentation to the appropriate laboratory promptly to avoid violating holding time restrictions.
- Instruct the laboratory to use reporting limits that are equal to or less than the applicable DQOs, regional water quality objectives/screening levels, or recommendation of a licensed professional.

Special protocols for low-flow sampling equipment

In addition to the protocols listed above, sampling using low-flow sample equipment should adopt the following protocols derived from EPA's Low-flow (minimal drawdown) ground-water sampling procedures (Puls and Barcelona, 1996). These protocols apply to low-flow sampling equipment that generally pumps between 0.1 and 0.5 liters per minute. These protocols are not intended for bailers.

Special protocols for passive sampling equipment

In addition to the protocols listed above, passive diffusion samplers should follow protocols set forth in USGS Fact Sheet 088-00.

PROTOCOLS FOR MONITORING SEAWATER INTRUSION

The Delta-Mendota Subbasin is highly unlikely to have Significant and Unreasonable Seawater Intrusion. For that reason, monitoring protocols for seawater intrusion have not been developed. In the unlikely event that seawater intrusion must be monitored in the Delta-Mendota Subbasin, the SJREC GSA will review BMP's to address the concern.

+**PROTOCOLS FOR MEASURING STREAMFLOW**

Monitoring of streamflow is necessary for incorporation into water budget analysis and for use in evaluation of stream depletions associated with groundwater extractions. The use of existing monitoring locations should be incorporated to the greatest extent possible. Many of these streamflow monitoring locations currently follow the protocol described below.

Establishment of new streamflow discharge sites should consider the existing network and the objectives of the new location. Professional judgment should be used to determine the appropriate permitting that may be necessary for the installation of any monitoring locations along surface water bodies. Regular frequent access will be necessary to these sites for the development of ratings curves and maintenance of equipment.

To establish a new streamflow monitoring station special consideration must be made in the field to select an appropriate location for measuring discharge. Once a site is selected, development of a relationship of stream stage to discharge will be necessary to provide continuous estimates of streamflow. Several measurements of discharge at a variety of stream stages will be necessary to develop the ratings curve correlating stage to discharge. The use of Acoustic Doppler Current Profilers (ADCPs) can provide accurate estimates of discharge in the correct settings. Professional judgment must be exercised to determine the appropriate methodology. Following development of the ratings curve a simple stilling well and pressure transducer with data logger can be used to evaluate stage on a frequent basis. A simple stilling well and staff gage is illustrated in **Figure 6**.

Streamflow measurements should be collected, analyzed, and reported in accordance with the procedures outlined in USGS Water Supply Paper 2175, Volume 1. – Measurement of Stage Discharge and Volume 2. – Computation of Discharge. This methodology is currently being used by both the USGS and DWR for existing streamflow monitoring throughout the State.

Figure 6 – Simple Stilling Well and Staff Gage Setup

PROTOCOLS FOR MEASURING SUBSIDENCE

Evaluating and monitoring inelastic land subsidence can utilize multiple data sources to evaluate the specific conditions and associated causes. To the extent possible, the use of existing data should be utilized. Subsidence can be estimated from numerous techniques, they include: level surveying tied to known stable benchmarks or benchmarks located outside the area being studied for possible subsidence; installing and tracking changes in borehole extensometers; obtaining data from continuous GPS (CGPS) locations, static GPS surveys or Real-Time-Kinematic (RTK) surveys; or analyzing Interferometric Synthetic Aperture Radar (InSAR) data. No standard procedures exist for collecting data from the potential subsidence monitoring approaches. However, an approach may include:

- Identification of land subsidence conditions.
  - Evaluate existing regional long-term leveling surveys of regional infrastructure, i.e. roadways, railroads, canals, and levees.
  - Determine if significant fine-grained layers are present such that the potential for collapse of the units could occur should there be significant depressurization of the aquifer system.
  - Inspect geologic logs and the hydrogeologic conceptual model to aid in identification of specific units of concern.
  - Collect regional remote-sensing information such as InSAR, when and if available.
- Monitor regions of suspected subsidence where potential exists.
  - Use existing CGPS network to evaluate changes in land surface elevation. Review the need to establish new CGPS stations.
  - Establish leveling surveys transects to observe changes in land surface elevation.
  - Use existing extensometer network to observe land subsidence. An example of a typical extensometer design is illustrated in **Figure 7**. There are a variety of extensometer designs and they should be selected based on the specific DQOs. Review the need to establish new extensometer sites.

Various standards and guidance documents for collecting data include:

- Leveling surveys must follow surveying standards set out in the California Department of Transportation's Caltrans Surveys Manual. Any alternative shall be reviewed by a Professional Land Surveyor or Professional Civil Engineer registered in the State of California for accuracy and reasonableness.
- GPS surveys must follow surveying standards set out in the California Department of Transportation's Caltrans Surveys Manual. Any alternative shall be reviewed by a Professional Land Surveyor or Professional Civil Engineer registered in the State of California for accuracy and reasonableness.USGS has been performing subsidence surveys within several areas of California. These studies are sound examples for appropriate methods and should be utilized to the extent possible and where available:
  - http://ca.water.usgs.gov/land_subsidence/california-subsidencemeasuring.html
- Instruments installed in borehole extensometers must follow the manufacturer's instructions for installation, care, and calibration.
- Availability of InSAR data is improving and will increase as programs are developed. This method requires expertise in analysis of the raw data and will likely be made available as an interpretative report for specific regions.

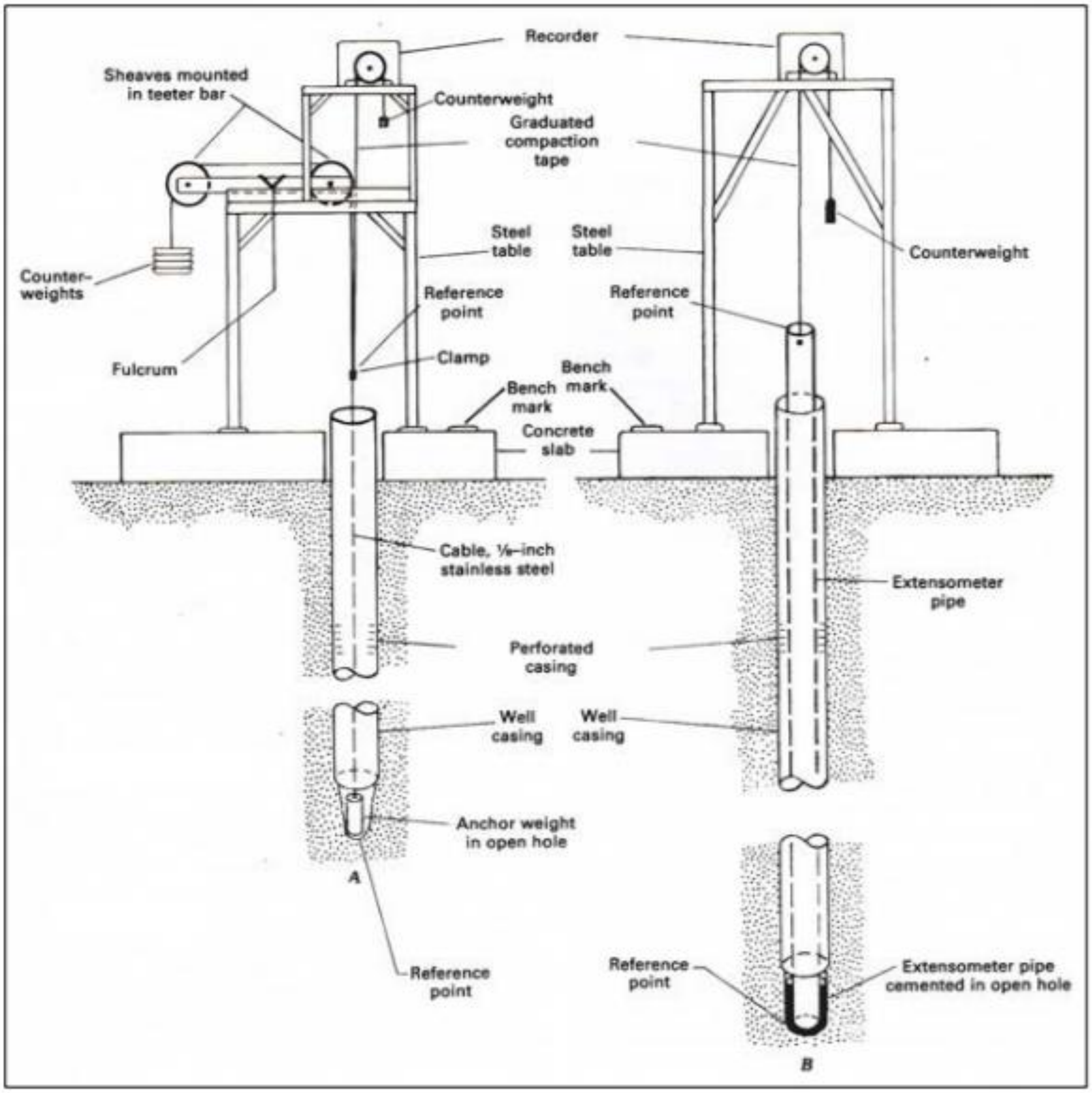

Figure 7 – Simplified Extensometer Diagram

6. KEY DEFINITIONS

The key definitions and sections related to Groundwater Monitoring Protocols, Standards, and Sites outlined in applicable SGMA code and regulations are provided below for reference.

Groundwater Sustainability Plan Regulations (California Code of Regulations §351)

- §351(h) "Best available science" refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice.
- §351(i) "Best management practice" refers to a practice, or combination of practices, that are designed to achieve sustainable groundwater management and have been determined to be technologically and economically effective, practicable, and based on best available science.

Monitoring Protocols Reference

§352.2. Monitoring Protocols

Each Plan shall include monitoring protocols adopted by the Agency for data collection and management, as follows:

(a) Monitoring protocols shall be developed according to best management practices.

(b) The Agency may rely on monitoring protocols included as part of the best management practices developed by the Department, or may adopt similar monitoring protocols that will yield comparable data.

(c) Monitoring protocols shall be reviewed at least every five years as part of the periodic evaluation of the Plan, and modified as necessary.

SGMA Reference

§10727.2. Required Plan Elements

(f) Monitoring protocols that are designed to detect changes in groundwater levels, groundwater quality, inelastic surface subsidence for basins for which subsidence has been identified as a potential problem, and flow and quality of surface water that directly affect groundwater levels or quality or are caused by groundwater extraction in the basin. The monitoring protocols shall be designed to generate information that promotes efficient and effective groundwater management.

7. RELATED MATERIALS CASE STUDIES

Luhdorff & Scalmanini Consulting Engineers, J.W. Borchers, M. Carpenter. 2014. Land Subsidence from Groundwater Use in California. Full Report of Findings prepared for California Water Foundation. April 2014. 151 p. http://ca.water.usgs.gov/land_subsidence/california-subsidence-cause-effect.html

Faunt, C.C., M. Sneed, J. Traum, and J.T. Brandt, 2015. Water availability and land subsidence in the Central Valley, California, USA. Hydrogeol J (2016) 24: 675. doi:10.1007/s10040-015-1339-x. https://pubs.er.usgs.gov/publication/701605

Poland, J.F., B.E. Lofgren, R.L. Ireland, and R.G. Pugh, 1975. Land subsidence in the San Joaquin Valley, California, as of 1972; US Geological Survey Professional Paper 437-H; prepared in cooperation with the California Department of Water Resources, 87 p. http://pubs.usgs.gov/pp/0437h/report.pdf

Sneed, M., J.T. Brandt, and M. Solt, 2013. Land subsidence along the Delta-Mendota Canal in the northern part of the San Joaquin Valley, California, 2003-10; USGS Scientific Investigations Report 2013-5142, prepared in cooperation with U.S. Bureau of Reclamation and the San Luis and Delta-Mendota Water Authority. https://pubs.er.usgs.gov/publication/sir20135142

Sneed, M., J.T. Brandt, and M. Solt, 2014. Land subsidence, groundwater levels, and geology in the Coachella Valley, California, 1993–2010: U.S. Geological Survey, Scientific Investigations Report 2014–5075, 62 p. http://dx.doi.org/10.3133/sir20145075

STANDARDS

California Department of Transportation, various dates. Caltrans Surveys Manual. http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/Manual_TOC.html

U.S. Environmental Protection Agency, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process, EPA QA/G-4 https://www.epa.gov/sites/production/files/documents/guidance_systematic_planning_dqo_process.pdf

Rice, E.W., R.B. Baire, A.D. Eaton, and L.S. Clesceri ed. 2012. Standard methods for the examination of water and wastewater. Washington, DC: American Public Health Association, American Water Works Association, and Water Environment Federation.

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Barcelona, M.J., J.P. Gibb, J.A. Helfrich, and E.E.Graske. 1985. Practical Guide for GroundWater Sampling. Illinois State Water Survey, Champaign, Illinois, 103 pages. www.orau.org/ptp/PTP%20Library/library/epa/samplings/pracgw.pdf

Buchanan, T.J., and W.P. Somers, 1969. Discharge measurements at gaging stations; techniques of water-resources investigations of the United States Geologic Survey chapter A8, Washington D.C. http://pubs.usgs.gov/twri/twri3a8/html/pdf.html

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California Department of Water Resources, 2010. Groundwater elevation monitoring guidelines. http://www.water.ca.gov/groundwater/casgem/pdfs/CASGEM%20DWR%20GW%20Guidelines%20Final%20121510.pdf

Holmes, R.R. Jr., P.J. Terrio, M.A. Harris, and P.C. Mills, 2001. Introduction to field methods for hydrologic and environmental studies, open-file report 01-50, USGS, Urbana, Illinois, 241 p. https://pubs.er.usgs.gov/publication/ofr0150

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Subcommittee on Ground Water of the Advisory Committee on Water Information, 2013. A national framework for ground-water monitoring in the United States. http://acwi.gov/sogw/ngwmn_framework_report_july2013.pdf

Vail, J., D. France, and B. Lewis. 2013. Operating Procedure: Groundwater Sampling SESDPROC-301-R3. https://www.epa.gov/sites/production/files/2015-06/documents/GroundwaterSampling.pdf

Wilde, F.D., January 2005. Preparations for water sampling (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A1, http://water.usgs.gov/owq/FieldManual/compiled/NFM_complete.pdf

ONLINE RESOURCES

Online System for Well Completion Reports (OSWCR). California Department of Water Resources. http://water.ca.gov/oswcr/index.cfm

Measuring Land Subsidence web page. U.S. Geological Survey. http://ca.water.usgs.gov/land_subsidence/california-subsidence-measuring.html

USGS Global Positioning Application and Practice web page. U.S. Geological Survey. http://water.usgs.gov/osw/gps/

Appendix O. Monitoring Network BMP

Monitoring Networks and Identification of Data Gaps Best Management Practice

1. OBJECTIVE

The objective of this Best Management Practice (BMP) is to assist in the development of Monitoring Networks and Identification of Data Gaps. The California Department of Water Resources (the Department or DWR) has developed a Best Management Practice for Monitoring Networks and Identification of Data Gaps, as part of the obligation in the Technical Assistance chapter (Chapter 7) of the Sustainable Groundwater Management Act (SGMA) to support the long-term sustainability of California's groundwater basins. The SJREC GSA has reviewed and updated this BMP for inclusion in the GSP. This BMP provides technical assistance to Groundwater Sustainability Agencies (GSAs) and other stakeholders to aid in the development of a monitoring network that is capable of providing sustainability indicator data of sufficient accuracy and quantity to demonstrate that the basin is being sustainably managed. In addition, this BMP is intended to provide information on how to identify and plan to resolve data gaps to reduce uncertainty that may be necessary to improve the ability of the GSP to achieve the sustainability goal for the basin.

This BMP includes the following sections:

1. Objective. A brief description of how and where monitoring networks are required under Sustainable Groundwater Management Act (SGMA) and the overall objective of this BMP.

2. Use and Limitations. A brief description of the use and limitations of this BMP.

3. Monitoring Network Fundamentals. A description of the general approach and background of groundwater monitoring networks.

4. Relationship of Monitoring Network to other BMPs. A description of how this BMP is connected with other BMPs.

5. Technical Assistance. Technical content of BMP providing guidance for regulatory sections.

6. Key Definitions. Descriptions of those definitions identified in the GSP Regulations, SGMA, or Basin Boundary Regulations.

7. Related Materials. References and other materials that provide supporting information related to the development of Groundwater Monitoring Networks.

2. USE AND LIMITATIONS

BMPs developed by the Department and revised by the SJREC GSA, provide technical guidance to GSAs and other stakeholders. Practices described in these BMPs do not replace the GSP Regulations, nor do they create new requirements or obligations for GSAs or other stakeholders. In addition, using this BMP to develop a GSP does not equate to an approval determination by the Department. All references to GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2. All references to SGMA relate to California Water Code sections in Division 6, Part 2.74.

3. MONITORING NETWORK FUNDAMENTALS

Monitoring is a fundamental component necessary to measure progress toward the achievement of any management goal. A monitoring network must have adequate spatial and temporal collection of multiple datasets, including groundwater levels, water quality information, land surface elevation, and surface water discharge conditions to demonstrate compliance with the GSP Regulations.

SGMA requires GSAs to establish and track locally defined significant and unreasonable conditions for each of the sustainability indicators. In addition, the collection of data from a robust network is required to ensure that uncertainty is appropriately reduced during the analysis of these datasets. Data collected in an organized and consistent manner will aid in ensuring that the interpretations of the data are as accurate as possible. Also, the consistency of the types, methods, and timing of data collection facilitate the sharing of data across basin boundaries or within basins.

Analyzing data from an adequate monitoring network within a basin can lead to refinement of the understanding of the dynamic flow conditions; this leads to the optimization of sustainable groundwater management.

4. RELATIONSHIP OF MONITORING NETWORKS TO OTHER BMPS

Groundwater monitoring is a fundamental component of SGMA as each GSP must include a sufficient network that provides data that demonstrate measured progress toward achievement of the sustainability goal for each basin. For this reason, a sufficient network will need to be developed and utilized to accomplish this component of SGMA.

It is important that data are developed in a manner consistent with the basin setting, planning, and projects/management actions steps identified on Figure 1 and the GSP Regulations. The inclusion of monitoring protocols in the GSP Regulations also emphasizes the importance of quality empirical data to support GSPs and provide comparable information from basin to basin.

Figure 1 provides a logical progression for the development of a GSP and illustrates how monitoring networks are linked to other related BMPs. This figure also shows the context of the BMPs as they relate to various steps to sustainability as outlined in the GSP Regulations. The monitoring protocol BMP is part of the Monitoring step identified in the logical progression illustration in **Figure 1**.

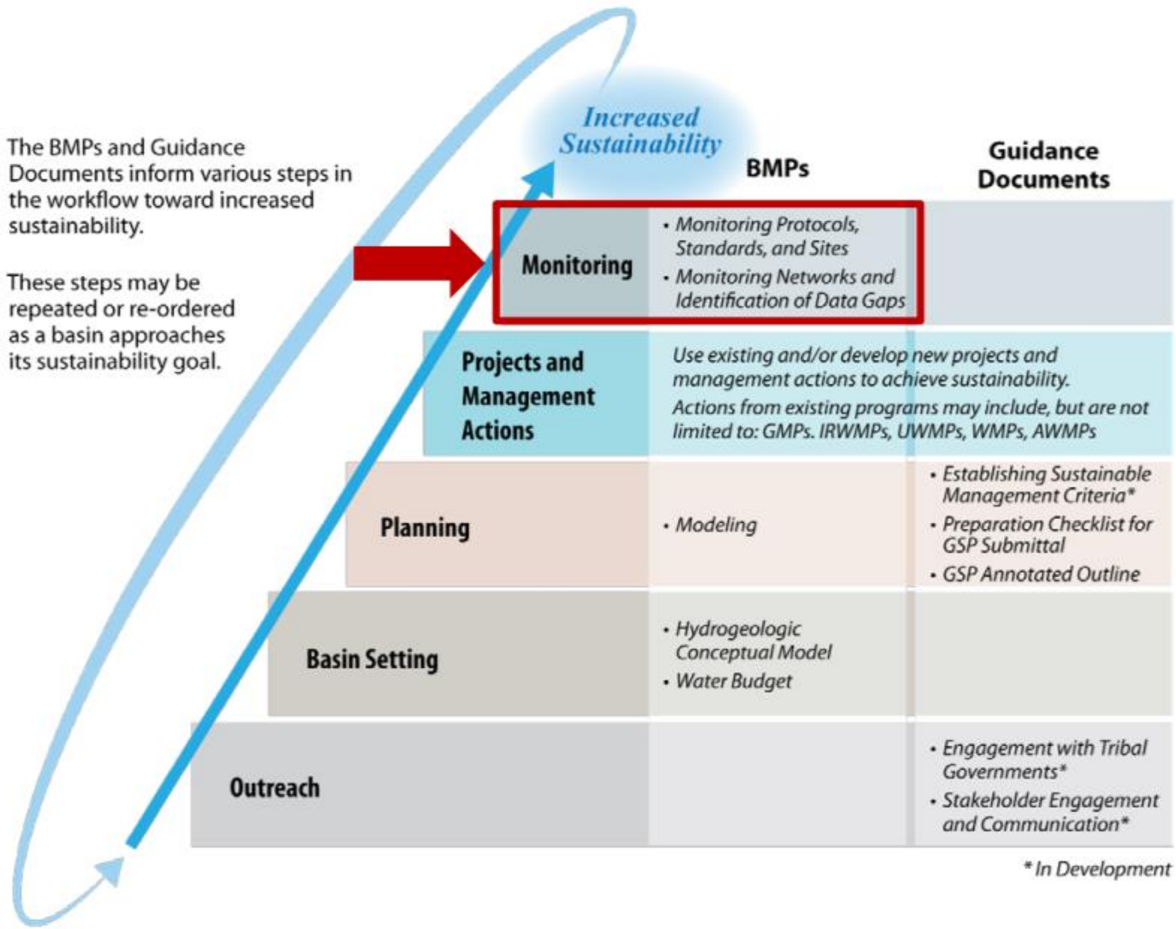


Figure 1 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability

5. TECHNICAL ASSISTANCE

This section provides technical assistance to support the development monitoring networks and identification of data gaps.

GENERAL MONITORING NETWORKS

23 CCR §354.32 Introduction to Monitoring Networks and §354.34 (a) and (b) Monitoring Network

> ***23 CCR §354.32. Introduction to Monitoring Networks***
> *This Subarticle describes the monitoring network that shall be developed for each basin, including monitoring objectives, monitoring protocols, and data reporting requirements. The monitoring network shall promote the collection of data of sufficient quality, frequency, and distribution to characterize groundwater and related surface water conditions in the basin and evaluate changing conditions that occur through implementation of the Plan.*
>
> ***23 CCR §354.34. Monitoring Network***
> *(a) Each Agency shall develop a monitoring network capable of collecting sufficient data to demonstrate short-term, seasonal, and long-term trends in groundwater and related surface conditions, and yield representative information about groundwater conditions as necessary to evaluate Plan implementation. (b) Each Plan shall include a description of the monitoring network objectives for the basin, including an explanation of how the network will be developed and implemented to monitor groundwater and related surface conditions, and the interconnection of surface water and groundwater, with sufficient temporal frequency and spatial distribution to evaluate the affects and effectiveness of Plan implementation. The monitoring network objectives shall be implemented to accomplish the following:*
> *(1) Demonstrate progress toward achieving measurable objectives described in the Plan.*
> *(2) Monitor impacts to the beneficial uses or users of groundwater.*
> *(3) Monitor changes in groundwater conditions relative to measurable objectives and minimum thresholds.*
> *(4) Quantify annual changes in water budget components.*

The GSP Regulations require GSAs to develop a monitoring network. The monitoring network must be capable of capturing data on a sufficient temporal frequency and spatial distribution to demonstrate short-term, seasonal, and long-term trends in basin conditions for each of the sustainability indicators, and provide enough information to evaluate GSP implementation. A monitoring network should be developed in such a way that it demonstrates progress toward achieving measurable objectives.

As described in the Monitoring Protocols, Standards, and Sites BMP, it is suggested that each GSP incorporate the Data Quality Objective (DQO) process following the US EPA Guidance on Systematic Planning Using the Data Quality Objectives Process (EPA, 2006). Although strict adherence to this method is not required, it does provide a robust approach to ensuring data is collected with a specific purpose in mind, and efforts for monitoring are as efficient as possible to achieve the objectives of the GSP and compliance with the GSP Regulations.

The DQO process presents a method that can be applied directly to the sustainability criteria quantitative requirements through the following steps:

1. State the problem – define sustainability indicators and planning considerations of the GSP and sustainability goal

2. Identify the goal – describe the quantitative measurable objectives and minimum thresholds for each of the sustainability indicators

3. Identify the inputs – describe the data necessary to evaluate the sustainability indicators and other GSP requirements (i.e., water budget)

4. Define the boundaries of the study – This is commonly the extent of the Bulletin 118 groundwater basin or subbasin, unless multiple GSPs are prepared for a given basin. In that case, evaluation of the coordination plan and specifically how the monitoring will be comparable and meet the sustainability goals for the entire basin should be described

5. Develop an analytical approach – Determine how the quantitative sustainability indicators will be evaluated (i.e., are special analytical methods required that have specific data needs)

6. Specify performance or acceptance criteria – Determine what quality the data must have to achieve the objective and provide some assurance that the analysis is accurate and reliable

7. Develop a plan for obtaining data – Once the objectives are known determine how these data should be collected. Existing data sources should be used to the greatest extent possible

These steps of the DQO process should be used to guide GSAs to development of the most efficient monitoring process to meet the measurable objectives of the GSP and the sustainability goal. The DQO process is an iterative process and should be evaluated regularly to improve monitoring efficiencies and meet changing planning and project needs. Following the DQO process GSAs should also include a data quality control and quality assurance plan to guide the collection of data.

GSAs should first evaluate their existing monitoring network and existing datasets when developing the monitoring network for their GSP, such as the California Statewide Groundwater Elevation Monitoring (CASGEM) program. The Assessment and Improvement of Monitoring Network Section of the Regulations describes a process by which GSAs can identify and fill in gaps in their monitoring network. The existing monitoring networks may require evaluation to ensure they meet the DQOs necessary for the GSP. Other considerations for developing a monitoring network include:

- Degree of monitoring. The degree of monitoring should be consistent with the level of groundwater use and need for various levels of monitoring density and frequency. Areas that are subject to greater groundwater pumping, greater fluctuations in conditions, significant recharge areas, or specific projects may require more monitoring (temporal and/or spatial) than areas that experience less activity or are more static.
- Access Issues. GSAs may have to deal with access issues such as unwilling landowners, access agreements, destroyed wells, or other safety concerns with accessing a monitoring site.
- Adjacent Basins. Understanding conditions at or across basin boundaries is important. GSAs should coordinate with adjacent basins on monitoring efforts to be consistent both temporally and spatially. Coordinated efforts and shared data will help GSAs understand their basins' conditions better and potentially better understand groundwater flow conditions across boundaries.

- Consider all sustainability indicators. GSAs should look for ways to efficiently use monitoring sites to collect data for more than one or all of the sustainability indicators. Similarly, when installing a new monitoring site, GSAs should take that opportunity to gather as much information about the subsurface conditions as possible.

There are many other considerations that GSAs must understand when developing monitoring networks that are specific to the various sustainability indicators: chronic lowering of groundwater levels, reduction of groundwater storage, seawater intrusion, degraded water quality, land subsidence, or depletions of interconnected surface waters. In addition, establishment of a monitoring network should be evaluated in conjunction with the Monitoring Protocols, Standards, and Sites; Hydrogeologic Conceptual Model (HCM); Water Budget; and Modeling BMPs when considering the data needs to meet GSP measurable objectives and the sustainability goal.

SPECIFIC MONITORING NETWORKS

> **23 CCR §354.34(d)-(j):**
> (d) The monitoring network shall be designed to ensure adequate coverage of sustainability indicators. If management areas are established, the quantity and density of monitoring sites in those areas shall be sufficient to evaluate conditions of the basin setting and sustainable management criteria specific to that area.
> (e) A Plan may utilize site information and monitoring data from existing sources as part of the monitoring network.
> (f) The Agency shall determine the density of monitoring sites and frequency of measurements required to demonstrate short-term, seasonal, and long-term trends based upon the following factors:
> (1) Amount of current and projected groundwater use.
> (2) Aquifer characteristics, including confined or unconfined aquifer conditions, or other physical characteristics that affect groundwater flow.
> (3) Impacts to beneficial uses and users of groundwater and land uses and property interests affected by groundwater production, and adjacent basins that could affect the ability of that basin to meet the sustainability goal.
> (4) Whether the Agency has adequate long-term existing monitoring results or other technical information to demonstrate an understanding of aquifer response.
> (g) Each Plan shall describe the following information about the monitoring network:
> (1) Scientific rationale for the monitoring site selection process.
> (2) Consistency with data and reporting standards described in Section 352.4. If a site is not consistent with those standards, the Plan shall explain the necessity of the site to the monitoring network, and how any variation from the standards will not affect the usefulness of the results obtained.
> (3) For each sustainability indicator, the quantitative values for the minimum threshold, measurable objective, and interim milestones that will be measured at each monitoring site or representative monitoring sites established pursuant to Section 354.36.
> (h) The location and type of each monitoring site within the basin displayed on a map, and reported in tabular format, including information regarding the monitoring site type, frequency of measurement, and the purposes for which the monitoring site is being used.
> (i) The monitoring protocols developed by each Agency shall include a description of technical standards, data collection methods, and other procedures or protocols pursuant to Water Code Section 10727.2(f) for monitoring sites or other data collection facilities to ensure that the monitoring network utilizes comparable data and methodologies.
> (j) An Agency that has demonstrated that undesirable results related to one or more sustainability indicators are not present and are not likely to occur in a basin, as described in Section 354.26, shall not be required to establish a monitoring network related to those sustainability indicators.

Monitoring data provide the basis for demonstrating that undesirable results are avoided and are necessary for adequately managing the basin. The undesirable result associated with each sustainability indicator is based on a unique set of representative monitoring points. Therefore, a single monitoring network may not be appropriate to address all sustainability indicators. The monitoring network will consist of an adequate magnitude of monitoring locations that will characterize the groundwater flow regime such that a GSA will have the ability to predict sustainability indicator responses to management actions and document those results. The data collected from these networks will be the foundation for communication to other connected basins as one may affect another. The transparent availability of data is intended to alleviate conflict by demonstrating conditions in a consistent manner such that assessment of the sustainability indicators is relatively consistent from basin to basin.

The use of existing monitoring networks established during implementation of CASGEM, Irrigated Lands Reporting Program (IRLP), Groundwater Ambient Monitoring and Assessment Program (GAMA), National Groundwater Monitoring Network, Existing Groundwater Management Planning, and other local programs could be used for a base monitoring network from which to build. These networks should be evaluated for compliance with GSP Regulations and DQOs.

This section addresses the design and installation of monitoring networks and sites. Agencies must address a number of issues prior to designing the monitoring site, including, but not limited to, establishing the reason for installing the monitoring site, obtaining access agreements, assessing how the monitoring site may improve the basin conceptual model, assessing how the monitoring site may reduce uncertainty, etc. Where management areas are established, each area must be considered when developing the monitoring network for each sustainability indicator.

Professional judgement will be essential to determine the degree of monitoring that will be necessary to meet the needs for the GSP. This BMP provides guidance, but should be coupled with site-specific monitoring needs to address the complexities of the groundwater basin and DQOs.

The following sections are organized by each of the sustainability indicators. These considerations should be applied to the network as a whole to ensure the quality of the data is consistent and reliable, and so that sound representative monitoring locations can be established, as described in the Representative Monitoring Points (RMP) section of this BMP.

A. Chronic Lowering of Groundwater Levels

> ***§354.34(c):*** *Each monitoring network shall be designed to accomplish the following for each sustainability indicator:*
> *(1) Chronic Lowering of Groundwater Levels. Demonstrate groundwater occurrence, flow directions, and hydraulic gradients between principal aquifers and surface water features by the following methods:*
> *(A) A sufficient density of monitoring wells to collect representative measurements through depth-discrete perforated intervals to characterize the groundwater table or potentiometric surface for each principal aquifer.*
> *(B) Static groundwater elevation measurements shall be collected at least two times per year, to represent seasonal low and seasonal high groundwater conditions.*

The observation and collection of groundwater level data is the cornerstone of data collected for SGMA compliance. Design of the groundwater level data monitoring network will be dependent upon the initial hydrogeologic conceptual model and will likely undergo refinement both temporally and spatially as management in the basin progresses. This isn't to say that the monitoring network will continually expand, but rather, through increased understanding, be more refined to gather the necessary information in the most efficient way possible to demonstrate sustainability, and exercise the basin to maintain conditions consistent with the sustainability goal and sustainable yield of the basin. The use of groundwater levels as a surrogate for other sustainability indicators will require reliable, consistent, high-quality, defendable data to demonstrate the relationship prior to use as a surrogate for other sustainability indicators.

It is preferable to use dedicated groundwater monitor wells with known construction information. The selection of wells should be aquifer-specific and wells that are screened across more than one aquifer should be avoided where possible. If existing wells are used, the perforated intervals should be known to be able to utilize water level or other data collected from that well. Development of the monitor well network must evaluate and consider both unconfined and confined aquifers, and assess where pumping wells are screened that affect monitoring at these locations. Agricultural or municipal wells can be used temporarily until either dedicated monitor wells can be installed or an existing well can be identified that meets the above criteria. If agricultural or municipal wells are used for monitoring, the wells must be screened across a single water-bearing unit, and care must be taken to ensure that pumping drawdown has sufficiently recovered before collecting data from a well.

Each well selected for inclusion in the monitoring network should be evaluated to ensure that water level data obtained meet the DQOs for that well. For example, some wells may be directly influenced by nearby pumping, or injection and observation of the aquifer response may be the purpose of the well. Otherwise, the network should contain an adequate number of wells to observe the overall static conditions and the specific project effects. Well construction details and pumping information for active and inactive wells located in the area of the selected monitor well location should be reviewed to determine whether construction details or pumping activity at those wells could affect water level or water quality data for the selected monitoring site.

There is no definitive rule for the density of groundwater monitoring points needed in a basin. **Table 1** was adopted from the CASGEM Groundwater Elevation Monitoring Guidelines (DWR, 2010). This table summarizes existing references to quantify the density of monitor wells per hundred square miles. While these estimates may provide guidance, the necessary monitoring point density for GSP depends on local geology, extent of groundwater use, and how the GSPs define undesirable results. The use of Hopkins (1984) analysis incorporates a relative well density based on the degree of groundwater use within a given area. Professional judgement will be essential to determining an adequate level of monitoring, frequency, and density based on the DQOs and the need to observe aquifer response to high pumping areas, cones of depression, significant recharge areas, and specific projects.

Table 1. Monitor Well Density Considerations

Reference	Monitor Well Density (wells per 100 miles^2)
Heath (1976)	0.2 - 10
Sophocleous (1983)	6.3
Hopkins (1984)	
Basins pumping more than 10,000 acre-feet/year per 100 miles^2	4.0

Basins pumping between 1,000 and 10,000 acre-feet/year per 100 miles^2	2.0
Basins pumping between 250 and 1,000 acre-feet/year per 100 miles^2	1.0
Basins pumping between 100 and 250 acre-feet/year per 100 miles^2	0.7

In addition to monitor well network density, the frequency of monitoring to characterize the groundwater dynamics within a basin or area is important. The discussion presented in the National Framework for Ground-water Monitoring in the United States (ACWI, 2013) utilizes a degree of groundwater use and aquifer characteristics to aid in determining an appropriate frequency. **Figure 2** (ACWI, 2013) and **Table 2** (ACWI, 2013) describe these considerations and provide recommended frequency of long-term monitoring. It should be noted that the initial characterization is not included; the initial characterization of a monitoring location will require more frequent monitoring to establish the dynamic range and identification of external stresses affecting the groundwater level. An understanding of the full range of monitor well conditions should be reached prior to establishing a long-term monitoring frequency. The considerations presented in **Figure 2** and **Table 2** should be evaluated to determine if the guidance meets the DQOs to support the GSP. Professional judgment should be used to refine the monitoring frequency and density.

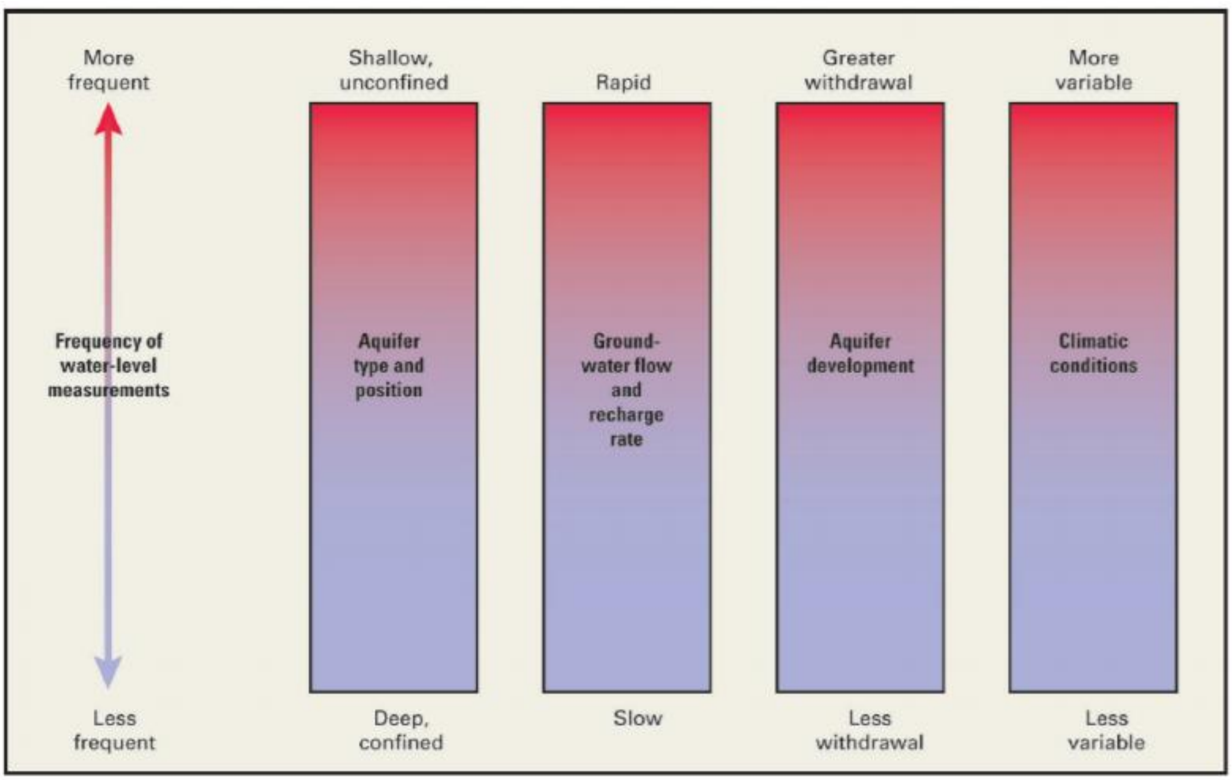


Figure 2. Factors Determining Frequency of Monitoring Groundwater Levels (Taylor and Alley, 2001, adapted from ACWI, 2013)

Table 2. Monitoring Frequency Based on Aquifer Properties and Degree of Use (adapted from ACWI, 2013)

Aquifer Type	Nearby Long-Term Aquifer Withdrawals		
	Small Withdrawals	Moderate Withdrawals	Large Withdrawals
Unconfined			
"low" recharge (<5 in/yr)	once per quarter	once per quarter	once per month
"high" recharge (>5 in/yr)	once per quarter	once per month	once per day
Confined			
"low" hydraulic conductivity (<200 ft/d)	once per quarter	once per quarter	once per month
"high" hydraulic conductivity (>200 ft/d)	once per quarter	once per month	once per day

The discussion below provides specific management practices for implementation of the GSP, where the general approaches for considering monitoring network density and frequency described above provide some guidance for the expectations for network design.

- New wells must meet applicable well installation standards set in California DWR Bulletin 74-81 and 74-90, or as updated.
- Groundwater level data will be collected from each principal aquifer in the basin.
- Groundwater level data must be sufficient to produce seasonal maps of potentiometric surfaces or water table surfaces throughout the basin that clearly identify changes in groundwater flow direction and gradient.
- Semi-annual groundwater levels will be collected to represent seasonal high and seasonal low values.
    - While semi-annual monitoring is required, more frequent, quarterly, monthly, or daily monitoring may be necessary to provide a more robust understanding of groundwater dynamics within the system.
    - Agencies will need to adjust the monitoring frequency to address uncertainty, such as in specific places where sustainability indicators are of concern, or to track specific management actions and projects as they are implemented.
    - Select wells should be monitored frequently enough to characterize the season high and low within the basin.
- Data must be sufficient for mapping groundwater depressions, recharge areas, and along margins of basins where groundwater flow is known to enter or leave a basin.
- Well density must be adequate to determine changes in storage.
- Data must be able to demonstrate the interconnectivity between shallow groundwater and surface water bodies, where appropriate.
- Data must be able to map the effects of management actions, i.e., managed aquifer recharge or hydraulic seawater intrusion barriers.
- Data must be able to demonstrate conditions at basin boundaries.

  - Agencies may consider coordinating monitoring efforts with adjacent basins to provide consistent data across basin boundaries.
  - Agencies may consider characterization and continued impacts of internal hydraulic boundary conditions, such as faults, disconformities, or other internal boundary types.
- Data must be able to characterize conditions and monitor adverse impacts as they may affect the beneficial uses and users identified within the basin.

Additional Information:

Ground-Water-Level Monitoring and the Importance of Long-Term Water-Level Data
http://pubs.usgs.gov/circ/circ1217/pdf/circ1217_final.pdf

A National Framework for Ground-Water Monitoring in the United States Fact Sheet:
http://acwi.gov/sogw/NGWMN_InfoSheet_final.pdf
Full Report: http://acwi.gov/sogw/ngwmn_framework_report_july2013.pdf

Statistical Design of Water-Level Monitoring Networks http://pubs.usgs.gov/circ/circ1217/pdf/pt4.pdf

Design of Ground-Water Level Observation-Well Programs
http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.1976.tb03635.x/epdf

B. Reduction of Groundwater Storage

> ***23 CCR §354.34(c)(2):*** *Reduction of Groundwater Storage. Provide an estimate of the change in annual groundwater in storage.*

While reduction in groundwater storage is not a directly measurable condition, it does rely heavily on the collection of accurate groundwater levels, as described in the preceding section, and a robust understanding of the HCM and textural observations from boreholes. The identification in the HCM of discrete aquifer units and surrounding aquitards will be essential in assessing changes in groundwater storage. The changes in groundwater levels reflect changes in storage and can thus be estimated with assumptions of thickness of units, porosity, and connectivity. These observations will be essential for use in calculating the water budget; see the Water Budget BMP for more detail.

Estimates of changes in storage are available from remote sensing-based investigations, but should be used cautiously as they tend to be regional in nature and may not provide the level of accuracy necessary to fully determine the conditions within the basin. The National Aeronautics and Space Administration (NASA) mission, Gravity Recovery and Climate Experiment (GRACE) satellites provide analysis results of differential gravity response associated with changes in groundwater occurrence and terrestrial water storage, http://www.nasa.gov/mission_pages/Grace/#.WATU_fkrKUk.

C. Seawater Intrusion

23 CCR §354.34(c)(3): *Seawater Intrusion. Monitor seawater intrusion using chloride concentrations, or other measurements convertible to chloride concentrations, so that the current and projected rate and extent of seawater intrusion for each applicable principal aquifer may be calculated.*

The Delta-Mendota Subbasin is highly unlikely to have Significant and Unreasonable Seawater Intrusion. For that reason, monitoring protocols for seawater intrusion have not been developed. In the unlikely event that seawater intrusion must be monitored in the Delta-Mendota Subbasin, the SJREC GSA will review BMP's to address the concern.

D. Degraded Water Quality

23 CCR §354.34(c)(4): *Degraded Water Quality. Collect sufficient spatial and temporal data from each applicable principal aquifer to determine groundwater quality trends for water quality indicators, as determined by the Agency, to address known water quality issues.*

Groundwater quality monitoring networks should be designed to demonstrate that the degraded water quality sustainability indicator is being observed for the purpose of meeting the sustainability goal. The monitoring network should consist largely as supplemental monitoring locations where known groundwater contamination plumes under existing regulatory management and monitoring exist, and additional safeguards for plume migration are necessary. In addition, some monitoring may be necessary to address other degraded water quality issues in which migration could impact beneficial uses of water, including, but not limited to, unregulated contaminant plumes and naturally occurring water quality impacts. Seawater intrusion and degraded water quality are naturally related, as many practices are interchangeable. The following represent specific practices to be employed in the execution of the GSP:

- Monitor groundwater quality data from each principal aquifer in the basin that is currently, or may be in the future, impacted by degraded water quality.
  - The spatial distribution must be adequate to map or supplement mapping of known contaminants.
  - Monitoring should occur based upon professional opinion, but generally correlate to the seasonal high and low, or more frequent as appropriate.
    - Where regulated plumes exist, monitoring should coincide with regulatory monitoring for plume migration comparison purposes.
    - Where unregulated degraded water quality occurs, monitoring should be consistent with the degree of groundwater use in the regions of the known impacts.
- Collect groundwater quality data from each principal aquifer in the basin that is currently, or may be in the future, impacted by degraded water quality.
  - Agencies should use existing water quality monitoring data as applicable. For example, these could include ILRP, GAMA, existing RWQCB monitoring and remediation programs, and drinking water source assessment programs.

- Define the three-dimensional extent of any existing degraded water quality impact.
- Data should be sufficient for mapping movement of degraded water quality.
- Data should be sufficient to assess groundwater quality impacts to beneficial uses and users.
- Data should be adequate to evaluate whether management activities are contributing to water quality degradation.

Additional References:

Framework for a ground-water quality monitoring and assessment program for California (GAMA) http://pubs.usgs.gov/wri/wri034166/

Estimation of aquifer scale proportion using equal area grids: Assessment of regional scale groundwater quality http://ca.water.usgs.gov/projects/gama/pdfs/Belitz_etal_2010_wrcr12701.pdf

E. Land Subsidence

23 CCR §354.34(c)(5): *Land Subsidence. Identify the rate and extent of land subsidence, which may be measured by extensometers, surveying, remote sensing technology, or other appropriate method.*

Inelastic land subsidence has been recognized in California for many decades. Observation of land subsidence sustainability indicators can utilize numerous techniques, including levelling surveying tied to known benchmarks, installing and tracking changes in borehole extensometers, monitoring continuous global position system (CGPS) locations, or analyzing interferometric synthetic aperture radar (InSAR) data. As with most sustainability indicators, conditions of subsidence, or lack thereof, can be correlated to groundwater levels as a surrogate. Each of these approaches uses different measuring points and techniques, and is tailored for specific data needs and geologic conditions.

Existing data should be used to the greatest extent. The USGS has conducted numerous studies and much of the data can be located through their webpage and reports: http://ca.water.usgs.gov/land_subsidence/index.html. DWR has compiled and uploaded subsidence data to the SGMA Data Viewer for use by GSA's: https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer. In addition, DWR has developed supporting studies and data available in the Groundwater Information Center interactive maps and reports: http://www.water.ca.gov/groundwater/gwinfo/index.cfm. The use of existing regular surveys of state infrastructure may also present a record of historical changes in elevation along roadways and canals. Prior to development of a specific subsidence monitoring network a screening level analysis should be conducted. The screening of subsidence occurrence should include:

- Review of the HCM and understanding of grain-size distributions and potential for subsidence to occur.
- Review of any known regional or correlative geologic conditions where subsidence has been observed.
- Review of historic range of groundwater levels in the principal aquifers of the basin.

- Review of historic records of infrastructure impacts, including, but not limited to, damage to pipelines, canals, roadways, or bridges, or well collapse potentially associated with land surface elevation changes.
- Review of remote sensing results such as InSAR or other land surface monitoring data.
- Review of existing CGPS surveys.

In general, the network should be designed to provide consistent, accurate, and reproducible results. Where subsidence conditions are occurring or believed to occur, a specific monitoring network should be established to observe the sustainability indicator such that the sustainability goal can be met. The following approaches can be used independently or in coordination with multiple methods and should be evaluated with the specific conditions and objectives in mind. Various standards and guidance documents that must be adhered to when developing a monitoring network include:

- Leveling surveys must follow surveying standards set out in the California Department of Transportation's Caltrans Surveys Manual. Any alternative shall be reviewed by a Professional Land Surveyor or Professional Civil Engineer registered in the State of California for accuracy and reasonableness. Specific websites where additional information can be found include:
    - http://www.dot.ca.gov/hq/row/landsurveys/
    - http://www.ngs.noaa.gov/datasheets/
    - https://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodeticcontrol-networks.htm#3.5
- CGPS surveys must follow surveying standards set out in the California Department of Transportation's Caltrans Surveys Manual. Specific websites where additional data can be found include:
    - http://www.dot.ca.gov/hq/row/landsurveys/
    - http://www.ngs.noaa.gov/CORS/
    - http://www.unavco.org/instrumentation/networks/status/pbo
    - http://www.dot.ca.gov/dist6/surveys/CVSRN/sitemap.htm
    - http://sopac.ucsd.edu/map.shtml
- The construction and use of borehole extensometers can yield information about total and unit-specific subsidence rates depending upon construction and purpose. Specific sites where additional data can be found include:
    - Extensometer methods commonly used by the USGS http://hydrologie.org/redbooks/a151/iahs_151_0169.pdf
    - Extensometry principles (p. 20-29) http://wwwrcamnl.wr.usgs.gov/rgws/Unesco/
    - Examples of extensometer construction, instrumentation, and data interpretation
        - Single-stage pipe extensometer (Edwards Air Force Base, CA; 1990), p. 20-23: http://pubs.usgs.gov/wri/2000/wri004015/
        - Dual-stage pipe extensometer (Lancaster, CA; 1995), p. 8-12: http://pubs.usgs.gov/of/2001/ofr01414/
        - Dual-stage pipe extensometer (San Lorenzo, CA; 2008), p. 12-13: https://pubs.er.usgs.gov/publication/ds890
- The use of InSAR data can be useful for screening and regular monitoring, especially as the technology becomes more widely available and usable. Specific sites where additional data can be found are listed below.

- Interferometric Synthetic Aperture Radar (InSAR) techniques are an effective way to measure changes in land-surface altitude over large areas. Some basic information about InSAR can be found here:
  - https://pubs.usgs.gov/fs/fs-051-00/pdf/fs-051-00.pdf
  - http://pubs.usgs.gov/fs/fs06903/pdf/fs06903.pdf
- Raw data (not processed into interferograms) are available from a variety of foreign space agencies or their distributors at variable costs (including free):
  - European Space Agency http://www.esa.int/ESA
  - Japanese Space Exploration Agency http://global.jaxa.jp/
  - Italian Space Agency http://www.asi.it/en
  - Canadian Space Agency http://www.asc-csa.gc.ca/eng/
  - German Aerospace Center http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10002/
- Data Processing: Processing raw data to high-quality InSAR data is not a trivial task.
  - Open source/research-grade software packages and commercially available software packages. A list of available software can be found here: http://www.unavco.org/software/data-processing/sarsoftware/sar-software.html
  - There are commercial companies that process InSAR data.
  - Processing raw data to quality-controlled InSAR data is an essential part of InSAR processing because of the numerous common sources of error. Discussions of these error sources are found here:
    - http://pubs.usgs.gov/sir/2014/5075/
    - https://pubs.er.usgs.gov/publication/sir20135142

F. Depletion of Interconnected Surface Water

23 CCR §354.34(c))(6): *Depletions of Interconnected Surface Water. Monitor surface water and groundwater, where interconnected surface water conditions exist, to characterize the spatial and temporal exchanges between surface water and groundwater, and to calibrate and apply the tools and methods necessary to calculate depletions of surface water caused by groundwater extractions. The monitoring network shall be able to characterize the following:*
(A) Flow conditions including surface water discharge, surface water head, and baseflow contribution.
(B) Identifying the approximate date and location where ephemeral or intermittent flowing streams and rivers cease to flow, if applicable.
(C) Temporal change in conditions due to variations in stream discharge and regional groundwater extraction.
(D) Other factors that may be necessary to identify adverse impacts on beneficial uses of the surface water.

Monitoring of the interconnected surface water depletions requires the use of tools, commonly modeling approaches, to estimate the depletions associated with groundwater extraction. Models require assumptions be made to constrain the numerical model solutions. These assumptions should be based on empirical observations determining the extent of the connection of surface water and groundwater systems, the timing of those connections, the flow dynamics of both the surface water and groundwater systems, and hydrogeologic properties of the geologic framework connecting these systems.

The following components should be included in the establishment of a monitoring network:

- Use existing stream gaging and groundwater level monitoring networks to the extent possible.
- Establish stream gaging along sections of known surface water groundwater connection.
    - All streamflow measurements should be collected, analyzed, and reported in accordance with the procedures outlined in USGS Water Supply Paper 2175, Volume 1. - Measurement of Stage Discharge and Volume 2. - Computation of Discharge.
        - https://pubs.er.usgs.gov/publication/wsp2175_vol1
        - https://pubs.er.usgs.gov/publication/wsp2175
    - Specific websites where additional information can be found include:
        - General source: http://water.usgs.gov/nsip/
        - Standards for the Analysis and Processing of Surface-Water Data and Information Using Electronic Methods https://pubs.er.usgs.gov/publication/wri20014044
        - USGS Streamflow Information
            - Real-time Streamflow Data for the Nation
            - Historical Streamflow Data for the Nation
            - WaterWatch
            - StreamStats
    - Location selection must account for surface water diversions and return flows; or select gaging locations and reaches over which no diversions or return flows exist.
- Establish a shallow groundwater monitor well network, as necessary, to characterize groundwater levels adjacent to connected streams and hydrogeologic properties.
    - Network should extend perpendicular and parallel to stream flow to provide adequate characterization to constrain model development.
    - Monitor to capture seasonal pumping conditions in vicinity-connected surface water bodies.

It may be beneficial to conduct other initial characterization surveys to establish an appropriate monitoring method to develop assumptions for a model or other technique to estimate depletion of surface water. These may include:

- Stream bed conductance surveys
- Aquifer testing for hydrogeologic properties
- Isotopic studies to determine source areas
- Geochemical studies to determine source areas
- Geophysical techniques to determine connectivity to stream channels and preferential flow pathways.

REPRESENTATIVE MONITORING POINTS

The use of RMPs, which are a subset of a basin's complete monitoring network as demonstrated in **Figure 3**, can be used to consolidate reporting of quantitative observations of the sustainability indicators.

23 CCR §354.36. Representative Monitoring (a)-(c): *Each Agency may designate a subset of monitoring sites as representative of conditions in the basin or an area of the basin, as follows:*
(a) Representative monitoring sites may be designated by the Agency as the point at which sustainability indicators are monitored, and for which quantitative values for minimum thresholds, measurable objectives, and interim milestones are defined.
(b) Groundwater elevations may be used as a proxy for monitoring other sustainability indicators if the Agency demonstrates the following:

(1) Significant correlation exists between groundwater elevations and the sustainability indicators for which groundwater elevation measurements serve as a proxy.

(2) Measurable objectives established for groundwater elevation shall include a reasonable margin of operational flexibility taking into consideration the basin setting to avoid undesirable results for the sustainability indicators for which groundwater elevation measurements serve as a proxy.

(c) The designation of a representative monitoring site shall be supported by adequate evidence demonstrating that the site reflects general conditions in the area.

In this figure, the complete monitoring network is represented by black dots. The RMPs for each sustainability indicator are represented by various colored bull's-eyes. In this example, the network of RMPs is unique for each sustainability indicator. Agencies can adopt a single network of RMPs or have a unique set of RMPs for each sustainability indicator.

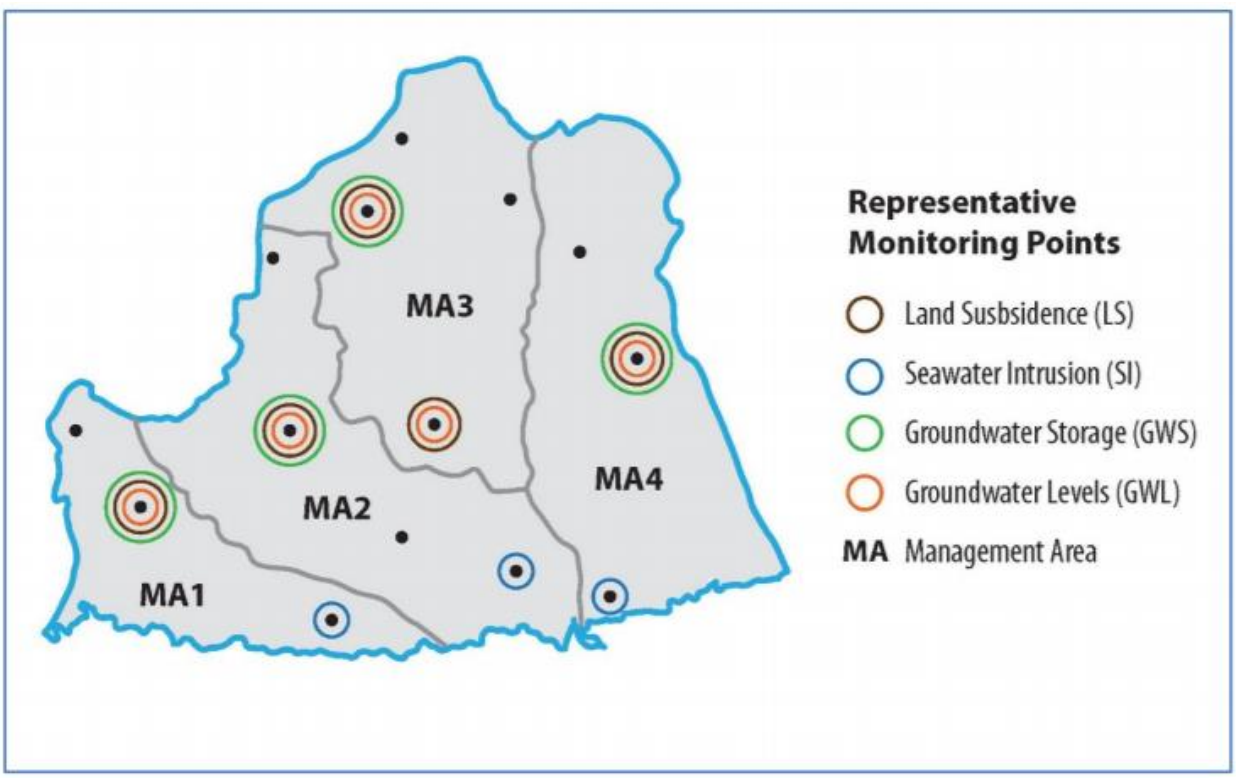


Figure 3: Representative Monitoring Points

If RMPs are used to represent groundwater elevations from a number of surrounding monitor wells, the GSP should demonstrate that each RMP's historical measured groundwater elevations, groundwater elevation trends, and seasonal fluctuations are similar to the historical measurements in the surrounding monitor wells. If RMPs are used to represent groundwater quality from a number of surrounding monitor wells, the GSP should demonstrate that each RMP's historical measured groundwater quality and groundwater quality trends are similar to historical measurements in the surrounding monitor wells.

The use of groundwater levels as a proxy may be utilized where clear correlation can be made for each sustainability indicator. The use of the proxy can facilitate the illustration of where minimum thresholds and measureable objectives occur. A series of RMPs or a single RMP may be adequate to characterize a management area or basin. Use of the RMP should include identification and description of possible interference with the monitoring objective.

NETWORK ASSESSMENT AND IMPROVEMENTS

23 CCR §354.38. Assessment and Improvement of Monitoring Network (a)-(e)
(a) Each Agency shall review the monitoring network and include an evaluation in the Plan and each five-year assessment, including a determination of uncertainty and whether there are data gaps that could affect the ability of the Plan to achieve the sustainability goal for the basin.
(b) Each Agency shall identify data gaps wherever the basin does not contain a sufficient number of monitoring sites, does not monitor sites at a sufficient frequency, or utilizes monitoring sites that are unreliable, including those that do not satisfy minimum standards of the monitoring network adopted by the Agency.
(c) If the monitoring network contains data gaps, the Plan shall include a description of the following:
(1) The location and reason for data gaps in the monitoring network.
(2) Local issues and circumstances that limit or prevent monitoring.
(d) Each Agency shall describe steps that will be taken to fill data gaps before the next fiveyear assessment, including the location and purpose of newly added or installed monitoring sites.
(e) Each Agency shall adjust the monitoring frequency and distribution of monitoring sites to provide an adequate level of detail about site-specific surface water and groundwater conditions and to assess the effectiveness of management actions under circumstances that include the following:
(1) Minimum threshold exceedances.
(2) Highly variable spatial or temporal conditions.
(3) Adverse impacts to beneficial uses and users of groundwater.
(4) The potential to adversely affect the ability of an adjacent basin to implement its Plan or impede achievement of sustainability goals in an adjacent basin.

Network assessment and improvements are commonly identified as 'data gaps' in the monitoring network and refer to "a lack of information that significantly affects the understanding of basin setting or evaluation of the efficacy of the Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed." The monitoring network is a key component in the development of GSPs and will influence the development and understanding of the basin setting, including the hydrogeologic conceptual model, groundwater conditions, and water budget; and proposed minimum thresholds and measurable objectives. GSAs should consider previous analyses of data gaps of their monitoring network through existing programs, such as CASGEM monitoring plans. **Figure 4** shows a flowchart that demonstrates a process that GSAs should use to identify and address data gaps.

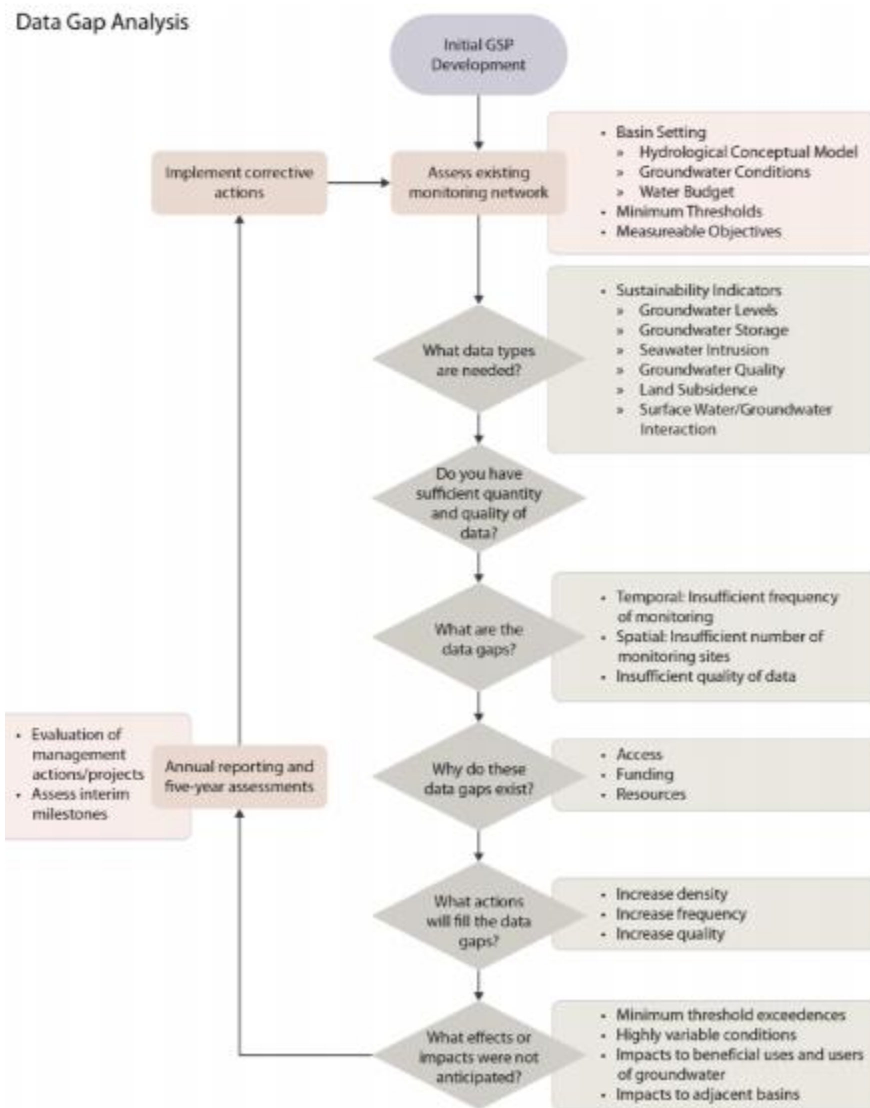


Figure 4. Data Gap Analysis Flow Chart

Professional judgment will be needed from GSAs to identify possible data gaps in their monitoring network of the sustainability indicators. Data gaps can result from monitoring information that is not of sufficient quantity or quality. Data of insufficient quantity typically result from missing or incomplete information, either temporally or spatially. Examples of temporal data gaps include a hydrograph with data that is too infrequent, has inconsistent intervals, or has a short historical record, as shown in **Figure 5**. Spatial data gaps may occur from a monitoring network with low or uneven density in three dimensions, as shown in **Figure 6.**

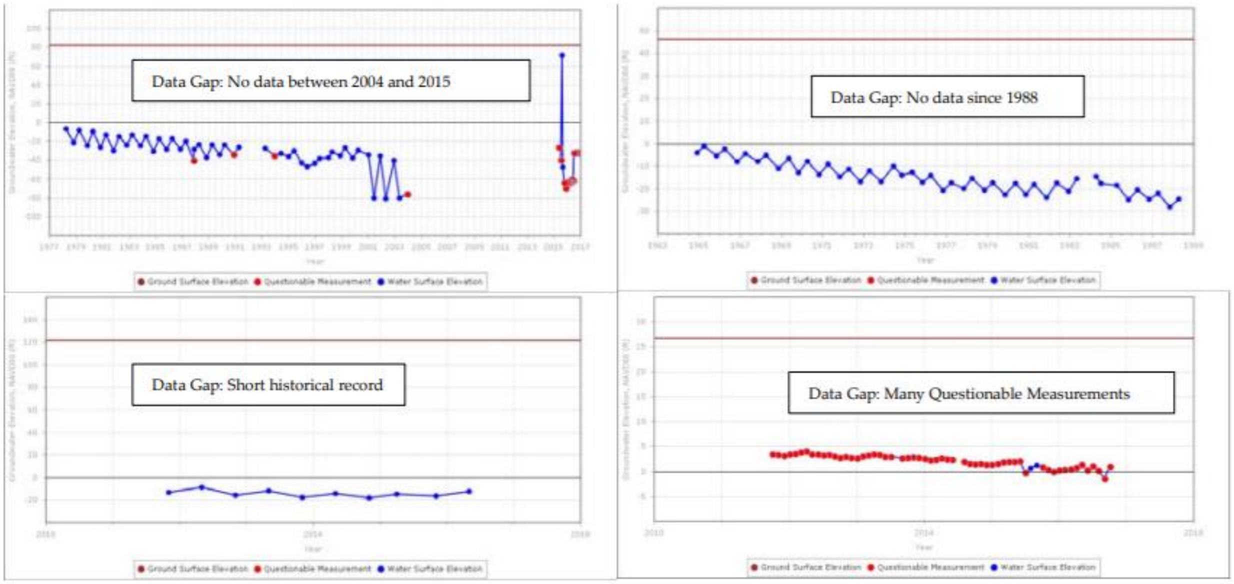


Figure 5. Examples of Hydrographs with Temporal Data Gaps

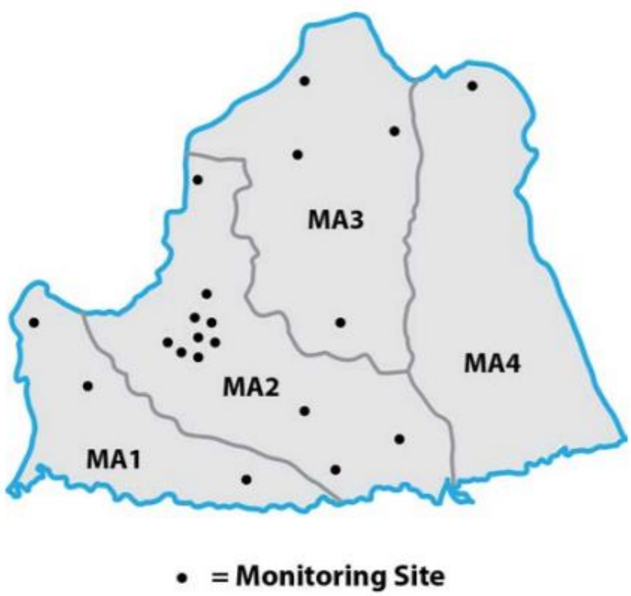


Figure 6. Example Monitoring Network with Spatial Data Gaps

Poor quality data may also be the cause of data gaps. Data must be of sufficient quality to enable scientifically defensible decisions. Poor quality data may at times be worse than no data because it could lead to incorrect assumptions or biases. Some things to consider when questioning the quality of data include: collection conditions and methods, sampling quality assurance/quality control, and proper calibration of meters/equipment. As part of the CASGEM program, DWR reports groundwater elevation data from local agencies, which include the option for "Questionable Measurement Codes." These codes are one way of identifying poor quality data.

There may be various reasons for data gaps, including site access, funding, and lack of staffing resources. By identifying and correcting the reasons behind data gaps, GSAs may be able to avoid further data gaps.

Direct actions GSAs could take to fill data gaps include:

- Increasing the frequency of monitoring. For instance, some groundwater elevation measurements are taken twice a year in the spring and fall, but perhaps those measurements need to be increased to quarterly, monthly, or more frequently, if needed.
- Increasing the spatial distribution and density of the monitoring network.
- Increasing the quality of data through improved collection methods and data management methods.

As GSPs are implemented, GSAs may identify other data gaps, especially if there are minimum threshold exceedances, highly variable spatial or temporal conditions, adverse impacts to beneficial uses and users of groundwater, and impacts to adjacent basins' ability to achieve sustainability. Any or all of these conditions may indicate a need to refine the monitoring network.

Agencies are required to assess their monitoring networks every five years. During those assessments, data gaps may also be identified as agencies monitor the progress of their management actions/projects and the status of their interim milestones. These regular assessments will allow the GSAs to adaptively manage, focus, and prioritize future monitoring.

DATA REPORTING

23 CCR §352.6. Data Management System
Each Agency shall develop and maintain a data management system that is capable of storing and reporting information relevant to the development or implementation of the Plan and monitoring of the basin.

The use of a Data Management System (DMS) is required for all GSPs. The DMS should include clear identification of all monitoring sites and a description of the quality assurance and quality control checks performed on the data being entered. Uploading of the collected data should occur immediately following collection to address any quality concerns in a timely manner and prevent the potential for development of data gaps. Coordination of data structures between adjacent basins will facilitate data sharing and increase data transparency.

DWR will be providing an updated information that may be used for this BMP as the suggested data structure is developed.

6. KEY DEFINITIONS

SGMA DEFINITIONS (CALIFORNIA WATER CODE §10721)

> (r) "Planning and implementation horizon" means a 50-year time period over which a groundwater sustainability agency determines that plans and measures will be implemented in a basin to ensure that the basin is operated within its sustainable yield.

(u) “Sustainability goal” means the existence and implementation of one or more groundwater sustainability plans that achieve sustainable groundwater management by identifying and causing the implementation of measures targeted to ensure that the applicable basin is operated within its sustainable yield.

(v) “Sustainable groundwater management” means the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results.

(w) “Sustainable yield” means the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result.

(x) “Undesirable result” means one or more of the following effects caused by groundwater conditions occurring throughout the basin:

(1) Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.

(2) Significant and unreasonable reduction of groundwater storage.

(3) Significant and unreasonable seawater intrusion.

(4) Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.

(5) Significant and unreasonable land subsidence that substantially interferes with surface land uses.

(6) Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water

GSP REGULATIONS DEFINITIONS (CALIFORNIA CODE OF REGULATIONS §351)

(l) “Data gap” refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed.

(o) “Interconnected surface water” refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.

(q) “Interim milestone” refers to a target value representing measurable groundwater conditions, in increments of five years, set by an Agency as part of a Plan.

(s) “Measurable objectives” refer to specific, quantifiable goals for the maintenance or improvement of specified groundwater conditions that have been included in an adopted Plan to achieve the sustainability goal for the basin.

(t) “Minimum threshold” refers to a numeric value for each sustainability indicator used to define undesirable results.

(u) “NAD83” refers to the North American Datum of 1983 computed by the National Geodetic Survey, or as modified.

(v) “NAVD88” refers to the North American Vertical Datum of 1988 computed by the National Geodetic Survey, or as modified.

(y) “Plan implementation” refers to an Agency’s exercise of the powers and authorities described in the Act, which commences after an Agency adopts and submits a Plan or Alternative to the Department and begins exercising such powers and authorities.

(aa) “Principal aquifers” refer to aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems.

(ab) “Reference point” refers to a permanent, stationary and readily identifiable mark or point on a well, such as the top of casing, from which groundwater level measurements are taken, or other monitoring site.

(ac) “Representative monitoring” refers to a monitoring site within a broader network of sites that typifies one or more conditions within the basin or an area of the basin.

(ad) “Seasonal high” refers to the highest annual static groundwater elevation that is typically measured in the Spring and associated with stable aquifer conditions following a period of lowest annual groundwater demand

(ae) “Seasonal low” refers to the lowest annual static groundwater elevation that is typically measured in the Summer or Fall, and associated with a period of stable aquifer conditions following a period of highest annual groundwater demand.

(ag) “Statutory deadline” refers to the date by which an Agency must be managing a basin pursuant to an adopted Plan, as described in Water Code Sections 10720.7 or 10722.4.

(ah) “Sustainability indicator” refers to any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results, as described in Water Code Section 10721(x).

(ai) “Uncertainty” refers to a lack of understanding of the basin setting that significantly affects an Agency’s ability to develop sustainable management criteria and appropriate projects and management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed.

7. RELATED MATERIALS

NETWORK DESIGN

- Design of a Real-Time Ground-Water Level Monitoring Network and Portrayal of Hydrologic Data in Southern Florida
    - http://fl.water.usgs.gov/PDF_files/wri01_4275_prinos.pdf
- Optimization of Water-Level Monitoring Networks in the Eastern Snake River Plain Aquifer Using a Kriging-Based Genetic Algorithm Method
    - http://pubs.usgs.gov/sir/2013/5120/pdf/sir20135120.pdf

GUIDANCE

California Department of Water Resources, 2010. California statewide groundwater elevation monitoring (CASGEM) groundwater elevation monitoring guidelines, December, 36 p. http://www.water.ca.gov/groundwater/casgem/documents.cfm

Heath, R. C., 1976. Design of ground-water level observation-well programs: Ground Water, V. 14, no. 2, p. 71-77.

Hopkins, J., 1994. Explanation of the Texas Water Development Board groundwater level monitoring program and water-level measuring manual: UM-52, 53 p. http://www.twdb.texas.gov/groundwater/docs/UMs/UM-52.pdf

Sophocleous, M., 1983. Groundwater observation network design for the Kansas groundwater management districts, USA: Journal of Hydrology, vol.61, pp 371-389.

Subcommittee on ground water of the advisory committee on water information, 2013. A National Framework for Ground-Water Monitoring in the United States, 168 p. http://acwi.gov/sogw/ngwmn_framework_report_july2013.pdf

Appendix P. Grassland Bypass Project Summary

Grassland Bypass Project

Project Summary

June 2017




Grassland Bypass Project – Background and Description.

The Grassland Bypass Project has reduced agricultural drainage discharge from the Grassland Drainage Area to the San Joaquin River by 89% since the project started in 1996. The has resulted in a reduction of 97% of the selenium load and 83% of the salt load discharged to the San Joaquin River compared to pre-project discharges.

The Grassland Drainage Area (see **Figure 1**) is a highly productive agricultural region on the Westside of the San Joaquin Valley. The region is approximately 100,000 acres lying generally south of Los Banos, between the San Joaquin River and Interstate 5. The region is overlain by coastal range sediments that are generally heavy clays and contain a variety of dissolved minerals including boron and selenium. These soil conditions have contributed to a healthy and productive agricultural environment but their heavy clay nature has also created a perched water table that threatens this productivity. The perched water table is managed with subsurface (tile) drain systems and deep earthen channels which provide an outlet for the shallow groundwater. However, the subsurface drain water is high in dissolved minerals including salt and selenium, which pose an environmental risk to wildlife. In the past, this drain water was discharge through channels that also supplied fresh water to the Grasslands. Because of the risk to wildlife, these wetland supply channels could not deliver water to Grasslands while carrying tile drainage, and ultimately the Grassland Bypass Project was developed.

The Grassland Bypass Project is an innovative project designed to improve water quality in drainage channels used to deliver water to wetland areas. The Grassland Bypass Project consolidated regional subsurface flows into a single channel, removing drain water from nearly 100 miles of wetland supply canals. Selenium load allocations (total maximum monthly loads or TMMLs) were also incorporated into the project, which reduce annually (see **Figure 2**). The Grassland Area Farmers have developed a plan to eliminate agricultural drainage discharge from the region. This plan has evolved into the Westside Regional Drainage Plan (Westside Plan).

The Westside Plan is intended to 1) identify scientifically sound projects proven to be effective in reducing drainage; 2) develop an aggressive implementation plan initially utilizing existing projects documented to be environmentally sound; and 3) curtail discharges to the San Joaquin River in accordance with impending regulatory constraints while maintaining the ability to farm.

The plan focuses on regional drainage projects that can be implemented on a short timeline. Drainage must be addressed on a regional basis but must allow for each sub-area's specific needs and resources. The Plan's key management components for the Grassland Drainage Area are: 1) Source Control, 2) Groundwater Management, 3) Drainage Reuse Projects, and 4) Drain Water Treatment and/or Salt Disposal. As drainage projects are implemented, they will be evaluated for long-term sustainability of the complete solution.

Figure 2
Grassland Drainage Area
Selenium Discharge and Targets

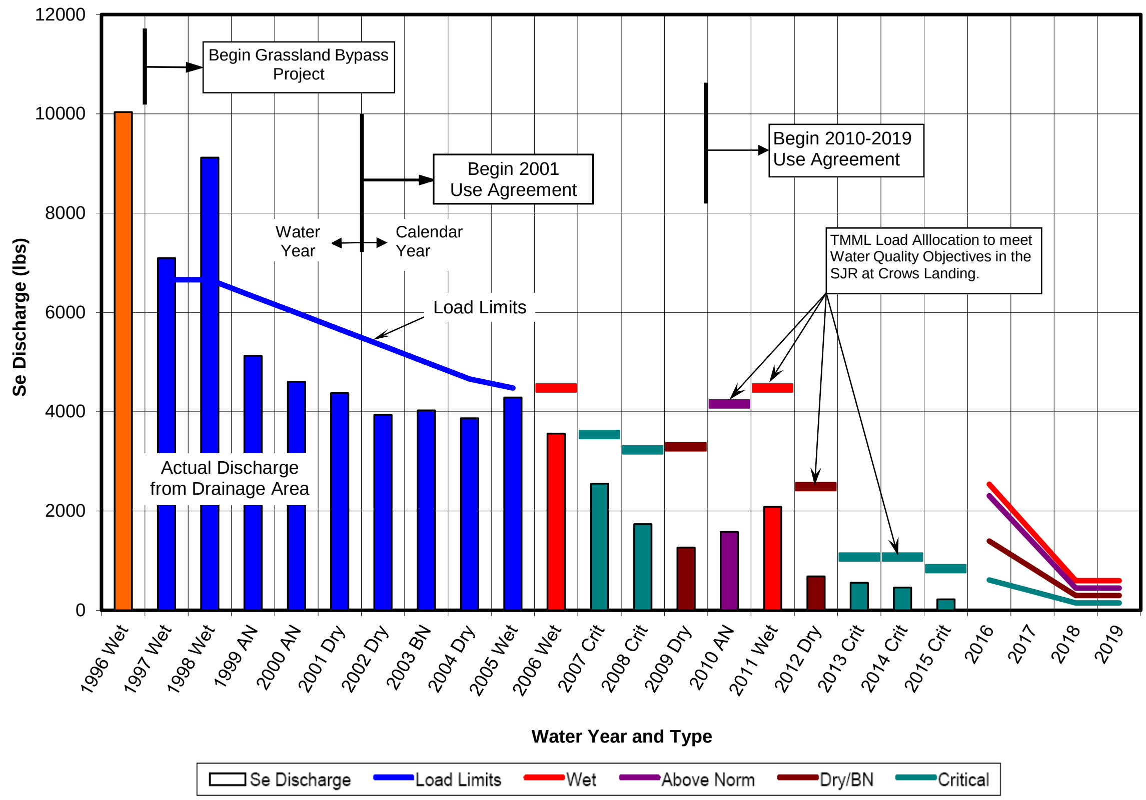
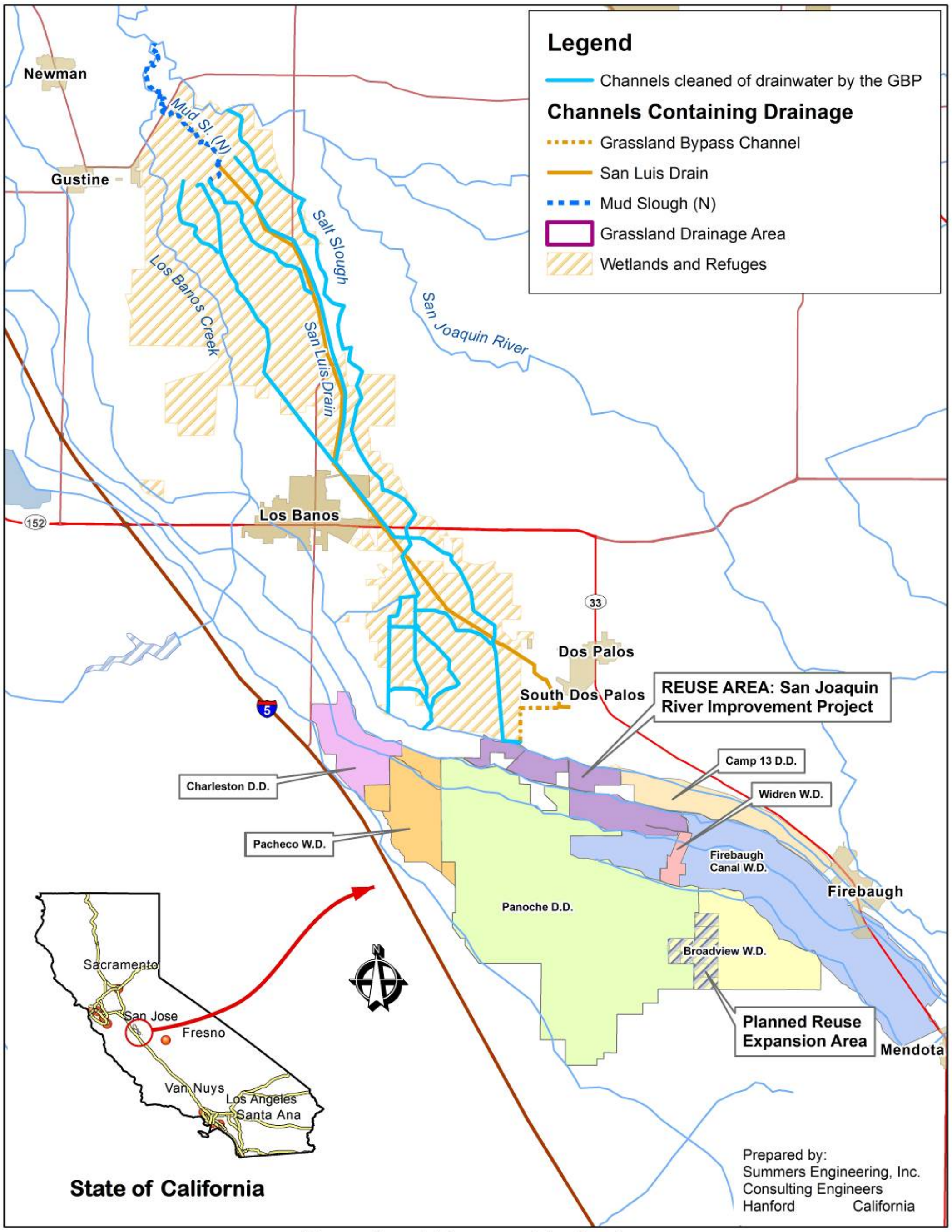


Figure 1

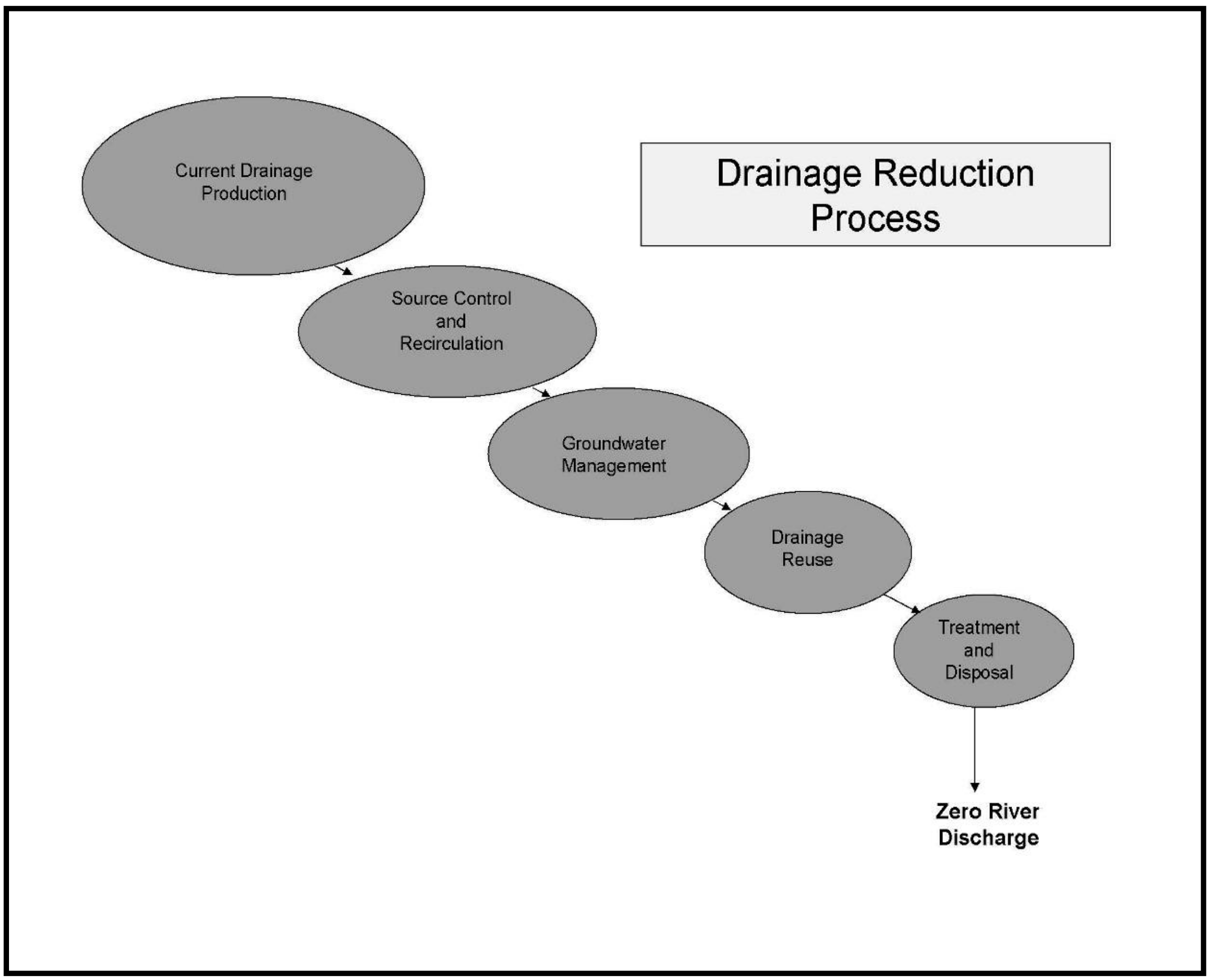


Grassland Bypass Project
Location Map

Drainage Management Components

The Westside Plan identified four effective projects to manage and reduce drainage discharge through the Grassland Bypass Project. These include source control projects such as irrigation and infrastructure improvements to reduce the overall subsurface drainage production, groundwater management to lower the perched water level, drainage reuse to reduce the volume of drain water through the irrigation of salt tolerant crops, and drainage treatment to remove the salt and dissolved minerals. The ultimate goal of this plan will be to eliminate agricultural drainage discharge from the Grassland Drainage Area. **Figure 3** shows the drainage solution components.

Figure 3: Drainage Solution Components



Source Control Projects. Source control projects are projects that can reduce the volume of water contributing to subsurface drainage production usually by reducing deep percolation. Source control projects can usually be divided into two categories: irrigation improvements and distribution infrastructure improvements.

Irrigation improvement projects include converting from a low efficiency irrigation system (such as furrow irrigation) to a high efficiency system (such as drip or micro sprinklers). The State of California and the local districts have made financial assistance (in the form of low interest loans) available to growers as an incentive to convert from conventional irrigation practices to high efficiency drip irrigation (and similar systems). As of 2016, approximately 75% of the irrigated acreage within the Grassland Drainage Area ha systems.


Microsprinklers

Distribution infrastructure improvement projects typically include the replacement of an unlined irrigation canals with a concrete lined channel or pipeline. Unlined channels within the Grassland Drainage Area can contribute more than 200 acre feet of seepage per year for each unlined mile. More than 30 miles of unlined canals have been lined or converted to pipelines since the beginning of the Grassland Bypass Project.


Canal Lining

Drainage Recirculation. Drainage recirculation is the process of redirecting drain water back into the irrigation system and it is one of the first drainage management tools implemented by the Grassland Area Farmers. Virtually all of the districts within the Grassland Drainage Area have some capacity for recirculation. Drainage recirculation is carefully monitored to maintain a blended water quality sufficient for agricultural use.

Panoche Drainage District Recirculation Plant

Groundwater Management. A study performed in 2002, by the San Joaquin River Exchange Contractor's Water Authority (Exchange Contractor's) and the U.S. Bureau of Reclamation indicated that the pumping of strategically placed wells (pumping above the Corcoran Clay) could lower the perched water table and reduce the discharge of nearby subsurface drainage systems. A portion of the funding provided through the Proposition 50 grant has been allocated for some of this work and 18 wells have been installed.

Drainage Reuse. In order to meet the selenium load requirements, Panoche Drainage District began diverting subsurface drain water on to pasture fields as a source of irrigation water in 1998. Over the next few years, trials, experiments, and research helped identify the salt tolerant crops that would best consume the saline drain water. Funding assistance from California Proposition 13 allowed for the purchase of 4,000 acres of marginal land that was developed to salt tolerant crops and became the San Joaquin River Improvement Project (SJRIP). Today, the SJRIP has expanded to 6,000 acres, with approximately 350 acres of pistachios and the remaining land planted to salt tolerant forage grasses (mostly Jose Tall Wheatgrass). The SJRIP has provided a key tool to manage almost all of the subsurface drainwater produced by conventional agriculture. By 2014, reuse on the SJRIP eliminated discharge through the San Luis Drain to the San Joaquin River during the summer months. **Table 1**, below shows the volume of subsurface drain water diverted to the SJRIP since its inception in 1998.

Table 1: SJRIP Drainage Reuse.

Water Year	Reused Drain Water (acre feet)	Reused Selenium (pounds)	Reused Boron (pounds)	Reused Salt (tons)
1998¥	1,211	329	NA	4,608
1999¥	2,612	321	NA	10,230
2000¥	2,020	423	NA	7,699
2001	2,850	1,025	61,847	14,491
2002	3,711	1,119	77,134	17,715
2003	5,376	1,626	141,299	27,728
2004	7,890	2,417	193,956	41,444
2005	8,143	2,150	210,627	40,492
2006	9,139	2,825	184,289	51,882
2007	11,233	3,441	210,582	61,412
2008	14,955	3,844	238,435	80,900
2009	11,595	2,807	198,362	60,502
2010	13,119	3,298	370,752	75,362
2011	21,623	4,394	454,675	102,417
2012	23,735	3,293	545,180	118,445
2013	26,170	3,527	568,907	118,883
2014	30,870	3,711	879,800	179,560
2015	31,460	2,644	969,640	178,620
2016	24,573	2,401	886,770	162,421

Jose Tall Wheatgrass on the SJRIP

Pistachio on the SJRIP

Salt Balance: Drainage reuse has been an extremely effective tool in reducing drainage volume discharged from the Grassland Drainage Area but it is not without challenges. Because of the saline nature of the water applied, soil salinity needs to be carefully managed to prevent salt buildup in the root zone. To provide for a salt balance, subsurface drainage systems have been installed on 1,700 acres and ultimately will be installed on most the SJRIP lands. These subsurface drainage systems (or "tile" systems) will allow up to 25% leaching for the saltiest applied water. The long term salt balance and viability will be provided by the drainage systems and appropriate regular leaching including annual rainfall.

Drainage Treatment/Disposal. Conventional wisdom implies that some mechanical system will be required to from the salts from the drainwater leached from the SJRIP. While it is unclear if this conventional wisdom is indeed fact, the Grassland Basin Drainers have supported many treatment tests over the past two decades. Many different methods have been tested and none of these approaches have resulted in a viable and affordable treatment process. Until an effective treatment process is discovered, the Grassland Area Farmers will rely on the continued operation of the SJRIP and drainage reuse in order to manage drainwater and prevent discharge to the San Joaquin River. Portions of the SJRIP have received drainwater for irrigation continuously since 1998 with no reduction in crop production so there is reason to expect successful operation of the SJRIP far into the future.

Project Impacts

The Grassland Bypass Project has been successful in reducing the volume of subsurface drain water discharged from the 100,000 acre Grassland Drainage Area which maintaining viable farming within the region. In 1995, prior to the Grassland Bypass Project, more than 57,000 acre feet of drain water was discharged through the wetland channels. This not only impacted the water quality of the San Joaquin River system but exposed waterfowl attracted to the Grassland area wetlands to elevated levels of selenium and other constituents. The Grassland Bypass Project eliminated drainage discharge into the wetland channels[1] and consolidated all of the drainage within the Grassland Drainage Area into one channel. By 2016, the volume of discharged drain water was reduced from 57,574 acre feet to about 7,670 (an 87% reduction in discharge). Similar reductions occur in the discharged load of selenium, salt, and boron. **Table 2** shows the annual reduction in drainage discharge and associated constituent load. The concentrations of selenium in the San Joaquin River have reduced with the project. **Figure 4** shows the selenium concentrations at Crows Landing downstream of the Merced River which is the TMML compliance point.

Table 2: Grassland Bypass project Annual Discharge and Loads

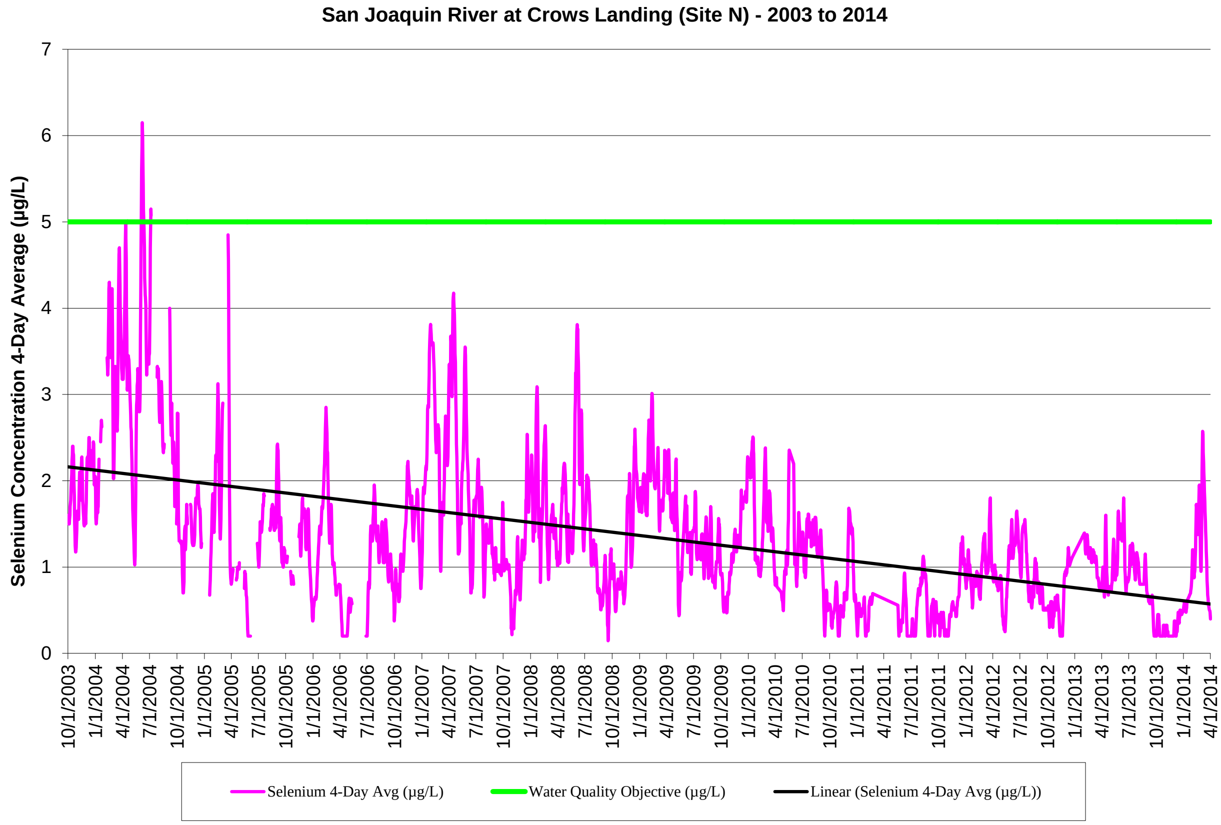
Discharge Comparison from Grassland Drainage Area

	WY 95	WY 96	WY 97	WY 98	WY 99	WY 00	WY 01	WY 02	WY 03	WY 04	WY 05
Volume (AF)	57,574	52,978	39,856	49,289	32,317	31,342	28,235	28,358	27,345	27,640	29,957
Se (lbs)	11,875	10,034	7,096	9,118	5,124	4,603	4,377	3,939	4,032	3,860	4,305
Salt (tons)	237,530	197,526	172,602	213,533	149,081	139,303	142,415	128,411	126,500	121,138	138,908
B (1,000 lbs)	868	723	753	983	630	619	423	544	554	530	585
Se (ppm)	0.076	0.070	0.066	0.068	0.058	0.054	0.057	0.051	0.054	0.051	0.053
Salt (µmhos/cm)	4,102	3,707	4,306	4,308	4,587	4,420	5,016	4,503	4,600	4,358	4,611
Boron (ppm)	5.5	5.0	7.0	7.3	7.2	7.3	5.5	7.1	7.5	7.1	7.2

	WY 06	WY 07	WY 08	WY 09	WY 10	WY 11	WY 12	WY 13	WY 14	WY 15	WY 16	Reduction from WY 95 to WY 16
Volume (AF)	25,995	18,531	15,665	13,166	14,529	18,513	10,486	10,258	7,125	6,079	7,670	87%
Se (lbs)	3,563	2,554	1,736	1,264	1,577	2,067	733	638	317	354	385	97%
Salt (tons)	119,646	79,094	66,254	55,556	67,661	87,537	38,398	54,663	44,834	40,779	46,207	81%
B (1,000 lbs)	539	278	269	233	315	440	245	309	244	212	215	76%
Se (ppm)	0.050	0.051	0.041	0.035	0.040	0.041	0.026	0.023	0.016	0.021	0.018	
Salt (µmhos/cm)	4,577	4,244	4,206	4,196	4,631	4,702	3,641	5,299	6,257	6,670	5,990	
Boron (ppm)	7.6	5.5	6.3	6.5	8.0	8.7	8.6	11.1	12.6	12.8	10.3	

[1] Except for during extreme storm events.

Figure 4 – Selenium Concentrations in the San Joaquin River downstream of the Merced



Appendix Q. Update on Groundwater Conditions in the Newman Sub-Area of the SJREC GSP

UPDATE ON GROUNDWATER CONDITIONS IN THE NEWMAN SUB-AREA OF THE SJREC GSP

prepared for
San Joaquin River Exchange
Contractors GSA
Los Banos, California

and
City of Newman GSA
Newman, California

by
Kenneth D. Schmidt & Associates
Groundwater Quality Consultants
Fresno, California

May 2019

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May 31, 2019

Mr. Chris White, Executive Director
San Joaquin River Exchange
Contractors GSA
P. O. Box 2115
Los Banos, CA 93635

Re: Newman Sub-Area of the
SJREC GSP

Dear Chris:

Submitted herewith is our report on groundwater conditions in the Newman Sub-area of the SJREC GSP. We appreciate the cooperation of the CCID and City of Newman in providing information for this report.

Sincerely Yours,

Kenneth D. Schmidt
Geologist No. 1578
Certified Hydrogeologist 176

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INTRODUCTION

As part of the Groundwater Sustainability Plan (GSP) for the San Joaquin River Exchange Contractors (SJREC) service area, GSPs for a number of cities, including Newman, are being incorporated into the SJREC GSP. Kenneth D. Schmidt and Associates (KDSA, 1992 and 2001) prepared two reports on groundwater conditions in the vicinity of the City of Newman for the Central California Irrigation District (CCID) and the City.

This report is intended to provide an update on groundwater conditions within the Newman Study Area boundary (Figure 1). This boundary encompasses lands that are planned for future urban development. This study area is generally bounded by Stuhr Road on the north, the CCID Main Canal on the west, Hallowell Road on the south, and includes land east of the Canal School Road and southwest of the San Joaquin River, where the City effluent is handled. Lands west of the Main Canal and near Hills Ferry Road in Stanislaus County are within the Northwestern Delta Mendota GSA. Lands in a fairly large area east of Canal School Road and in Merced County are in the Merced County Delta Mendota GSA. Lands surrounding most of the City are in the SJREC GSA.

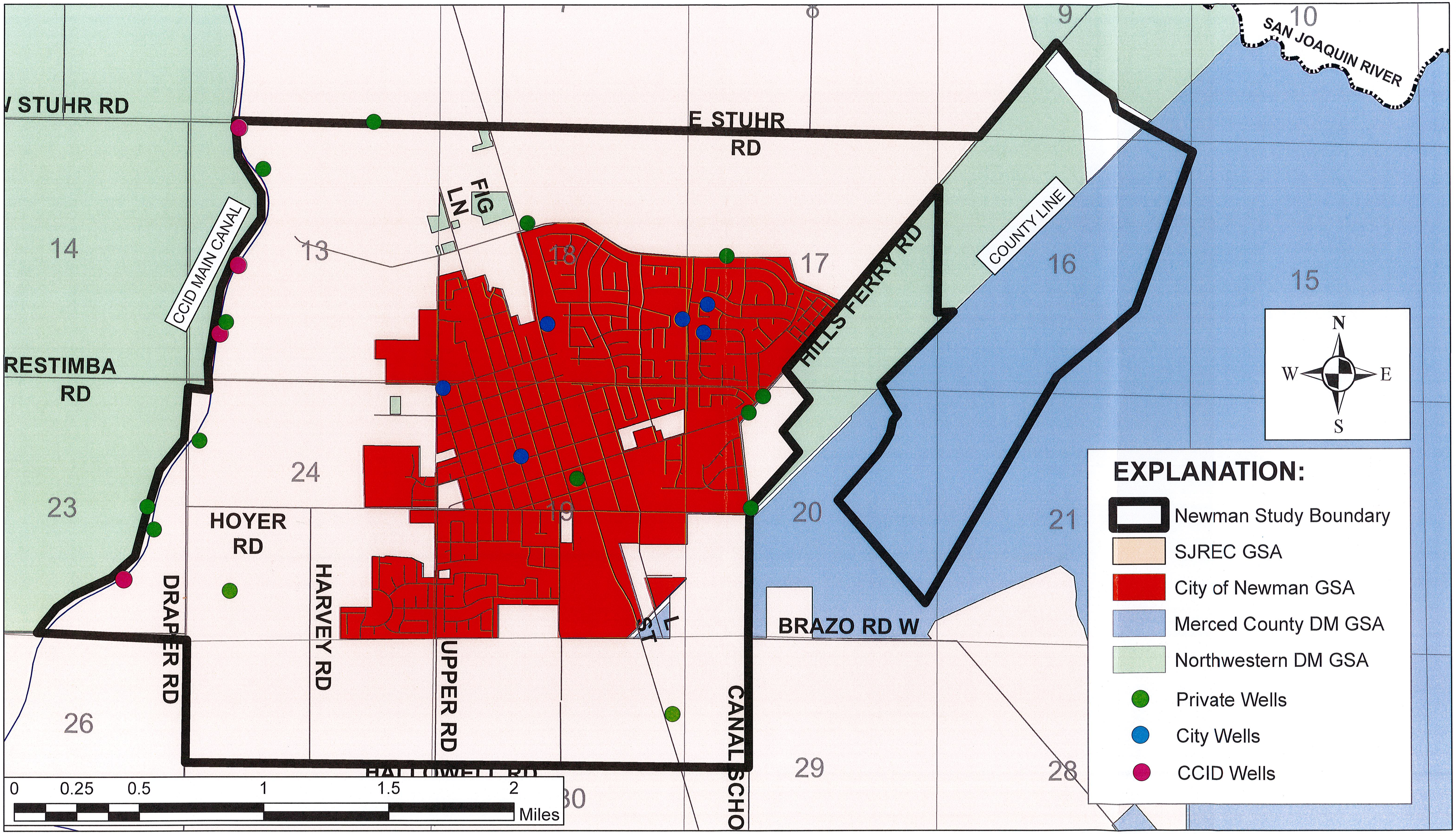

FIGURE 1 - LOCATION OF NEWMAN SUB-AREA, STUDY AREA BOUNDARY, AND SELECTED WELLS

Of particular interest in this update are: 1) the extent of groundwater overdraft, 2) land subsidence, 3) the historical water budget and that for future urban development of the study area, and 4) groundwater quality issues.

SUBSURFACE GEOLOGIC CONDITIONS

Alluvial deposits comprise the aquifer in the Newman area. Subsurface deposits near Newman are termed the older alluvium and the Tulare Formation. Page (1986) indicated that the base of the fresh groundwater (electrical conductivity less than 3,000 micromhos per centimeter at 25°C) was about 900 feet deep near Newman. KDSA (2018) indicated that the base of the usable aquifer in the vicinity, or bottom of the basin in SGMA terminology, was greater than 800 feet deep. A major confining bed is present beneath much of the west side of the San Joaquin Valley, including the Newman area. This clay is termed the Corcoran Clay (E-clay), and divides the aquifer system into upper and lower aquifers. The Corcoran Clay is readily discernible from the drillers logs for most wells in the area, due to its blue color. The over-lying and under-lying deposits are usually tan or brown in color.

Most groundwater near Newman is pumped from relatively shallow wells tapping the upper aquifer, but active City wells and some irrigation wells tap the lower aquifer. Information on the lower aquifer is available from at least four wells or test holes that have been drilled in the City to a depth of more than 500 feet.

KDSA developed two subsurface geologic cross sections extending through the City (Figure 2). Drillers and electric logs for water wells and test holes were obtained from the City, the CCID, and the California Department of Water Resources in Fresno for use in developing these cross sections. A test hole (No. 7) was done by the City in the northeast part of the City and Well No. 8 was subsequently constructed at this site. No CCID wells have been drilled in the area since the 2001 report.

Subsurface Geologic Cross Section A-A′ (Figure 3) extends from near Orestimba Road and the Main Canal on the west through City Wells No. 6, No. 1, No. 4, a test hole near Hills Ferry Road and Canal School Road, to a private well (17R1) near the extension of Hunt Road, about one-half mile west of the Newman Wasteway. Electric logs are available for three wells or test holes along this section. One of these is a 712-foot deep test hole (20D) that was drilled for the City near Hills Ferry Road and Canal School Road. Another is a 500-foot deep test hole that was drilled near City Well No. 6. Another is for CCID Well No. 3, which is 422 feet deep. Drillers logs are available for the other three wells along this section. All of the wells and test holes along this section penetrated the Corcoran Clay. The top of this clay ranges from about 220 feet deep near CCID Well No. 3 to about 275 feet at City Well No. 4. The Corcoran Clay thickens sub-

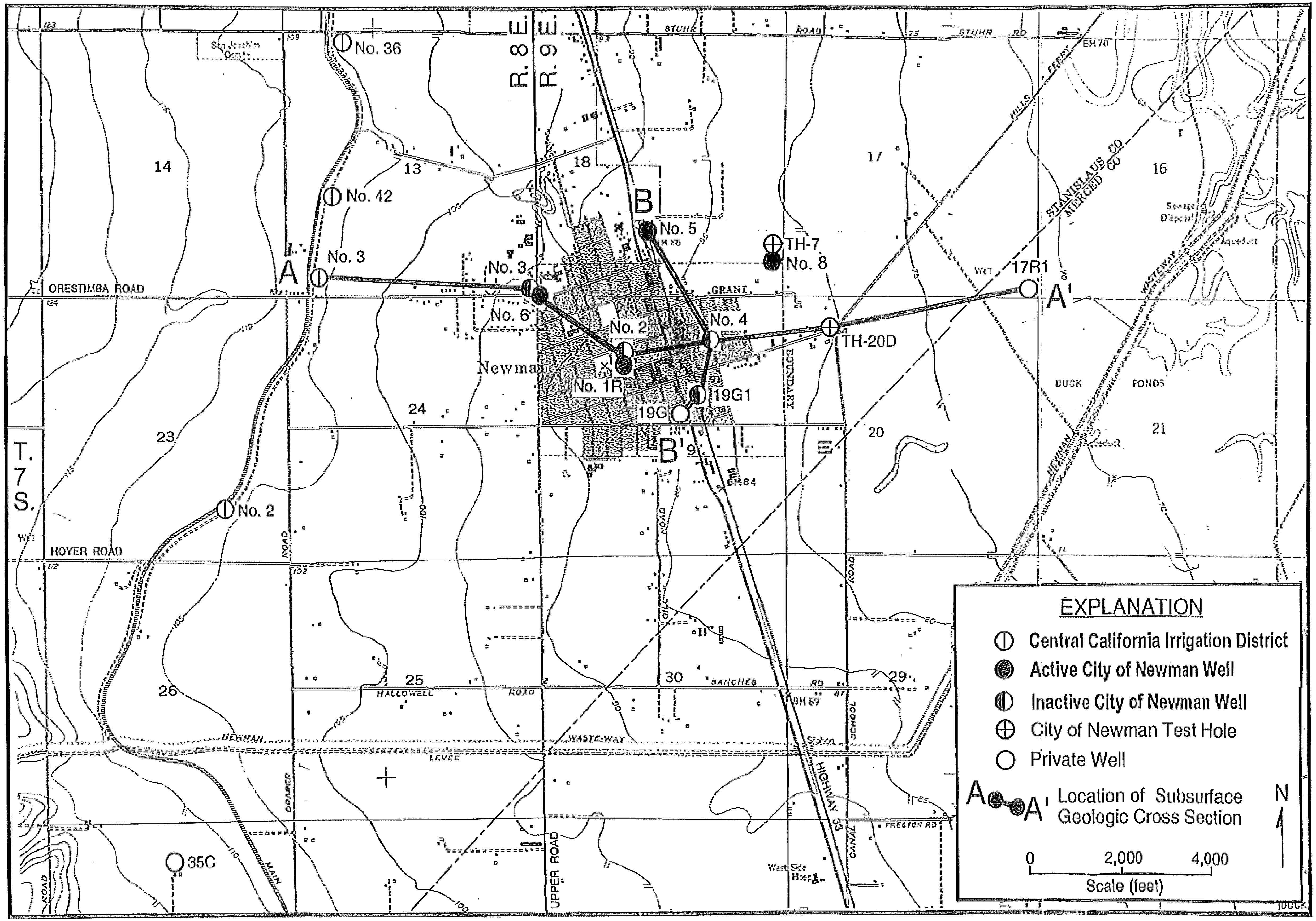

FIGURE 2-LOCATION OF SELECTED TEST HOLES AND WELLS
AND SUB-SURFACE GEOLOGIC CROSS SECTIONS

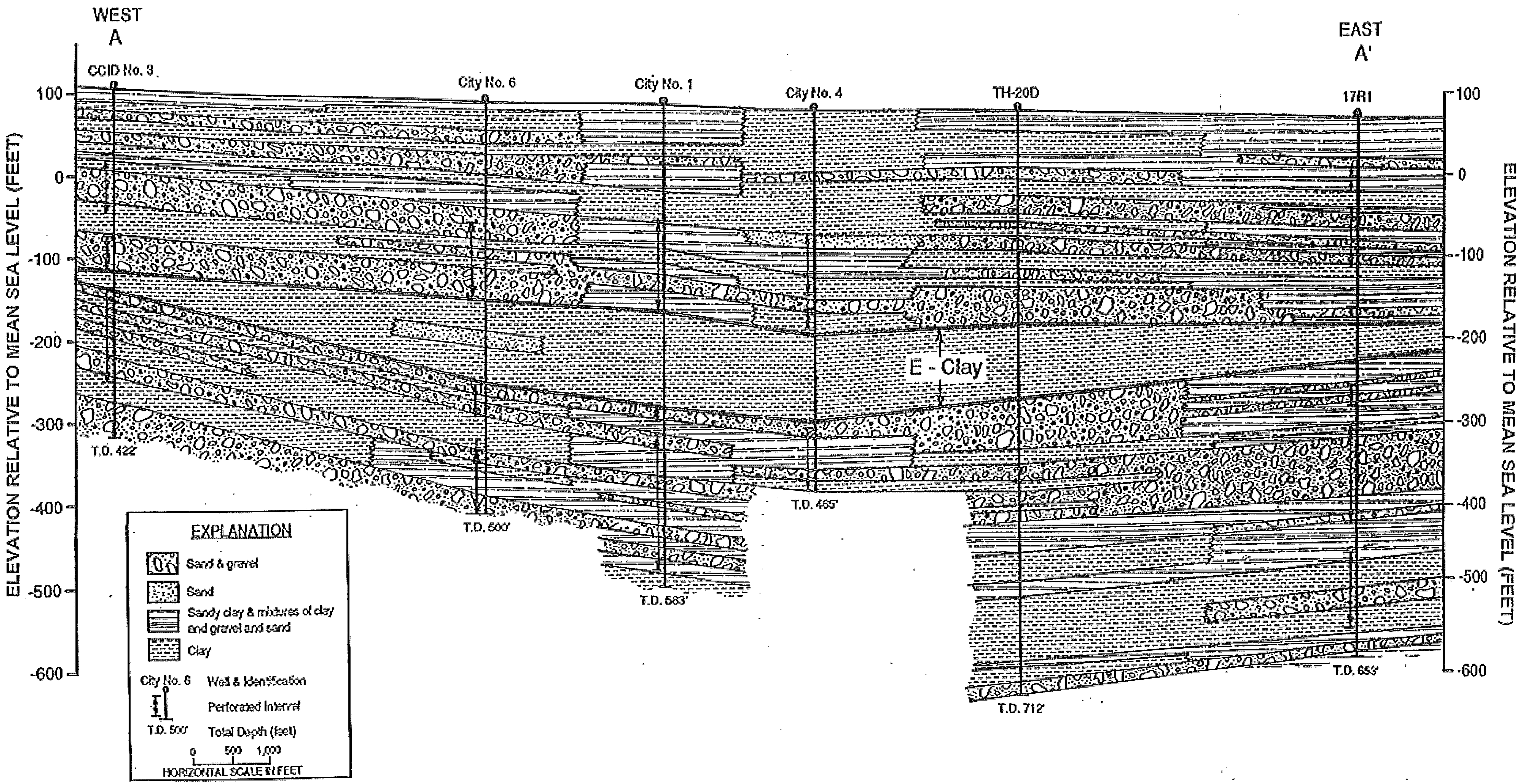

FIGURE 3 - SUBSURFACE GEOLOGIC CROSS SECTION A - A'

stantially toward Highway 33, from about 20 feet at CCID Well No. 3 to about 115 feet at City Well No. 1. Along Cross Section A-A′, the clay is thickest and deepest beneath the area near Highway 33.

Sand and gravel layers are more common in the upper aquifer beneath the west part of the study area (i.e., at CCID Well No. 3). Some of the coarsest deposits in the upper aquifer are within the lower 100 feet, just above the Corcoran Clay. In contrast, fine-grained layers are more predominant in the upper aquifer near Highway 33 (City Well No. 4). Information at Test Hole 20D indicates that below a depth of about 500 feet, sand and gravel layers are uncommon in the lower aquifer. In general, deposits of the lower aquifer appear to be coarsest immediately beneath the E-clay, and to become finer with increasing depth. Two former City wells along this section (Nos. 1 and 4) primarily drew and CCID Well No. 3 draws water from these two widespread, coarse-grained zones above and below the Corcoran Clay. In contrast, City Well No. 1R produces water exclusively from the lower aquifer.

Cross Section B-B′ (Figure 4) extends from north to south, from City Well No. 5 through City Well No. 4 and then two private wells. This section is based entirely on drillers logs, and was correlated with information from Section A-A′, which intersects Cross Section B-B′ at City Well No. 4. Coarse-grained

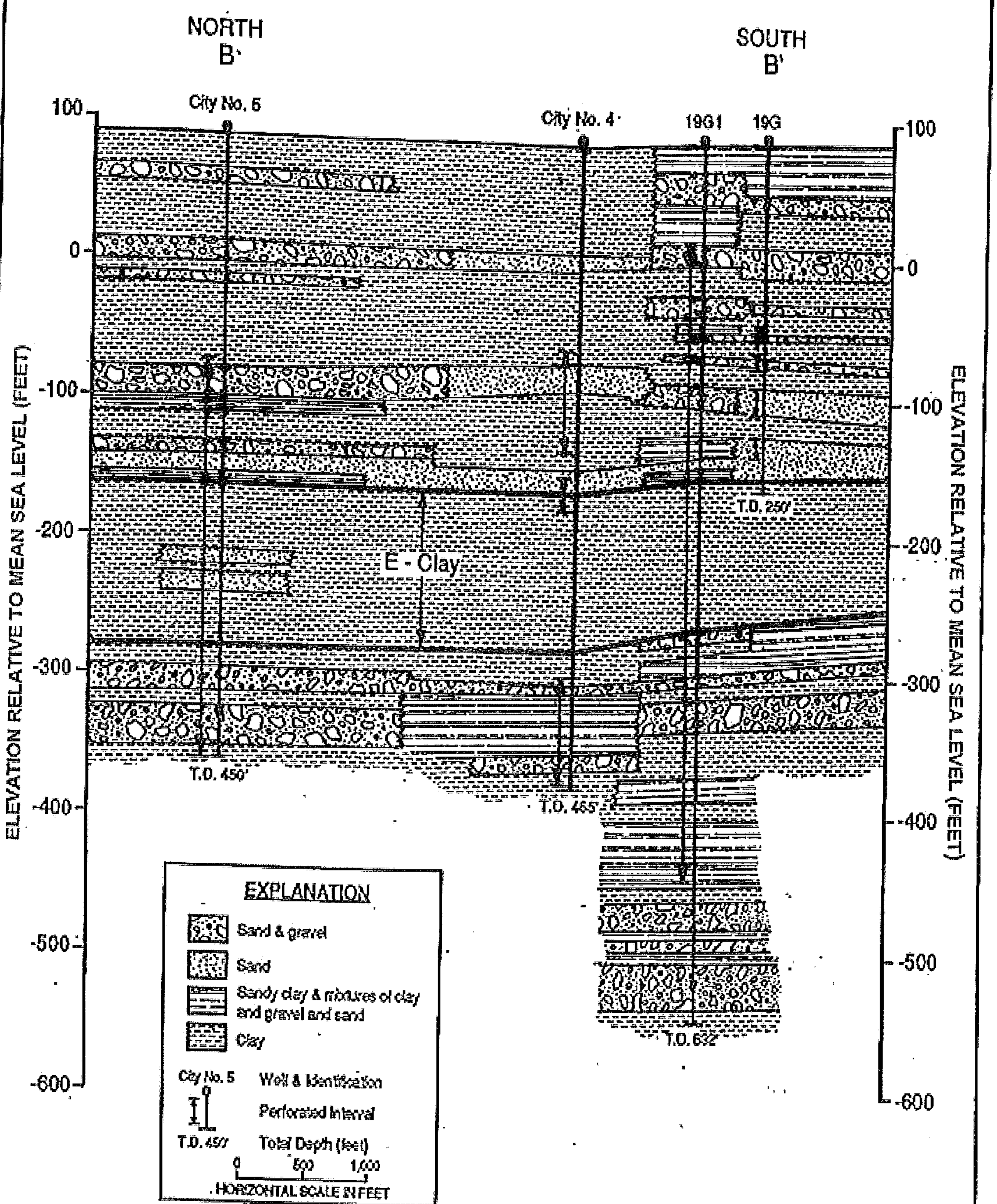

FIGURE 4 - SUBSURFACE GEOLOGIC CROSS SECTION B - B'

strata were found at a depth of more than 600 feet at Well 19G1, which is the deepest well along this section. Well 19G1 was drilled to a depth of 632 feet at the Golden Valley Creamery in 1947. This section also shows a predominance of coarse-grained strata within the lower 100 feet of the upper aquifer and just below the Corcoran Clay.

Test Hole No. 7 was drilled to a depth of 505 feet by Maggiora Brothers, Inc. of Watsonville in September 1992 (Figure 1). The Corcoran Clay was indicated to be present for about 260 to 354 feet in depth. A number of permeable strata were found both above and below the Corcoran Clay at this site. City Well No. 8 was subsequently completed near this test hole.

WELL CONSTRUCTION DATA

City Wells

There are presently four active City Wells. Table 1 provides information on dates drilled, depths, and perforated intervals for these wells.

Drillers logs are available for Well Nos. 1R, 5, 6, and 8 and electric logs are available for Wells No. 5, 6, and 8. Cased depths of the active wells range from 450 to 635 feet. Wells No. 1R and 6 tap strata only in the lower aquifer, whereas Wells No. 5 and 8 are composite wells that tap both aquifers.

TABLE 1-CONSTRUCTION DATA FOR CITY OF NEWMAN WELLS

No.	Date Drilled	Drilled Depth (feet)	Cased Depth (feet)	Casing Diameter (inches)	Perforated Interval (feet)	Annular Seal (feet)
1R	08/94	645	635	16	340-620	0-50
5	62/69	465	450	14	162-450	0-50
6	09/90	510	500	16	350-500	0-50
8	03/04	498	485	16	180-480	0-100

CCID Wells

Table 2 provides construction data for four CCID wells west and northwest of Newman, along the Main Canal. Depths of these wells range from 350 to 432 feet, and all are composite wells, tapping both the upper and lower aquifer.

WATER LEVELS

Near Newman, most of the available water-level measurements are for wells tapping the upper aquifer, but some measurements are for composite wells that also tap the lower aquifer. In general, water levels are deeper in deeper wells, which indicates a downward direction of groundwater flow in the area. This is common in much of the San Joaquin Valley.

Water-Level Elevations

KDSA (2001, Figure 4) presented a water-level elevation contour map for the upper aquifer in Spring 2000. Water-level contours for the upper aquifer beneath most of the urban area were not provided due to a lack of measurements. Water-level elevations in the upper aquifer west of Newman ranged from 86 to 108 feet above mean sea level, and the direction of groundwater flow was primarily to the east. Water-level elevations in the upper aquifer in the area southeast of Newman ranged from 68 to 78 feet

TABLE 2-CONSTRUCTION DATA FOR CCID WELLS

No.	Date Drilled	Drilled Depth (feet)	Cased Depth (feet)	Casing Diameter (inches)	Perforated Interval (feet)
2	02/54	350	341	16	90-152
				14	157-337
3	02/54	422	360	16	85-150
					180-225
					245-355
36	01/65	-	398	16	90-132
				14	132-393
42	01/67	-	391	16	90-391

above mean sea level in Spring 2000, and the direction of groundwater flow was to the northeast. Near Newman, the average water-level slope in the upper aquifer was about eight feet per mile.

Water-level elevations of less than about 75 feet in the area west of Newman appeared to have been representative of the lower aquifer. KDSA (2001, Figure 5) showed water-level elevations for the lower aquifer in Spring 2000. Water-level elevations for wells apparently tapping the lower aquifer at and west of Newman ranged from about 66 to 75 feet above mean sea level, and the direction of groundwater flow was to the northeast in Spring 2000. A cone of depression was present beneath the Newman urban area, where water-level elevations ranged from 52 to 56 feet southwest of Newman. The average slope of the piezometric surface of the lower aquifer upgradient of Newman was about 17 feet per mile in Spring 2000.

Figure 5 shows water-level elevations and the direction of groundwater flow for the upper aquifer in Spring 2011. An upper aquifer map for Spring 2017 or other years after 2011 could not be prepared, due to a lack of data in the DWR data base. Limited data for Spring 2017 indicate a water-level elevation of 86 feet above mean sea level near the Main Canal south of Preston Road and 57 feet north of Stuhr Road and average water-level slope of about 8.8 feet per mile. In Spring 2011, the average water-level

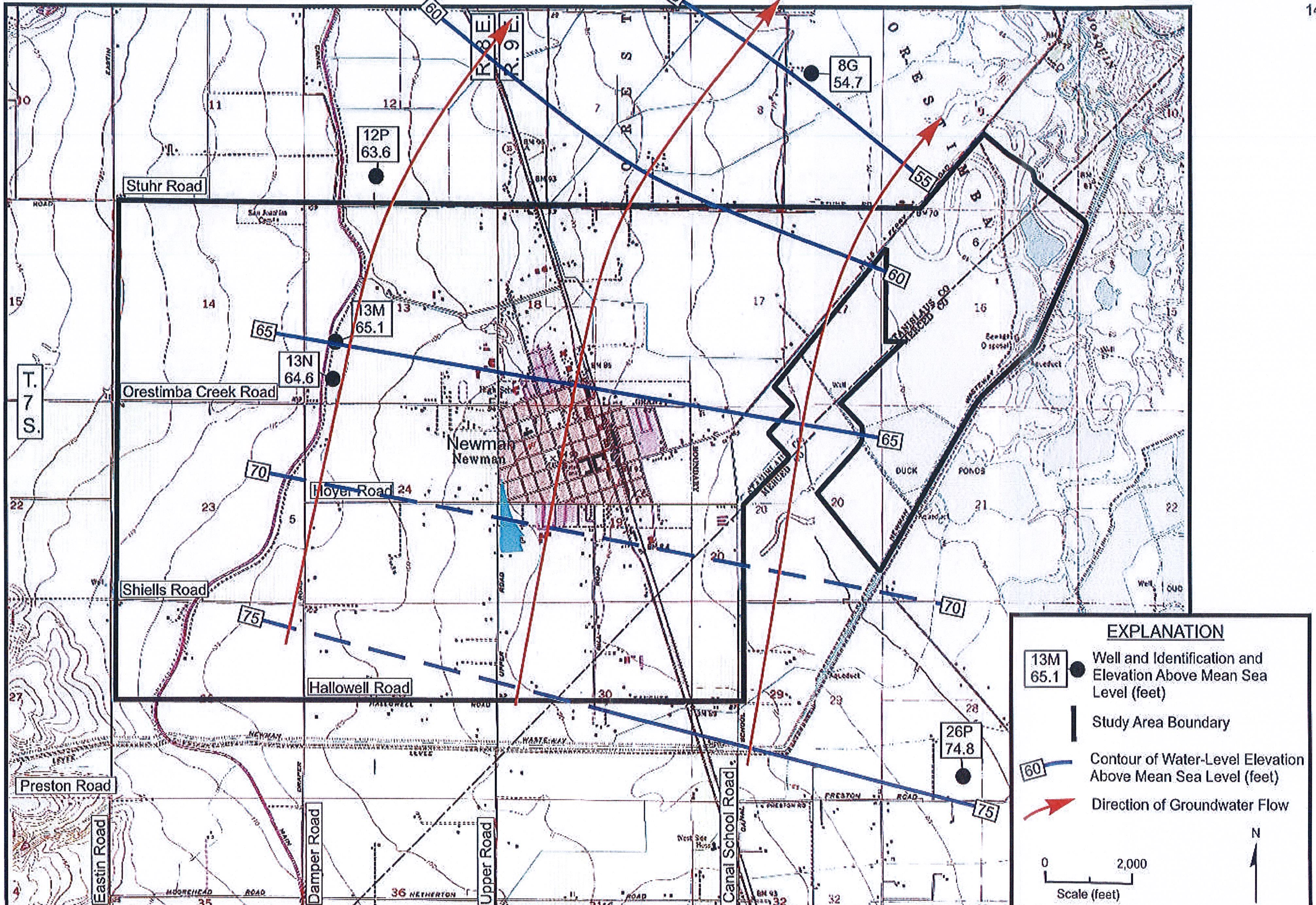

FIGURE 5 - WATER-LEVEL ELEVATIONS AND DIRECTION OF GROUNDWATER FLOW FOR UPPER AQUIFER (SPRING 2011)

slope was about 8.4 feet per mile. The direction of groundwater flow was to the north-northeast.

Figure 6 shows water-level elevations and the direction of groundwater flow for lower aquifer in Spring 2017. Some of the water-level elevations are for measurements in composite wells, and these values may be somewhat higher than actual elevations in the lower aquifer. Water-level elevations ranged from 49 feet above mean sea level at CCID wells near No. 3 the Main Canal to less than 20 feet at City Well No. 8. An easterly direction of groundwater flow was indicated.

Time Trends

The hydrologic base period utilized for the SJREC GSA is from 2003 to 2012. Thus Spring 2003-Spring 2013 water-level measurements were reviewed in terms of time trends.

City Wells

Water-level measurements for Well 1-R are only available for 2001-04, which is too short of a period to be utilized in this evaluation. Figure 7 is a water-level hydrograph for Well No. 5. The spring water levels in this well have slightly declined since 2001. Between Spring 2003 and Spring 2013, the water level in this well fell an average of about 0.7 foot per year. Figure 8 is a water-level hydrograph for Well No. 6. The spring water levels in

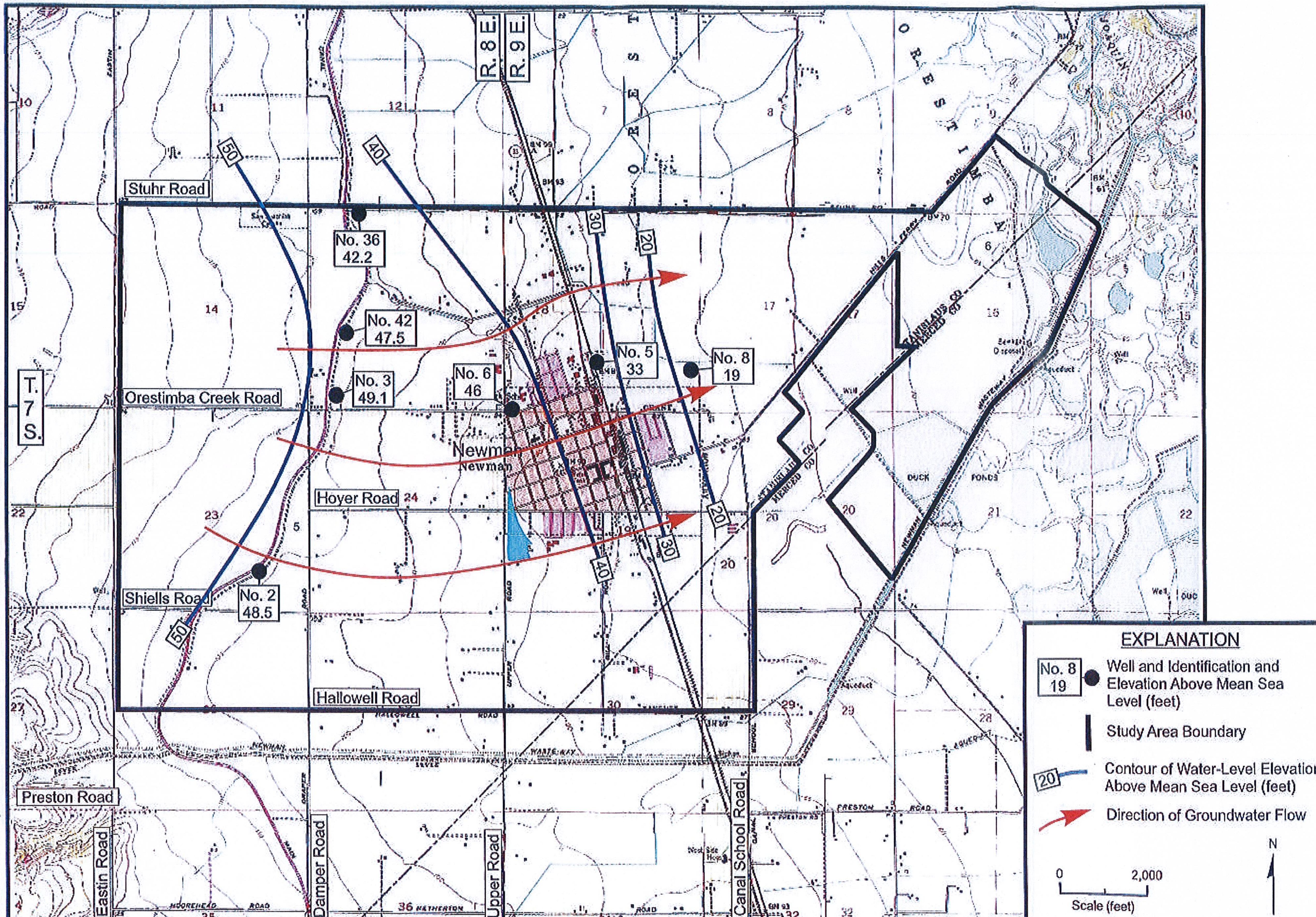

FIGURE 6 - WATER-LEVEL ELEVATIONS AND DIRECTION OF GROUNDWATER FLOW FOR LOWER AQUIFER (SPRING 2017)

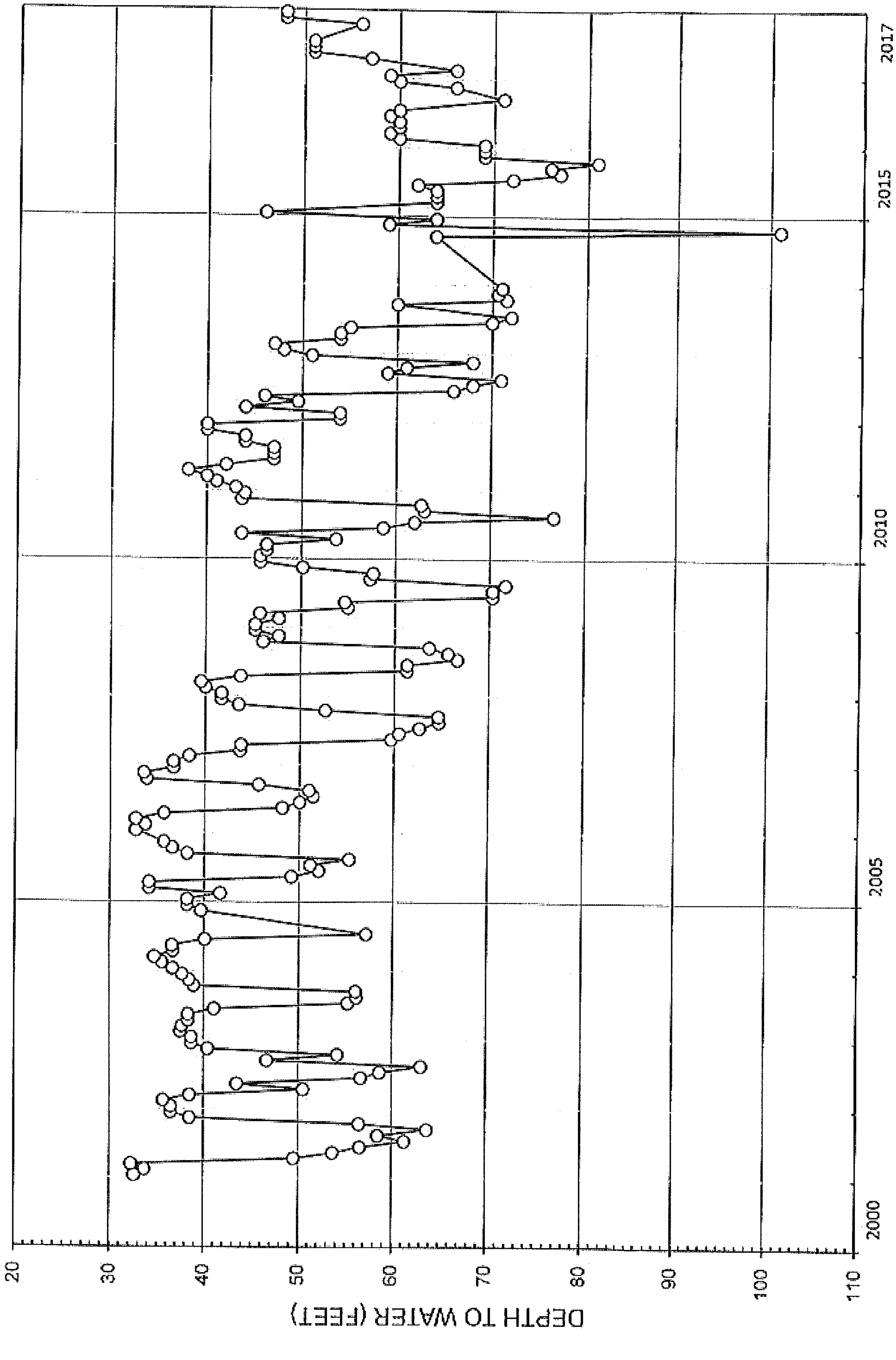

FIGURE 7- WATER-LEVEL HYDROGRAPH FOR CITY OF NEWMAN WELL NO. 5

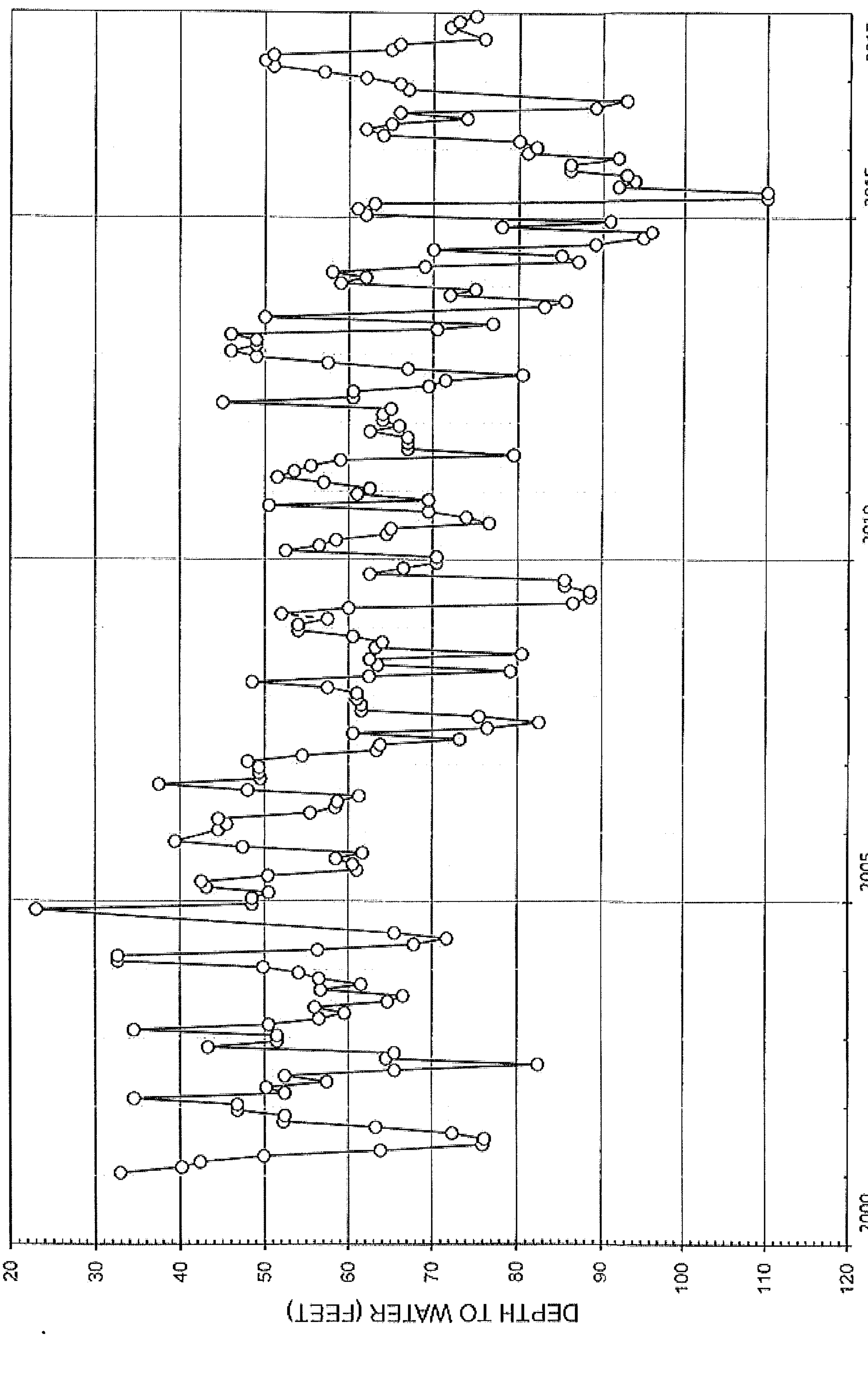

FIGURE 8- WATER-LEVEL HYDROGRAPH FOR CITY OF NEWMAN WELL NO. 6

this well have also declined since 2001. Between Spring 2003 and Spring 2013, the water level in this well fell an average of 1.3 feet per year. Both Wells No. 5 and 6 are composite wells. Figure 9 shows a water-level hydrograph for Well No. 8, which is a lower aquifer well. Measurements for this well prior to 2005 aren't available. Spring water levels fell from 21 feet in 2005 to 40 feet in 2012, or an average decline of 2.1 feet per year. This decline is considered representative of the lower aquifer in the City.

CCID Wells

Long-term water-level hydrographs for the four CCID wells are provided in Figure 10, 11, 12, and 13. Since 1965, water levels in these wells were relatively stable prior to 2013. Water levels in all of these wells fell during 2013-16, and had partially recovered by Spring 2018. Between Spring 2003 and Spring 2013, water levels in two of these wells (No. 3 and 42) were essentially stable. Water levels in the other two wells (No. 2 and No. 36) fell at average rates ranging from 0.2 to 0.8 foot per year. Overall, records for the four CCID wells indicate an average water-level decline of 0.25 foot per year. All of these wells are composite wells, tapping both aquifers.

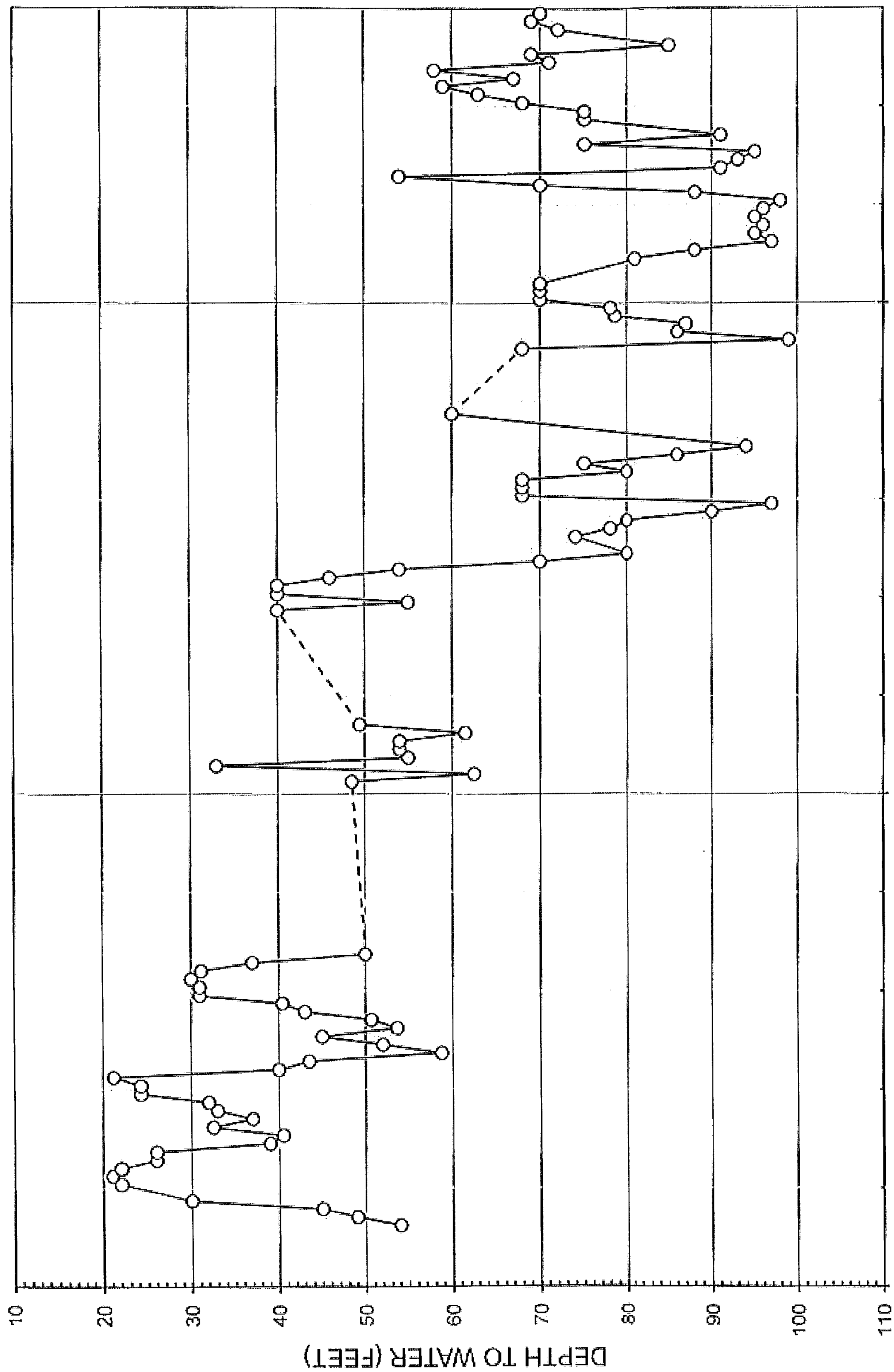

FIGURE 9- WATER-LEVEL HYDROGRAPH FOR CITY OF NEWMAN WELL NO. 8

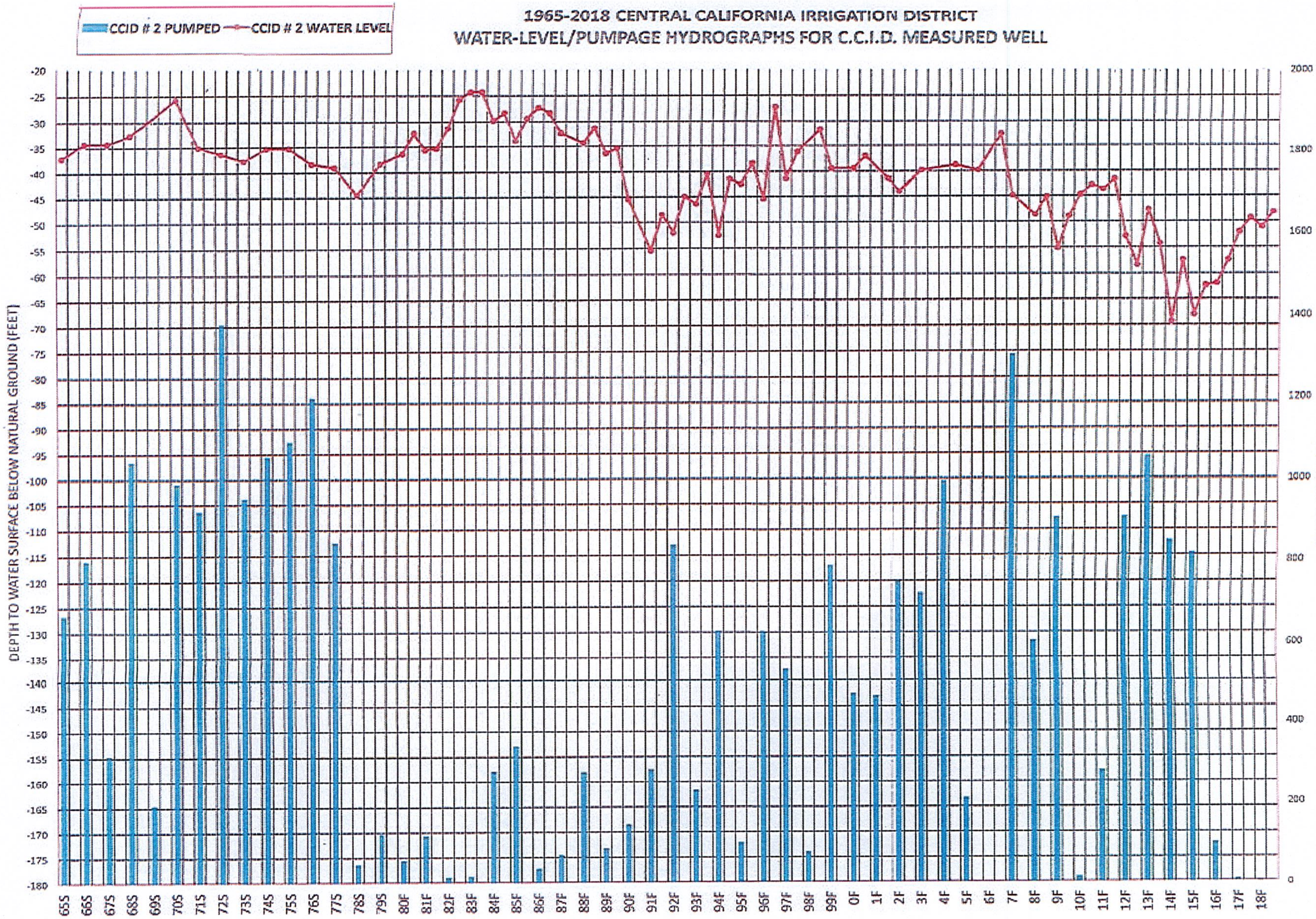

FIGURE 10 - LONG-TERM WATER LEVEL AND PUMPAGE HYDROGRAPHS FOR COMPOSITE DISTRICT WELL NO. 2 IN THE NEWMAN WELL FIELD

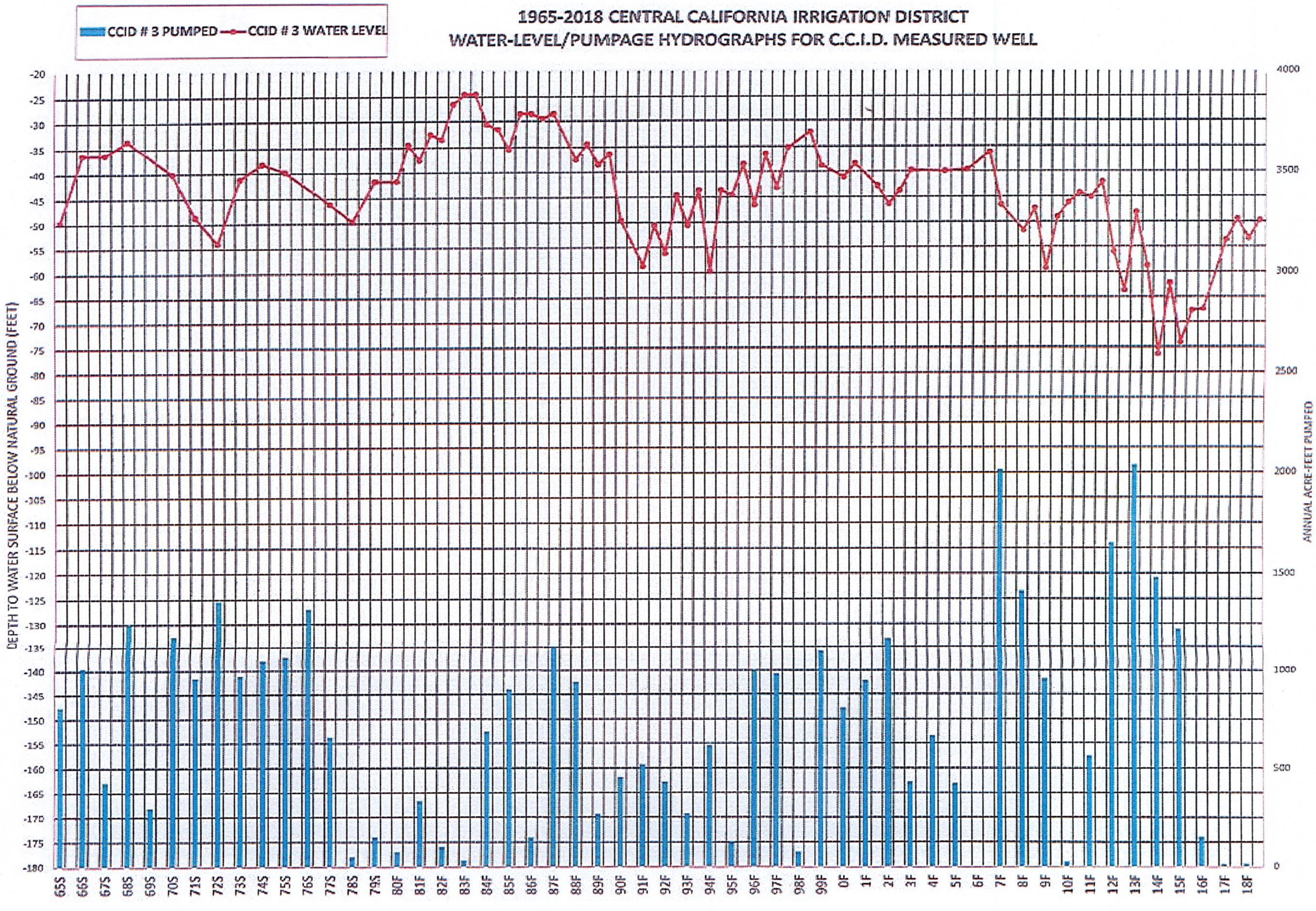

FIGURE 11 - LONG-TERM WATER LEVEL AND PUMPAGE HYDROGRAPHS FOR THE DISTRICT WELL NO. 3 IN THE NEWMAN WELL FIELD

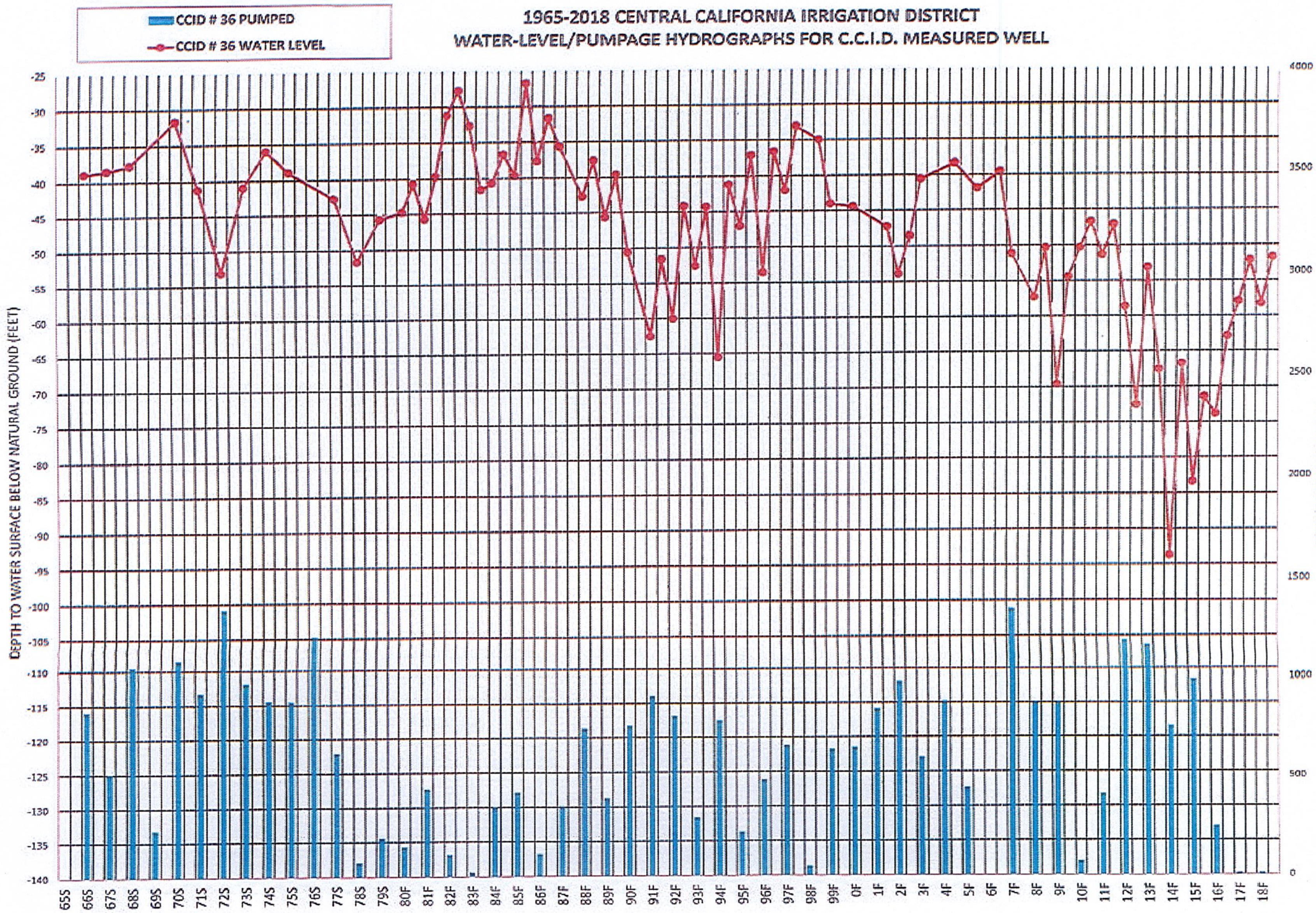

FIGURE 12 - LONG-TERM WATER LEVEL AND PUMPAGE HYDROGRAPHS FOR THE DISTRICT WELL NO. 36 IN THE NEWMAN WELL FIELD

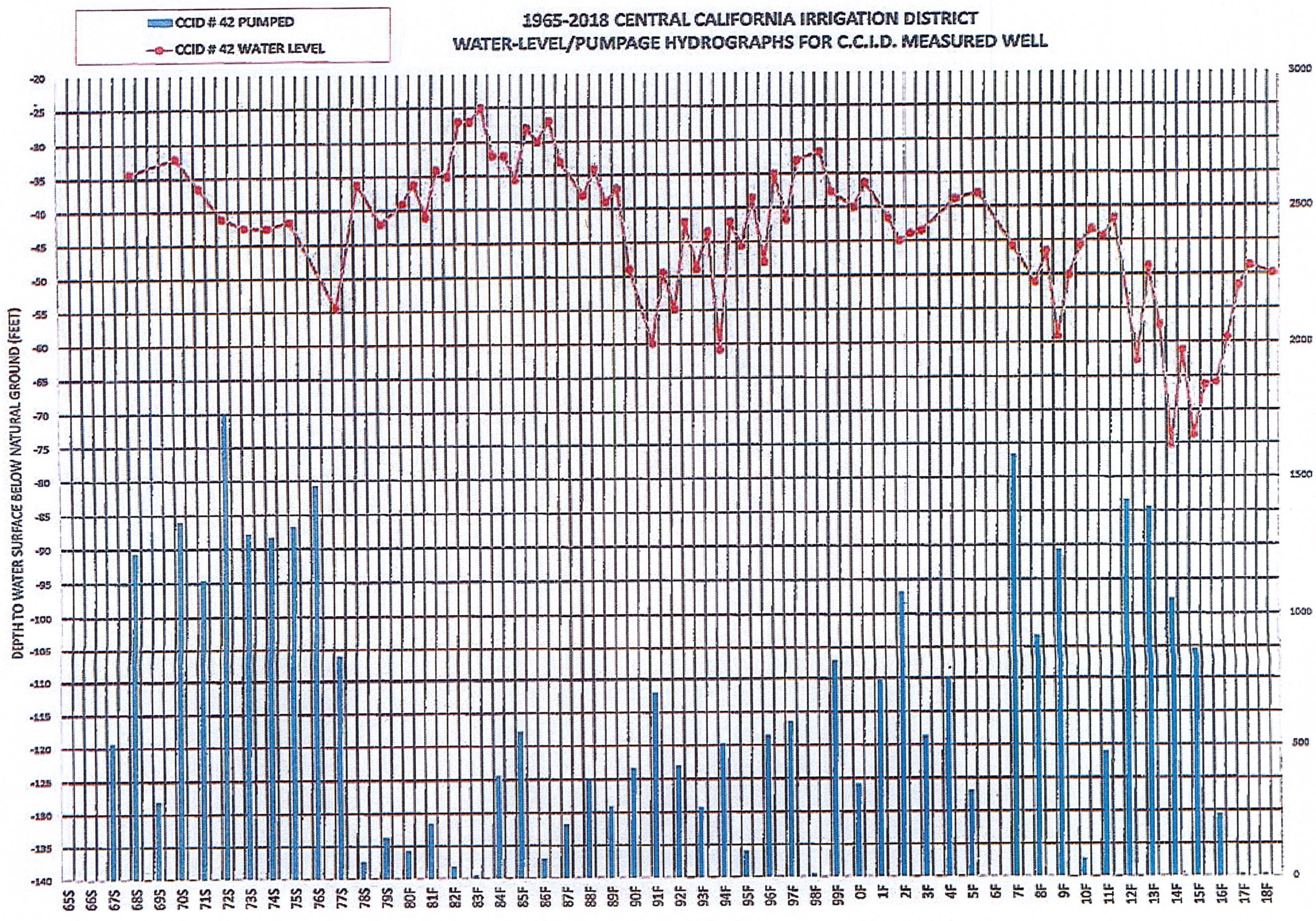

FIGURE 13 - LONG-TERM WATER LEVEL AND PUMPAGE HYDROGRAPHS FOR THE DISTRICT WELL NO. 42 IN THE NEWMAN WELL FIELD

AQUIFER CHARACTERISTICS

Table 3 summarizes pump test data for three of the active City wells for the 1990's. Recent pump test have not been provided. Pumping rates of the City wells ranged from about 1,200 to 1,600 gpm, and specific capacities ranged from 30 to 73 gpm per foot. The highest specific capacity was for Well No. 6. Table 4 shows pump test results for four CCID wells in October 2016. Pumping rates ranged from about 1,380 to 1,740 gpm. Except for one well, specific capacity values ranged from 62 to 68 gpm per foot. Based on information in the 1992 KDSA report, the transmissivity of the upper aquifer beneath the City is estimated to be about 23,000 gpd per foot. The combined transmissivity of the upper and lower aquifers above a depth of about 550 feet at Newman is estimated to average about 90,000 gpd per foot. This indicates the high productivity of the lower aquifer at Newman. The combined transmissivity of the upper and lower aquifers above a depth of about 420 feet near the Main Canal is estimated to be about 120,000 gpd per day per foot.

Darcy's Law can be used to estimate groundwater flow into the urban area. Using a transmissivity of 23,000 gpd per foot, a width of flow of about 2.6 miles (using general Plan boundaries) in Spring 2011, and an average water-level slope of about 8.4 feet per mile, the amount of groundwater flow in the upper aquifer

TABLE 3-PUMP TEST DATA FOR CITY OF NEWMAN WELLS

No.	Date Tested	Pumping Rate (feet)	Static Level (feet)	Pumping Level (inches)	Drawdown (feet)	Specific Capacity (gpm/ft)
1R	8/27/94	1,600	77.0	130.0	53.0	30.2
5	7/06/92	1,600	47.0	95.1	48.1	33.3
6	10/05/90	1,200	47.0	63.5	16.5	72.7

Data from City of Newman records.

TABLE 4-PUMP TEST DATA FOR CCID WELLS

No.	Date Tested	Pumping Rate (feet)	Static Level (feet)	Pumping Level (inches)	Drawdown (feet)	Specific Capacity (gpm/ft)
2	10/15/16	1,378	65.8	85.8	20.1	62.4
3	10/15/16	1,744	71.6	78.8	7.2	200.0
36	10/15/16	1,520	78.8	100.3	21.5	67.5
42	10/15/16	1,603	69.9	91.9	22.1	66.6

Records from CCID.

was calculated to be about 560 acre-feet per year. For the lower aquifer, using a transmissivity of 67,000 gpd per foot, a width of flow of 2.75 miles, and an average water-level slope of about 10 feet per mile, there were about 2,100 acre-feet per year of groundwater inflow for Spring 2017. As discussed in the following section, about 2,100 acre-feet of groundwater were pumped in the urban area in 2017. An estimated 1,750 acre-feet per year of this pumpage was from the lower aquifer. The amount of groundwater flow into the General Plan was greater than the net consumptive use of groundwater pumped in the urban area (i.e., pumpage minus incidental recharge).

PUMPAGE

Table 5 provides a summary of annual pumpage by the City of Newman, the CCID, and from private wells in the study area from 2003-2017. City pumpage increased from about 1,000 acre-feet per year in 1991, to 1,800 acre-feet per year in 2000, and 2,700 acre-feet per year in 2007. After 2007, City pumping decreased to about 2,200 acre-feet in 2011 due to water conservation measures. City pumpage was 2,600 acre-feet in 2012, and then decreased due to water conservation measures to about 1,900 acre-feet in 2015. The average City pumpage during 2002-17 was 2,340 acre-feet per year. The average CCID well pumpage during 2003-17 was about 3,260 acre-feet per year. Total pumpage by CCID from their

TABLE 5-ANNUAL PUMPAGE (1989-2017)
(ACRE FEET PER YEAR)

Year	City Wells	CCID Wells	Private Wells
2002	2,038	-	-
2003	2,089	2,552	1,493
2004	2,381	3,356	1,808
2005	2,498	1,399	1,920
2006	2,670	-	527
2007	2,716	4,802	1,957
2008	2,682	4,862	1,883
2009	2,470	3,956	1,459
2010	2,275	163	255
2011	2,208	1,716	1,021
2012	2,593	5,078	784
2013	2,534	4,857	2,516
2014	2,324	4,719	2,338
2015	1,918	4,055	6,687
2016	2,004	834	698
2017	2,083	-	756
Average	2,343	3,258	1,690

wells varies substantially, depending on canal water supplies. For example, only about 160 acre-feet were pumped in 2010, whereas about 5,080 acre-feet were pumped in 2012. There are also a number of private irrigation wells in the study area, and CCID provided estimates of pumpage from these wells. Pumpage from these wells ranged from about 260 acre-feet in 2010 to 6,690 acre-feet in 2015. The average pumpage from these private wells was 1,690 acre-feet per year for 2003-2017. The average total pumpage in the study area was thus about 7,300 acre-feet from 2003-17.

CITY EFFLUENT

Table 6 shows amounts of City effluent for 2003-2016. About 300 acres of pasture, alfalfa, oats and corn have normally been irrigated with the effluent, and this has been supplemented by well pumpage. There are 135 acres of holding ponds for the effluent. The amount of effluent used for irrigation ranged from about 600 acre-feet per year to 1,300 acre-feet per year during 2003-16. The average amount of effluent applied during this period was 900 acre-feet per year. Of this amount, an estimated 70 percent, or 630 acre-feet per year was consumed by evapotranspiration. The total amount of effluent during this period is estimated to have been about half of the City pumpage, or about 1,200 acre feet per year. This indicates that an average of

TABLE 6-AMOUNTS OF CITY EFFLUENT
USED FOR IRRIGATION

Year	Amount (acre-feet)
2003	800
2004	800
2005	800
2006	1,100
2007	1,400
2008	1,400
2009	1,100
2010	800
2011	900
2012	1,600
2013	1,700
2014	1,500
2015	1,300
2016	1,000
Average	1,200

An estimated 300 acre-feet per year of effluent was evaporated from holding ponds.

about 300 acre-feet per year of effluent was probably lost to evaporation from the holding ponds. An average of about 360 acre-feet per year of well pumpage has been used to supplement the effluent for irrigation.

CANAL WATER DELIVERIES

Table 7 shows CCID canal water deliveries to lands in the study area for 2003-16. Canal water was delivered to 2,600 acres of land each year during this period. The amount of canal water ranged from 450 acre-feet in 2004 to 9,600 acre-feet in 2009. The average amount of canal water delivered was 7,500 acre-feet per year during this period, or an average of 2.9 acre-feet per acre per year.

CONSUMPTIVE USE

Urban

Urban consumptive use includes evapotranspiration of water from outside water use (lawns, parks, etc), and evapotranspiration and evaporation of City effluent. The outside water use is estimated by subtracting the amount of effluent from the City pumpage. The average City pumpage from 2002-17 was 2,340 acre-feet per year and the average amount of City effluent was about 1,200 acre-feet per year. This indicates that an average of about 300 acre-feet per year was probably lost due to pond

TABLE 7-CCID CANAL WATER DELIVERIES
TO LANDS IN STUDY AREA

Year	Amount (acre-feet)
2003	8,200
2004	8,300
2005	7,200
2006	7,700
2007	9,300
2008	8,900
2009	9,600
2010	7,500
2011	6,500
2012	7,800
2013	7,600
2014	4,500
2015	5,800
2016	5,600

The canal water was used for irrigation of 2,600 acres of land.

evaporation. An average of about 360 acre-feet per year of well pumpage has been used to supplement the effluent for irrigation. The average City outside water use would be 1,140 acre-feet per year. The evapotranspiration for the outside water use is estimated to be 70 percent of this, or 800 acre-feet per year. For the effluent, it is estimated that an average of 630 acre-feet per year was consumed by evapotranspiration of irrigated crops and 300 acre-feet per year was lost due to evaporation from the holding ponds. The total urban consumptive use was thus about 1,700 acre-feet per year (rounded).

Rural

CCID estimated the evapotranspiration of applied water to crops in the study area. The ITRC water use study report for 1997-2008 was used to determine the evapotranspiration of applied water to crops (ET_{IW}) for 2003-08. For 2009-16, the total evapotranspiration (ETc) was determined from the IRRC metric report (landsat data). ET_{IW} values averaged 80 percent of the ETc values. Thus where ET_{IW} valued weren't available, the ETc values were multiplied by 80 percent to estimate the ET_{IW} values. The evapotranspiration of applied water to crops in the study area averaged about 7,700 acre feet per year for 2003-2016.

Total

The average urban and rural consumptive in the study area was 9,400 acre-feet per year for 2003-16.

LAND SUBSIDENCE

Records of land subsidence are available for the DMC, about 3.5 miles west of the study area. At that location there was about 0.5 foot of subsidence during 2014-16. Records of land subsidence along the San Joaquin River east of Newman indicate minimal subsidence. Land subsidence in the Newman urban area has not been measured.

CHANGE IN GROUNDWATER IN STORAGE

Water levels in wells tapping the upper unconfined aquifer in the Newman area have indicated no long-term change in storage. There has also been no significant change in storage in the confined aquifer, as it has remained full of water. However, there has been a one time decrease in storage for the confining beds, due to compaction of these beds, which has resulted in land subsidence. Assuming and average subsidence of about 0.1 foot per year over the 3,800 acre area, this amount of water for 2003-12 averaged about 40 acre-feet per year.

GROUNDWATER QUALITY

Inorganic Chemical Constituents

City Wells

Table 8 provides the results of chemical analyses of water from active City wells in recent years.

Composite Wells. Wells No. 5 and 8 are composite wells. The total dissolved solids (TDS) concentrations in July 2017 ranged from 812 to 901 mg/l. Nitrate concentrations ranged from 11 to 32 mg/l, less than the MCL of 45 mg/l. Chloride concentrations ranged from 150 to 197 mg/l, less than the recommended of 250 mg/l. Concentrations or iron, manganese, arsenic, and selenium were less than the respective MCLs. Hexavalent chromium concentrations in water from Well No. 5 have ranged considerably in recent years, from non-detectable to 16 ppb. This is probably associated with varying pumping durations prior to when the water samples were collected for analyses. Hexavalent chromium concentrations in water from Well No. 8 have ranged from 4 to 10 ppb from 2015 to 2018, and decreased during this period. Alpha activities have been below the MCL of 15 picocuries per liter.

Lower Aquifer Wells. Wells No. 1R and 6 are lower aquifer wells. TDS concentrations in water from these wells ranged from 764 to 847 mg/l in July 2016. Nitrate concentrations ranged from 20 to

TABLE 8-CHEMICAL QUALITY OF WATER FROM CITY OF NEWMAN WELLS

Constituent (mg/l)	No. 1R	No. 5	No. 6	No. 8
Calcium	110	110	99	63
Magnesium	48	52	43	34
Sodium	104	115	86	138
Potassium	-	4	-	-
Bicarbonate	340	442	383	304
Sulfate	166	168	176	168
Chloride	222	150	136	197
Nitrate	22	32	20	11
Fluoride	0.2	0.2	0.2	0.2
pH	7.4	7.6	7.5	7.4
Electrical Conductivity (micromhos/cm @ 25°C)	1,530	1,440	1,300	1,390
Total Dissolved Solids (@ 180°C)	847	901	764	812
Iron	<0.1	<0.1	<0.1	<0.1
Manganese	<0.02	<0.02	<0.02	<0.02
Arsenic (ppb)	<2	<2	<2	<2
Hexavalent Chromium (ppb)	<1	0.1-16	5	4
Selenium (ppb)	<5	<5	<5	-
Alpha Activity (picocuries per liter)	6	-	5	<3
Date	7/6/16	7/2/13	7/6/16	7/6/17
Perforated Interval (feet)	340-620	162-450	351-500	180-480

22 mg/l, less than the MCL of 45 mg/l. Chloride concentrations ranged from 136 to 222 mg/l, less than the MCL of 250 mg/l. Concentrations of iron, manganese, arsenic, and selenium were below the respective MCLs. Hexavalent chromium concentrations in water from Well No. 1R have been about 1 ppb or less, well below the MCL of 10 ppb. Concentrations of hexavalent chromium in water from Well No. 6 have ranged from about 5 to 9.6 ppb in recent years, and have decreased since 2015. Alpha activities have ranged from about 4.5 to 5.6 picocuries per liter in water from Well No. 1R, and from about 3.1 to 9.9 picocuries per liter in water from Well No. 6, below the MCL of 15 picocuries per liter.

CCID Wells

Table 9 provides the results of inorganic chemical analyses of water from the four CCID wells in the study area for July 2017. All of these are composite wells. The perforated intervals shown are for the tops and bottoms of the perforations. TDS concentrations ranged from 870 to 1,200 mg/l and nitrate concentrations ranged from 7 to 11 mg/l, below the MCL of 45 mg/l. Chloride concentrations ranged from 190 to 250 mg/l, compared to the recommended MCL of 250 mg/l. Sulfate concentrations ranged from 120 to 220 mg/l, less than the recommended MCL of 250 mg/l. Boron concentrations ranged from 0.45 to 0.69 mg/l, high enough to affect boron sensitive crops, if the proposed water was used

TABLE 9-CHEMICAL QUALITY OF WATER FROM CCID WELLS

Constituent (mg/l)	No. 2	No. 3	No. 36	No. 42
Calcium	100	110	44	54
Magnesium	50	56	58	70
Sodium	130	130	120	170
Potassium	3	3	3	4
Bicarbonate	366	439	427	488
Sulfate	120	170	180	220
Chloride	210	170	190	250
Nitrate	7	7	10	11
pH	7.8	7.8	7.9	7.8
Electrical Conductivity (micromhos/cm @ 25°C)	1,400	1,500	1,600	1,900
Total Dissolved Solids (@ 180°C)	870	910	980	1,200
Boron	0.5	0.5	0.5	0.7
Date	7/25/17	7/25/17	7/25/17	7/25/17
Perforated Interval (feet)	90-337	85-337	90-393	90-391

without mixing. The pumpage from CCID wells is mixed with canal water before use, and the resulting boron concentrations are acceptable for irrigation.

HISTORICAL WATER BUDGET

The average canal water delivery to lands in the study area was 7,500 acre-feet per year for 2003-16. The total consumptive use averaged 9,200 acre-feet per year during this period. The average groundwater inflow was 2,660 acre-feet per year. The change in groundwater storage was 40 acre-feet per year. In order to maintain a water budget, the groundwater outflow averaged about 1,010 acre-feet per year.

REFERENCES

Kenneth D. Schmidt & Associates, 1992, "Groundwater Conditions in the Vicinity of the City of Newman" report prepared for CCID and City of Newman, 30p

Kenneth D. Schmidt & Associates, 2001, "Groundwater Conditions in the Vicinity of the City of Newman" report prepared for CCID and City of Newman, 33p

Page, R. L., 1986, "Geology of the Fresh Groundwater Basin of the San Joaquin Valley, California", U.S. Geological Survey Professional Paper 1401-C.

Appendix R. Update on Groundwater Conditions in the Gustine Sub-Area of the SJREC GSP

UPDATE ON GROUNDWATER CONDITIONS IN THE GUSTINE SUB-AREA OF THE SJREC GSP

prepared for
San Joaquin River Exchange
Contractors GSA
Los Banos, California

and
City of Gustine GSA
Gustine, California

by
Kenneth D. Schmidt & Associates
Groundwater Quality Consultants
Fresno, California

May 2019

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May 31, 2019

Mr. Chris White, Executive Director
San Joaquin River Exchange
Contractors GSA
P. O. Box 2115
Los Banos, CA 93635

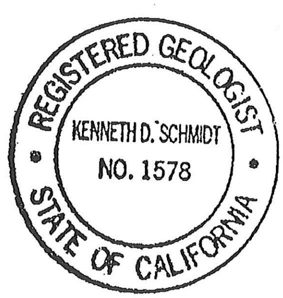
Re: Gustine Sub-Area of the
SJREC GSP

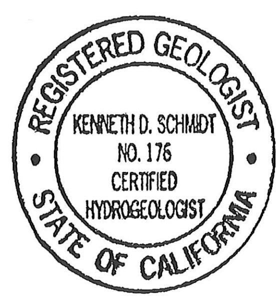
Dear Chris:

Submitted herewith is our report on groundwater conditions in the Gustine Sub-area of the SJREC GSP. We appreciate the cooperation of the CCID and City of Gustine in providing information for this report.

Sincerely Yours,

Kenneth D. Schmidt
Geologist No. 1578
Certified Hydrogeologist 176





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INTRODUCTION

As part of the Groundwater Sustainability Plan (GSP) for the San Joaquin River Exchange Contractors (SJREC) service area, GSPs for a number of cities, including Gustine, are being incorporated into the SJREC GSP. Kenneth D. Schmidt and Associates (KDSA, 1992 and 2001) prepared two reports on groundwater conditions in the vicinity of the City of Gustine for the Central California Irrigation District (CCID) and the City.

This report is intended to provide an update on groundwater conditions within the Gustine Study Area boundary (Figure 1). This boundary encompasses lands that are planned for future urban development. This study area is generally bounded by Jensen Road or Highway 140 on the north, Whitworth Road on the west, Gun Club Road on the south, and includes lands to the east where the City effluent is handled. Lands around the City of Gustine are in the SJREC GSA, and some lands to the north and south of the WWTF are in the Merced County Delta-Mendota GSA.

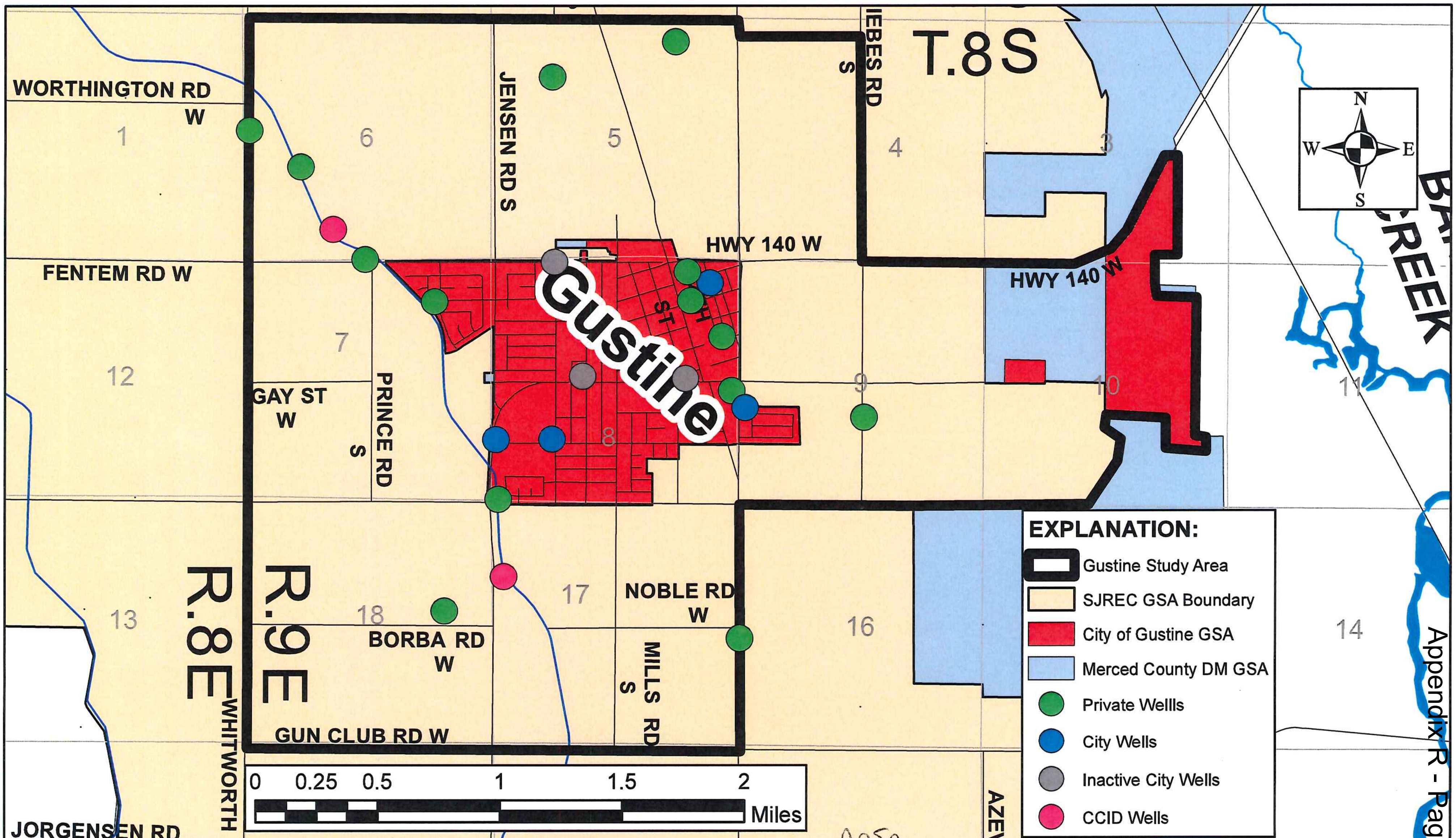


FIGURE 1-LOCATION OF GUSTINE SUB-AREA, STUDY AREA BOUNDARY, AND SELECTED WELLS

SUBSURFACE GEOLOGIC CONDITIONS

Alluvial deposits comprise the aquifer system beneath the western part of the San Joaquin Valley. Deposits near Gustine are termed the older alluvium and the Tulare Formation. Page (1986) indicated that the base of the fresh groundwater (electrical conductivity less than 3,000 micromhos per centimeter at 25°C) was about 900 feet deep near Gustine. This is considered the base of the usable groundwater in the vicinity. A major confining bed is present beneath much of the west side of the San Joaquin Valley, including Gustine. This clay is termed the Corcoran Clay, and divides the aquifer system into upper and lower aquifers. The Corcoran Clay is readily discernible from the drillers logs for most wells in the area, due to its blue color. The over-lying and under-lying deposits are usually tan or brown in color.

Most of the groundwater near Gustine is pumped from the upper aquifer (above the Corcoran Clay). One City well and some industrial and irrigation wells in the area were drilled to depths exceeding 450 feet, and tap the lower aquifer. As part of the previous investigations, three subsurface geologic cross sections extending through the City of Gustine were developed (Figure 2).

Subsurface Geologic Cross Section C-C' (Figure 3) extends from near Whitworth Road, between Sullivan and Gun Club Roads on

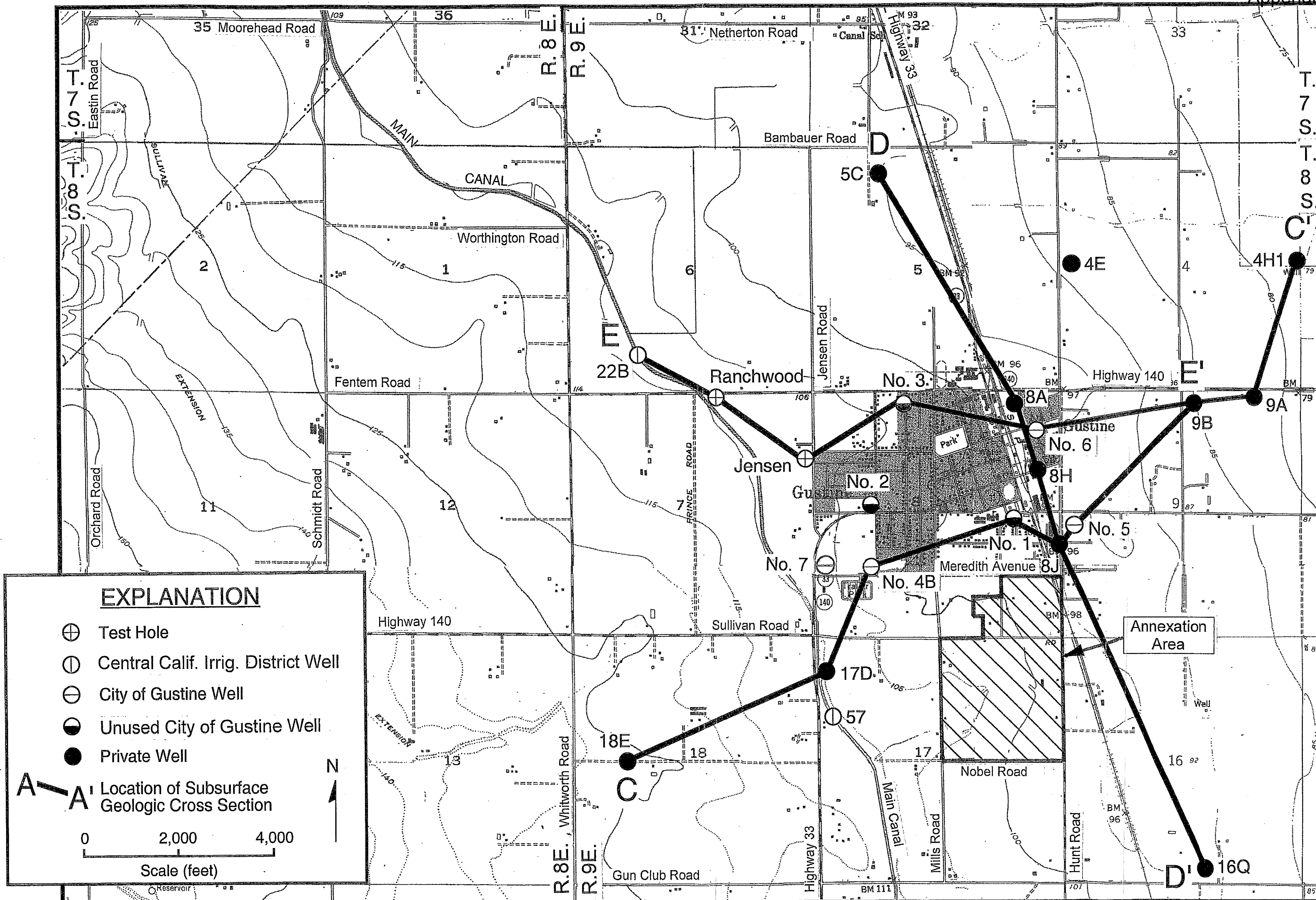


FIGURE 2-LOCATION OF SELECTED TEST HOLES AND WELLS AND SUBSURFACE GEOLOGIC CROSS SECTIONS

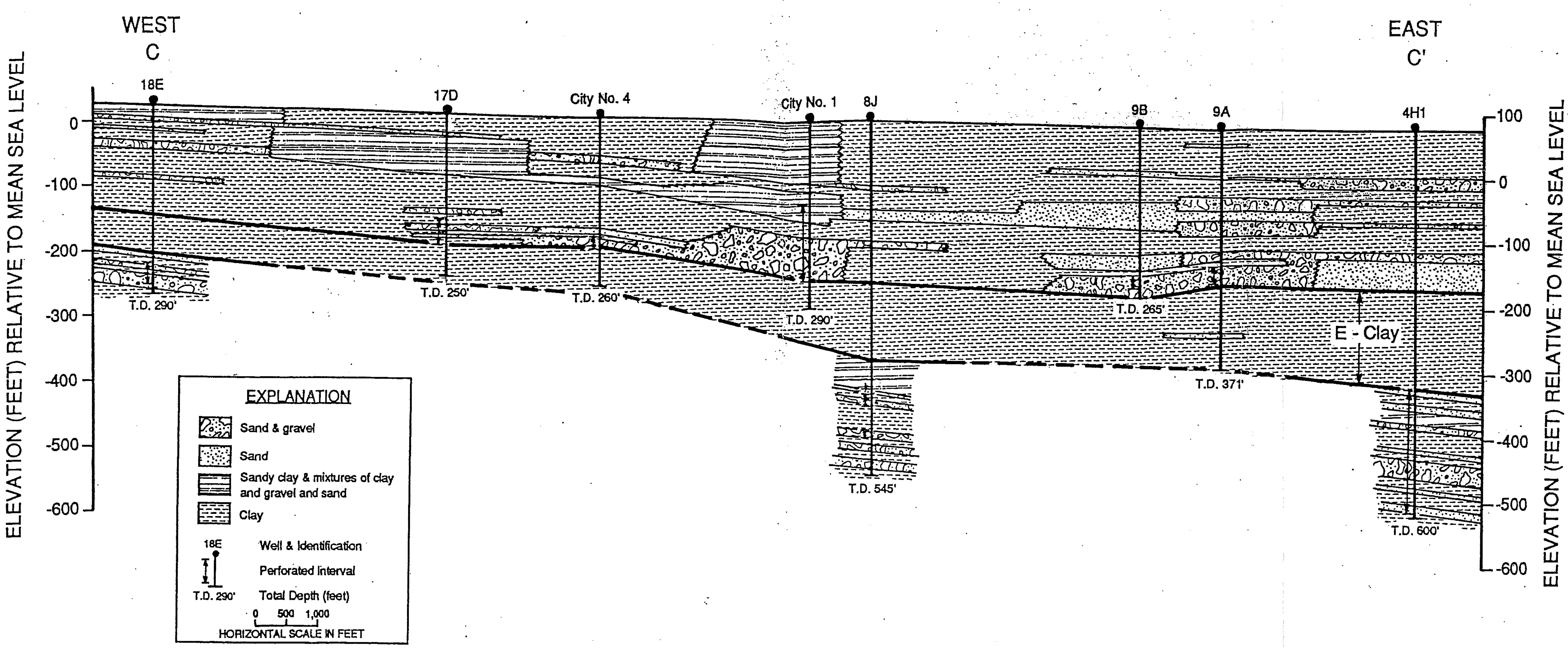


FIGURE 3-SUBSURFACE GEOLOGIC CROSS SECTION C-C'

the southwest, to the northeast through City Wells No. 1 and 4, thence northeast for about one and one-half miles. An electric log is available for City Well No. 1 and the other information was obtained from drillers logs. Two wells along this section (8J and 4H1) exceeded 540 feet in depth. Most of the wells along this section penetrated the Corcoran Clay, the top of which ranges from about 170 feet in depth at Well 18E to about 250 feet at Well 8J. The Corcoran Clay thickens to the northeast along this section, from about 60 feet at Well 18E to about 150 feet at Well 4H1. Beneath and northeast of the City, sand and gravel layers are common within the lower 100 feet of the upper aquifer. Below the Corcoran Clay, sand and gravel layers are relatively thin along this cross section.

Cross Section D-D' (Figure 4) extends from the northwest near Jensen and Baumbauer Roads, along Highway 33, through three industrial wells, to a point near Gun Club Road and half a mile east of Hunt Road. The top of the Corcoran Clay ranges from about 225 feet deep at Well 5C to 260 feet deep at Well 8A. The Corcoran Clay appears to be relatively flat along this section, because the section is perpendicular to the inferred dip of the alluvial deposits. The thickness of the Corcoran Clay along this section ranges from about 85 feet at Well 8A to 120 feet at Well 8J. The sand and gravel layers in the lower part of the upper aquifer are thickest at Well 8H, and appear to thin

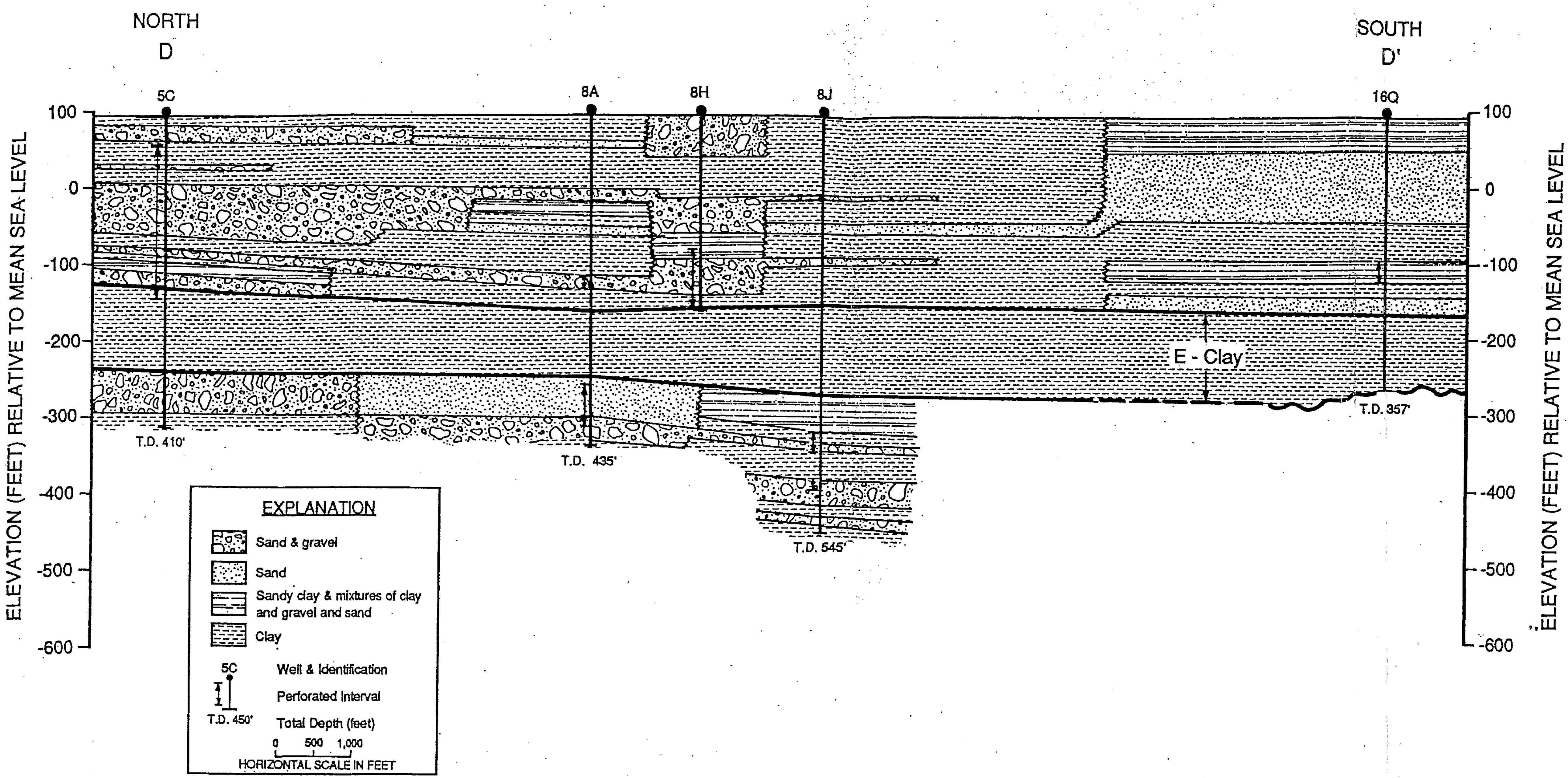


FIGURE 4-SUBSURFACE GEOLOGIC CROSS SECTION D-D'

to the south (at Well 16Q). Sand and gravel layers immediately below the Corcoran Clay are thickest to the northwest (Wells 5C and 8A). At Well 8J, sand and gravel layers in the lower aquifer are relatively thick and extend to a depth below 500 feet.

Cross Section E-E' (Figure 5) extends from CCID Well 22B adjacent to the Outside Canal, to the southeast and east, through City Wells No. 3 and 6. The top of the Corcoran Clay ranges from about 170 to 265 feet deep along this section. The Corcoran Clay along this section ranges from about 90 to 130 feet thick. Two thick, well developed sand and gravel strata were encountered above this clay along the northwest part of this section. Several thinner coarse-grained strata were also encountered below the clay at the Jensen test hole and City Well No. 6.

WELL CONSTRUCTION DATA

City

There are presently four active City wells (No. 4B, 5, 6, and 7). Table 1 provides information on dates drilled, depths, and perforated intervals for these wells. Drillers logs are available for all of these active wells and electric logs are available for Wells No. 1, 5, 6, and 7. Except for Well No. 5, cased depths range from 204 to 240 feet, and these wells tap water-

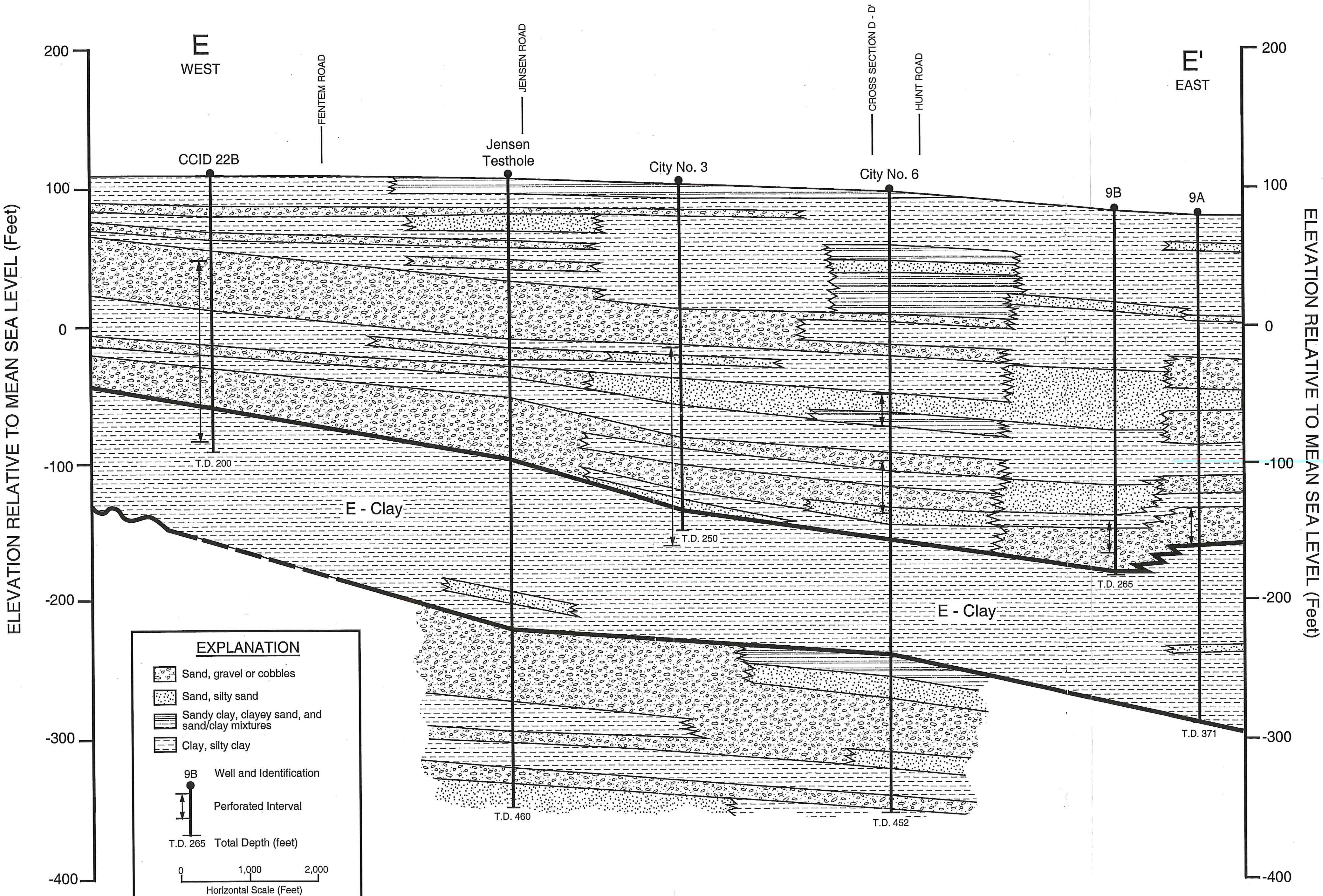


FIGURE 5-SUBSURFACE GEOLOGIC CROSS SECTION E-E'

TABLE 1-CONSTRUCTION DATA FOR CITY OF GUSTINE AND INDUSTRIAL WELLS

Well No.	State Location	Date Completed	Drilled Depth (feet)	Cased Depth (feet)	Diam. Casing (inches)	Perf. Int. feet)	Annular Seal (feet)
4B	8M2	09/93	250	200	16	167-200	0-167
5	9M	11/98	451	450	16	370-444	0-350
6	8A	12/98	250	240	16	145-230	0-130
7	4M	5/11	209	204	16	165-194	0-110
Formerly Beatrice Cheese	8A	05/73	435	200	16 414	- 12	0-50 210-410
Saputo	8H	12/56	254	254	14	174-254	0-60
Hillview Packing	8J	04/73	545	100	16	100-490	0-50

All of the wells are in T8S/R9E. Data from drillers logs, City of Gustine files, Avoset Foods, and Balding, Scott and Hotchkiss (1969). The perforated intervals are for the tops and bottoms of the perforated interval.

producing strata above the Corcoran Clay. Well No. 5 was perforated from 370 to 444 feet in depth and taps strata below the Corcoran Clay. This well has an annular seal extending to a depth of 350 feet.

CCID

The CCID has two wells along the Main Canal in the Gustine area. Table 2 shows construction data for these wells. Well No. 22B was completed in January 1999. Perforated casing was installed from 60 to 190 feet in depth in this well. Well No. 57 was installed in August 2000 and the casing is perforated from 70 to 190 feet in depth. Both wells tap strata above the Corcoran Clay.

Industrial

Drillers logs are available for three industrial wells in the City (Table 1). All of these wells are still active. Well 8a is cased to a depth of 414 feet and is a composite well (tapping both aquifers). Well 8H is 254 feet deep and taps only the upper aquifer. Well 8J is cased to a depth of 490 feet and is a composite well.

Gustine Drainage District

Table 3 contains construction data for Gustine Drainage District wells in the vicinity of Gustine. Depths of wells for which records are available and range from about 90 to 140 feet.

TABLE 2-CONSTRUCTION DATA FOR CCID WELLS

Well No.	Date Drilled	Drilled Depth(feet)	Cased Depth (feet)	Casing Diameter (inches)	Perforated Interval (feet)	Annular Seal feet)
22B	01/99	200	190	18	60-190	0-52
57	08/00	210	210	16	70-190	0-50

Data from drillers logs and Balding, Scott and Hotchkiss (1969).

TABLE 3-CONSTRUCTION DATA FOR GUSTINE DRAINAGE DISTRICT WELLS (T8S/R9E)

Well No.	State Location	Date Completed	Drilled Dept (feet)	Cased Depth (feet)	Casing Diam. (inches)	Perf.Int. (feet)
3	T8S/R9E-8N1	1953	136	136	16	130-250
14	5A2	1913	140	140	16	-
15	16M1	-	105	105	14	30-105
16	T7S/R9E-30H	1943	-	93	-	-

Data from drillers logs and Balding, Scott and Hotchkiss (1969).

The wells generally have shallow perforations, and were designed to tap the upper part of the upper aquifer. Water from one of these wells (No. 3) was used for irrigation at the Harry P. Schmidt Park in the City. Since 2001, tile drain systems have been installed beneath a number of irrigated fields. The tile drain systems have proven to be more effective to address sub-surface drainage problems, and drainage well pumping has gradually been replaced.

WATER LEVELS

Depth to Water

Near Gustine, most of the available water-level measurements are for wells tapping the upper aquifer. J.M. Lord, Inc. (1990) reported on depth to the shallow groundwater in the Gustine Drainage District, which surrounds the City of Gustine. In June 1989, depth to water ranged from less than five feet northeast and southeast of Gustine, to more than ten feet beneath parts of Gustine.

Water-Level Elevations

Water-level measurements for wells in the area were obtained from the California Department of Water Resources and CCID. The previous evaluation provided a water-level elevation contour map for Spring 2000, which was primarily based on large-capacity wells that tap the upper aquifer. A cone of depression beneath Gustine was indicated by those measurements. Water-level elevations in this depression ranged from about 70 to 80 feet above mean sea level, about 10 to 15 feet lower than those beneath the surrounding lands. Southwest of Gustine, water-level elevations ranged from about 100 to 120 feet above mean sea level. Northeast of Gustine, water-level elevations ranged from about 75 to 85 feet. The regional direction of groundwater flow in the upper aquifer near Gustine was to the northeast in Spring 2000. Limited data for the lower aquifer indicated a northerly direction of groundwater flow, toward Newman. Water-level elevations in the lower aquifer were indicated to be about 20 feet below the upper aquifer in Spring 2000.

Figure 6 shows water-level elevations and the direction of groundwater flow for March 2011. Water-level elevations ranged from 108 feet above mean sea level near Gun Club Road, about three miles southwest of the City to 78 feet about a mile northeast of the City. Southwest of Gustine, March 2011 water levels were about 20 feet lower than in Spring 2000. North of Gustine, water levels were close to those in Spring 2000. The direction of groundwater flow was to the northeast. A cone of depression was not indicated beneath the City, but that was due to a lack of water-level measurements for City wells.

Water-Level Trends

Frequent water-level measurements are available for several wells near Gustine during recent decades. Figure 7 shows water-

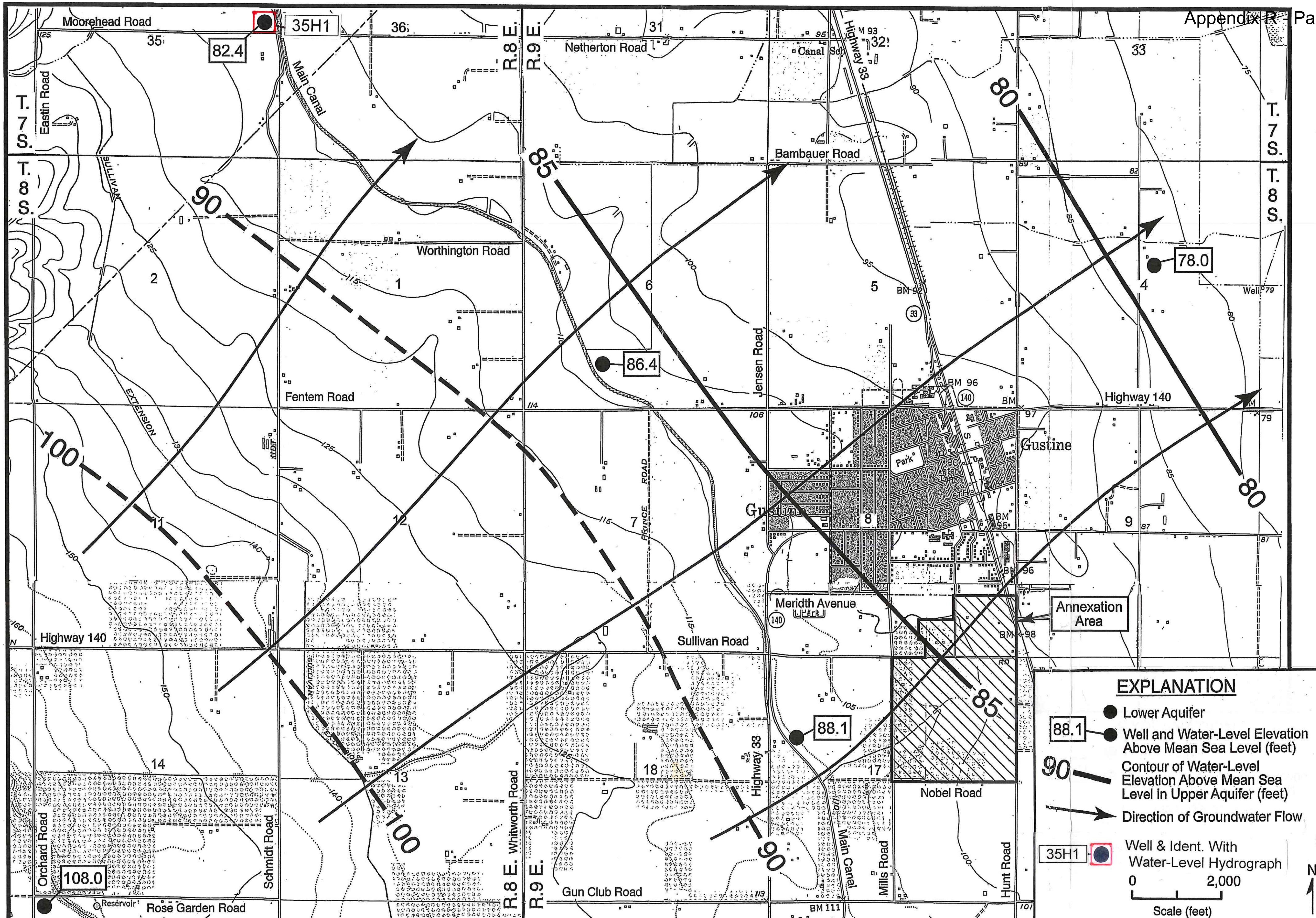
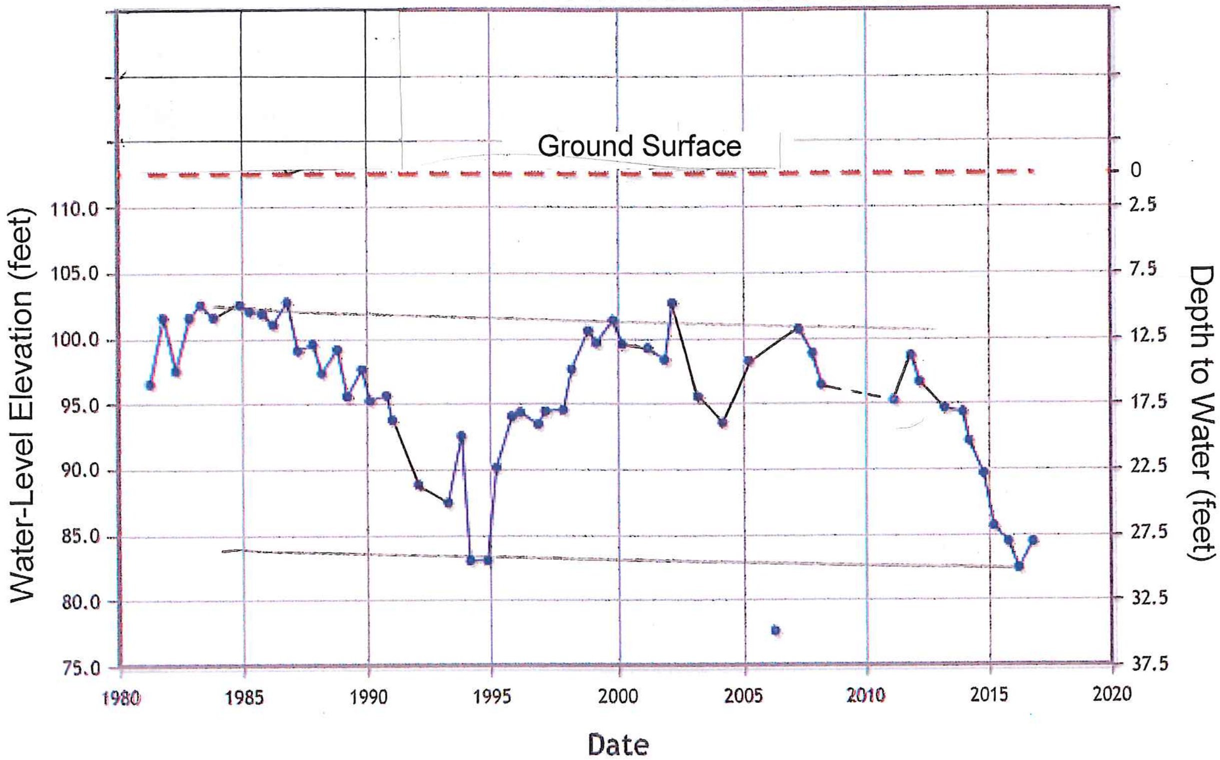
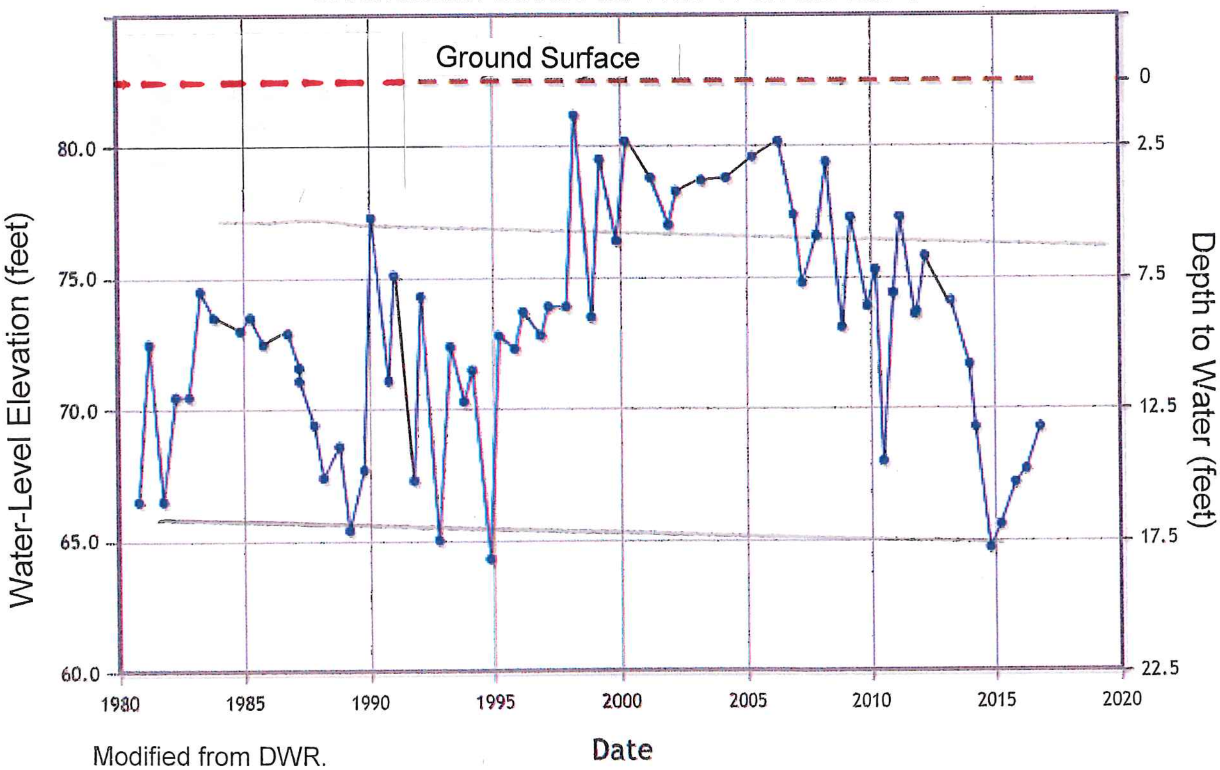


FIGURE 6-WATER-LEVEL ELEVATIONS AND DIRECTION OF GROUNDWATER FLOW FOR THE UPPER AQUIFER (SPRING 2011)

Groundwater Levels for Well T7S/R8E-35H1



Groundwater Levels for Well T7S/R9E-28P1



Modified from DWR.

FIGURE 7-WATER-LEVEL HYDROGRAPHS FOR UPPER AQUIFER WELLS

(Continued)

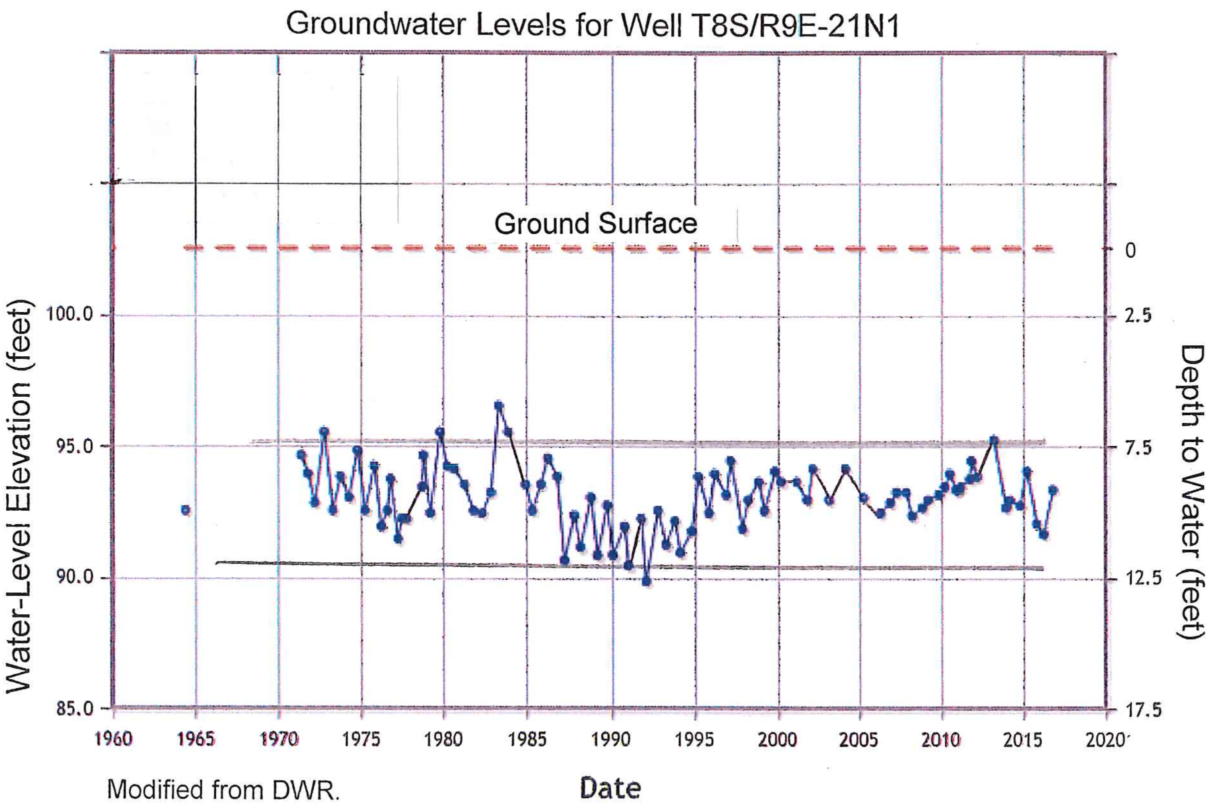


FIGURE 7-WATER-LEVEL HYDROGRAPHS FOR UPPER AQUIFER WELLS (CONTINUED)

level hydrographs for three of these wells. T7S/R8E-35H1 is located near Netherton Road and Schmidt Road. Depth to water usually ranged from about 12 to 22 feet. Overall, the water levels in this well slightly declined between 1982 and 2016, at an average rate of less than 0.1 foot per year. Well T7S/R9E-28P, is located near Kniebes Road and Preston Road, northeast of Gustine. Depth to water in this well has ranged from about 2 to 18 feet. Water levels in this well were stable from 1981 through 2016, except for the temporary declines during drought periods. Well T8S/R9E-21N is located near Taglio Road and Hunt Road, south of Gustine. Depth to water has ranged from about 7 to 12 feet. Water levels in this well were stable from 1964 through 2016.

Figure 8 shows water-level hydrographs for CCID Wells No. 22B and 57. Records for Well No. 22B extend from 1965 to 2018. Records for Well No. 57 extend from 2001 to 2018. The seasonally shallowest levels fell from early 2005 through early 2009, then rose through early 2013 to the shallowest levels during the period of record. The shallowest seasonal levels then fell through 2015, and partially recovered during 2016. Over the long term, the water levels fell about 6.5 feet over a 16-year period, or an average of 0.4 foot per year. As of early 2018, the water level still hadn't fully recovered. This decline was highly influenced by drought conditions in 2014-15. A shorter period of records is available for Well 57, but similar trends are indicated.

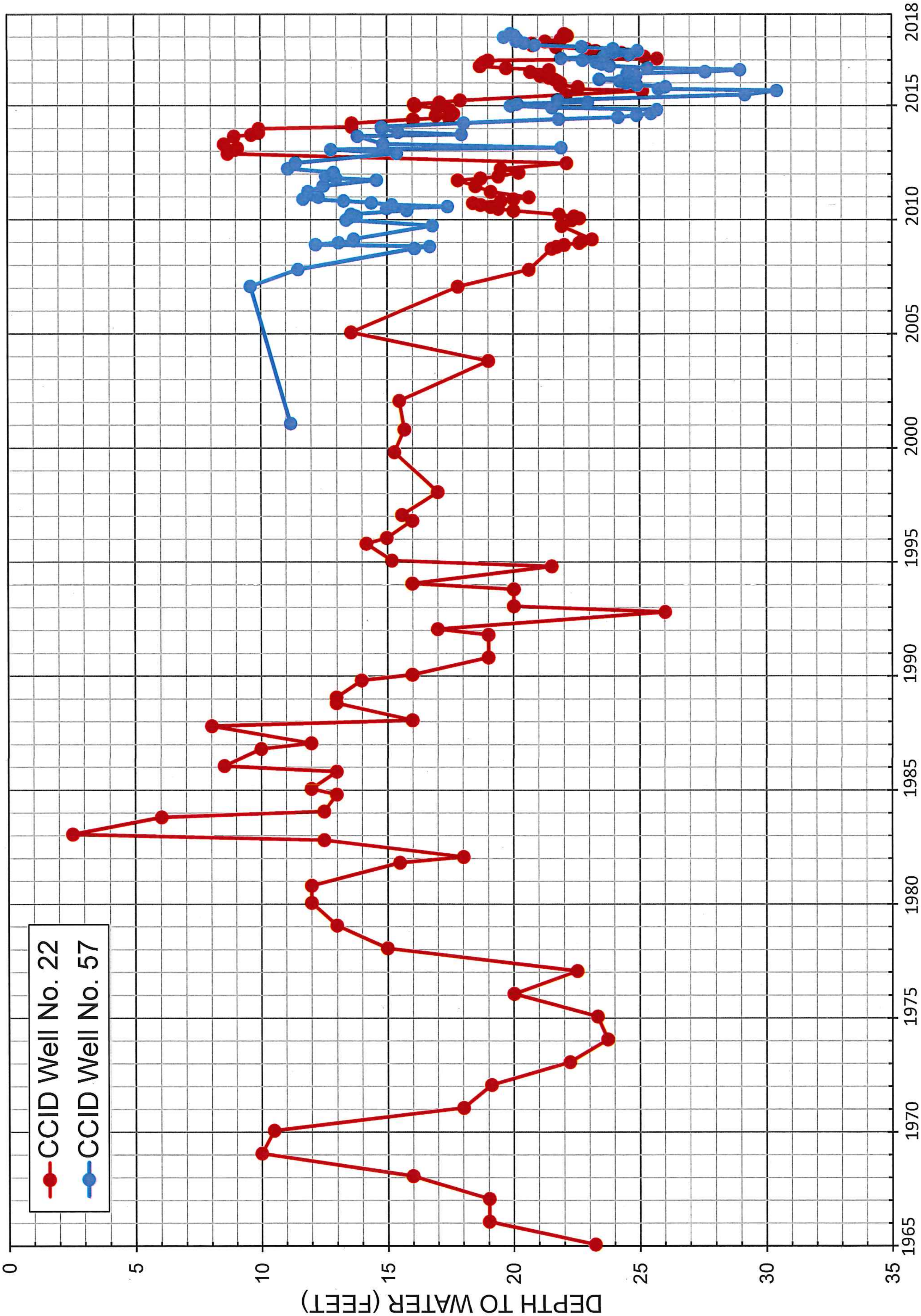


FIGURE 8 - WATER-LEVEL HYDROGRAPHS FOR CCID WELLS

Overall, there is no indication of groundwater overdraft in or near Gustine. In fact, the shallow groundwater levels are considered a problem in the surrounding irrigated areas. The evidence for this is the existence and ongoing activities of the Gustine Drainage District, which was developed to address this problem.

AQUIFER CHARACTERISTICS

Table 4 summarizes pump test data for City wells for the 1990's. More recent pump tests aren't available. Pumping rates for active City wells ranged from about 650 to 2,000 gpm. Specific capacities of these wells ranged from about 6 to 67 gpm per foot.

Table 5 summarizes recent pump test data for the two CCID wells for 2015-16. Pumping rates ranged from about 1,220 to 1,570 gpm and specific capacities ranged from about 14 to 40 gpm per foot.

Transmissivity was determined based on a nine-hour constant discharge test on City Well No. 5 on January 19, 1999. The average transmissivity based on drawdown and recovery data was 54,000 gpd per foot for strata below the Corcoran Clay. Transmissivity was also determined from a 24-hour pump test on City Well No. 6 during February 8-9, 1999. Recovery measurements indicated a transmissivity of 34,000 gpd per foot for strata above the Corcoran Clay. Specific capacities for wells tapping strata

TABLE 4-PUMP TEST DATA FOR CITY OF GUSTINE WELLS

Well No.	Date Tested	Pumping Rate (gpm)	Static Level (feet)	Pumping Level (feet)	Drawdown (feet)	Specific Capacity (gpm/ft)
4B	9/1/93	900	30.0	154	124	7.3
5	1/99	2,010	34.3	133.2	98.9	20.3
6	2/99	1,060	16.8	199.2	182.4	5.8
7		650				

Data for Well No. 4B from drillers log. Data for Wells No. 5, 6, and 7 from pump tests at end of well development.

TABLE 5-PUMP TEST DATA FOR CCID WELLS

Well No.	Date Tested	Pumping Rate (gpm)	Static Level (feet)	Pumping Level (feet)	Drawdown (feet)	Specific Capacity (gpm/ft)
22	10/15/16	1,568	26.0	65.7	39.7	39.5
57	06/15/15	1,219	69.0	157.0	88.0	13.7

Records from CCID.

above the clay indicate that values for Well No. 6 are less than the average for all of the upper aquifer wells. The transmissivity of the upper aquifer beneath the City can be estimated from specific capacity values. Using an average specific capacity of 50 gpm per foot and a conversion of 1,500, the transmissivity is estimated to be about 75,000 gpd per foot.

Darcy's law can be used to estimate groundwater inflow into the urban depression cone. Darcy's law is the fundamental equation for determining lateral groundwater flow in the aquifer. The flow is equal to the transmissivity times the water-level slope times the width of flow.

$Q = TIL$, where

Q = groundwater inflow (gpd)

I = water-level slope (feet per mile)

L = width of flow (miles).

Darcy's law is applicable in all such evaluations. The water-level map for Spring 2000 was used to determine the gradient because it shows the urban cone of depression. Using a width of flow of about 1.9 miles in Spring 2000, and an average water-level slope of about five feet per mile for the upper aquifer, the amount of inflow above the Corcoran Clay would be about 2,850 acre-feet per year. Additional amounts of groundwater inflow are also available from below the Corcoran Clay, but this can't presently be estimated, due to a lack of water-level measurements for deep wells in the area. The City of Gustine needs to measure static water levels in all City wells in the spring of each year.

PUMPAGE

Table 6 provides a summary of annual pumpage by the City of Gustine, the CCID, and private wells in the study area from 2003-2016. The City pumpage decreased after 2013, associated with water conservation measures undertaken during the drought. The annual pumpage in 2015 was 217 acre-feet less than in 2013, a reduction of about 17 percent. The average pumpage by the City during 2003-11 was about 1,250 acre-feet per year. Annual pumpage from the CCID wells in the study area ranged from 22 acre-feet in 2006 to 2,359 acre-feet in 2018. The average pumpage from these wells during 2003-16 was about 1,610 acre-feet per year. There are also a number of private wells in the study area (Figure 1). CCID provided estimates of pumpage from these wells. Pumpage from private wells ranged from about 40 to 2,658 acre-feet per year during 2003-16. The average pumpage from these wells was about 1,060 acre-feet per year. The average pumpage from all of the wells in the study area was thus about 3,900 acre-feet per year from 2003-16.

TABLE 6-ANNUAL PUMPAGE IN STUDY AREA

Year	Pumpage (Acre-feet per year)		
	City of Gustine Wells	CCID Wells	Private Wells
2003	1,350	1,705	1,216
2004	1,410	2,073	1,321
2005	1,290	502	288
2006	1,330	22	703
2007	1,466	2,206	1,834
2008	1,338	2,359	1,495
2009	1,043	2,149	1,601
2010	1,163	488	490
2011	1,156	896	806
2012	1,260	2,278	51
2013	1,271	2,231	598
2014	1,149	2,039	1,249
2015	1,054	2,003	2,658
2016	1,203	365	521
Average	1,249	1,610	1,060

Values are from City of Gustine and CCID records.

CITY EFFLUENT

There were about 625 acre-feet of City effluent discharged in 2015. About 140 acre-feet per year of this was used to irrigate hay and pasture. The remainder (485 acre-feet per year) percolated or was lost to evaporation from ponds and evapotranspiration from a marsh area. The consumptive use of City effluent is estimated to have been about 80 percent of the amount of effluent, or about 500 acre-feet per year.

CANAL WATER DELIVERIES

Table 7 shows CCID canal water deliveries to 3,600 acres of land in the study area for 2003-16. Canal water deliveries during 2003-2013 ranged from 9,800 acre-feet in 2013 to 13,800 acre-feet in 2013. The average delivery was 11,600 acre-feet per year during 2003-13. CCID canal water deliveries during 2014-16 ranged from 8,700 to 9,300 acre-feet year and averaged 9,000 acre-feet per year, reflective of drought conditions. For the entire period from 2003-16, the CCID average canal water delivery was about 11,000 acre-feet per year.

CONSUMPTIVE USE

Rural

The CCID provided estimates of the evapotranspiration of water applied for irrigation of crops in the study area. For

TABLE 7-CCID CANAL WATER DELIVERIES

Year	Acre-Feet per Year
2003	9,800
2004	11,500
2005	10,000
2006	10,700
2007	12,000
2008	11,800
2009	12,700
2010	10,600
2011	11,100
2012	13,400
2013	13,800
2014	8,900
2015	9,300
2016	8,700

consumptive use of crops, ITRC data for the evapotranspiration of applied water (ET_{IW}) was used for 2003-2008. Total evapotranspiration (ETc) for 2009-16 was based on the ITRC metric report (landsat data). The average ETc for 2003-16 was 10,300 acre-feet per year. The average ratio of ET_{IW} to ETc was 82%. Thus the estimated average ET_{IW} for 2003-16 was 8,450 acre-feet per year.

Urban

The City pumpage from 2003-16 averaged about 1,250 acre-feet per year and the effluent flow was about 625 acre-feet per year. The residual, or outside water use, was thus about 625 acre-feet per year. Assuming an irrigation efficiency of 70 percent, the consumptive use due to outside water use in the City was about 450 acre-feet. Combined with an estimated 500 acre-feet of evapotranspiration of effluent, the total urban consumptive use was 950 acre-feet per year.

Total

The total consumptive use in the study area was about this 8,450 + 950 or 9,400 acre-feet per year. This was about 1,600 feet less than the average canal water deliveries in the study area. This indicates a positive balance in the study area, without considering groundwater flows.

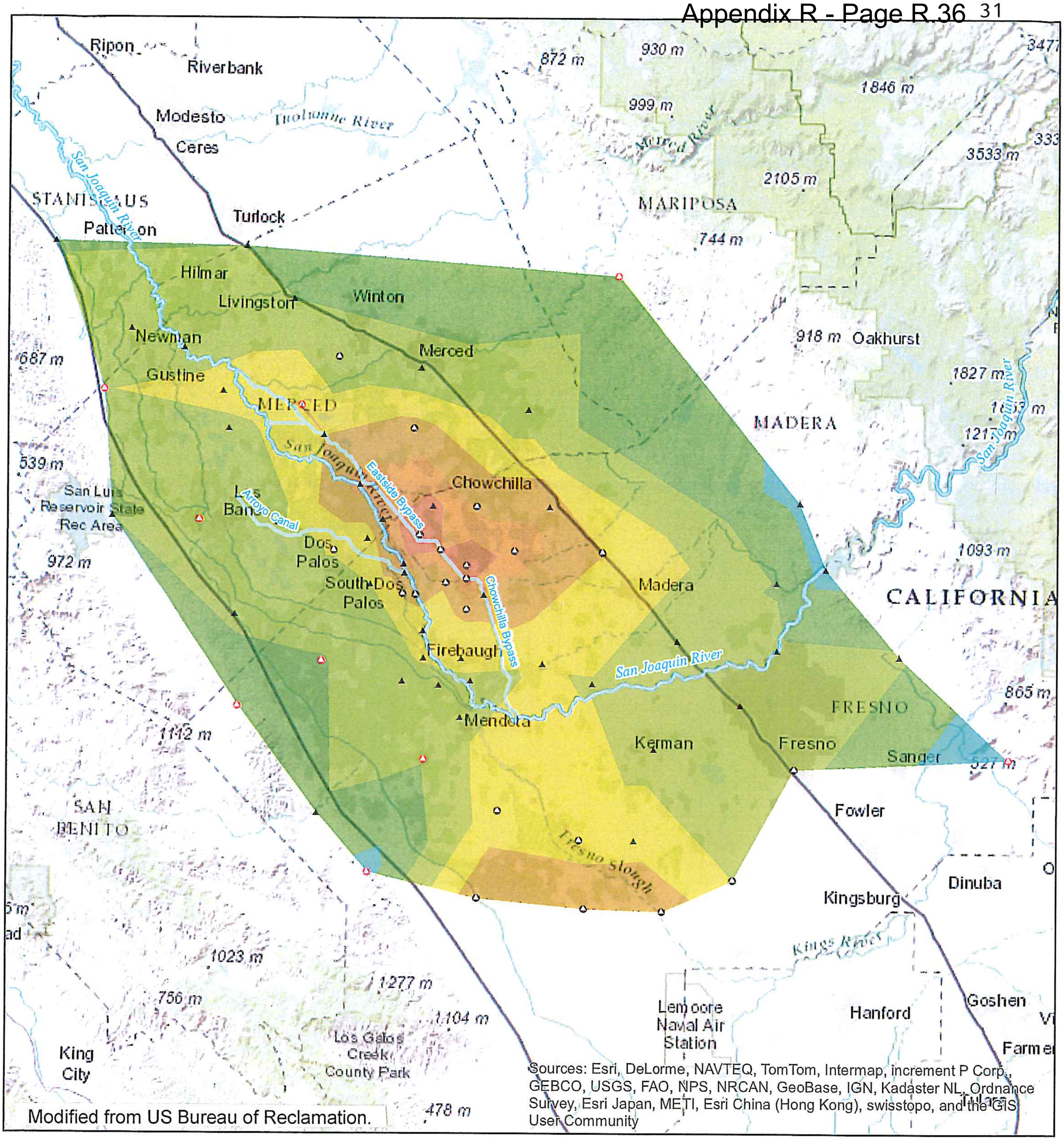
LAND SUBSIDENCE

Measurements at compaction recorders in the San Joaquin Valley have indicated that almost all of the historical land subsidence due to groundwater pumping has come from pumpage from the lower aquifer (below the Corcoran Clay). The nearest compaction recorder to Gustine with long-term records is the Oro Loma or Russell Avenue recorder, located near the Delta-Mendota Canal (DMC) and Russell Avenue. Pumpage from the lower aquifer at and near Gustine is indicated to be small. Most of the City pumpage and all of the CCID pumpage has been from the upper aquifer. Because of the limited pumpage from the lower aquifer in and near the City of Gustine and the lack of long-term water-level declines, land subsidence is expected to be small (less than 0.1 foot per year).

Periodic surveys of land subsidence have been done along the DMC, which is located about three and a half miles west of Gustine. Little subsidence was indicated west of Gustine. Recent (2012-15) measurements of land subsidence are available for the area near and southeast of Gustine from Reclamation (Figure 9). Less than 0.15 foot of subsidence was indicated near Gustine.

CHANGE IN GROUNDWATER STORAGE

Over the long-term, no significant change in groundwater storage is indicated for the study area.



Subsidence Rates (feet/year)
July12 to July15-Free
July 2012 to July 2015

- 0.15 to 0.3
- 0 to 0.15
- -0.15 to 0
- -0.3 to -0.15
- -0.45 to -0.3
- -0.6 to -0.45
- -0.75 to -0.6
- -0.9 to -0.75

GPS Coordinates

- GPS Point-December 2011
- GPS Point-added July 2012
- GPS Point-added December 2013

N

RECLAMATION
Managing Water in the West

FIGURE 9-RECENT LAND SUBSIDENCE

0 7 14 21 Miles

Subsidence rates calculated by comparing survey values a
GPS Stations for the dates specified in the legend.

GROUNDWATER QUALITY

City Wells

Table 8 contains the result of recent inorganic chemical analyses of water from the four active City of Gustine wells. Total dissolved solids (TDS) concentrations in water from these wells ranged from 621 mg/l to 840 mg/l in 2016-17. The highest TDS concentration was in water from Well No. 6. Nitrate concentrations in water from these wells ranged from 15 to 42 mg/l, below the MCL of 45 mg/l. The highest nitrate concentration was in water from Well No. 6, which is the most northeasterly upper aquifer City well. Nitrate concentrations in water from this well ranged from 2 to 42 mg/l during 2011-15. The lowest nitrate concentration was in water from Well No. 5, which taps the lower aquifer. Concentrations of iron, manganese, arsenic, fluoride, and selenium in water from the active City wells were below the respective MCLs.

The highest manganese concentrations were in water from Well No. 5. Manganese concentrations in water from this well were variable between 1999 and 2017, but were frequently between 0.02 and 0.03 mg/l, less than the secondary MCL of 0.05 mg/l.

The hexavalent chromium concentration in water from Well No. 5 was 2 ppb, less than the MCL of 10 ppb. This well taps the lower aquifer. Hexavalent chromium concentrations in water from

TABLE 8- CHEMICAL QUALITY OF WATER FROM CITY OF GUSTINE WELLS

Constituent (mg/l)	No. 4B	No. 5	No. 6	No. 7
Calcium	58	60	110	131
Magnesium	26	31	46	35
Sodium	73	240	110	80
Potassium	3	2	2	2
Bicarbonate	315	317	342	378
Sulfate	110	200	156	127
Chloride	98	270	180	118
Nitrate	21	15	42	18
Fluoride	<0.1	0.2	0.2	0.1
pH	7.4	7.3	7.8	7.2
Electrical Conductivity (micromhos/cm @ 25°C)	945	1,100	1,300	1,043
Total Dissolved Solids (@ 180°C)	621	660	840	716
Iron	<0.1	<0.1	<0.1	<0.1
Manganese	<0.02	<0.02	<0.02	<0.02
Arsenic (ppb)	<2	<2	<2	<2
Hexavalent Chromium (ppb)	8.3	2	9.6	9.7
Selenium (ppb)	<5	7.3	<5	<5
Alpha Activity (picocuries/l)	8	3	<3	<3
Date	7/13/16	10/8/14	10/8/14	1/9/14
Perforated Interval (feet)	167-200	370-400 410-444	145-165 190-230	165-194

Samples for analysis of hexavalent chromium were collected between 8/10/14 and 10/15/14. Samples for analysis of alpha activity were collected between 10/8/14 and 10/15/14 the other wells were much higher (8.3 to 9.7 ppb), and in water from Wells No. 6 and 7 were near the MCL of 10 ppb.

Alpha activities were determined in water from the active City wells in February 2014. Values ranged from less than 3 to 8 picocuries per liter, below the MCL of 15 picocuries per liter.

Samples of water collected from the active City of Gustine wells in December 2016 were analyzed for numerous trace organic chemical constituents. No trace organic chemical constituent problem was indicated for these wells.

CCID Wells

Table 9 provides the results of inorganic chemical analyses of water from CCID Wells No. 22B and 57 for samples collected in July 2017. TDS concentrations ranged from 820 to 950 mg/l and the waters were of the mixed calcium bicarbonate-chloride or bicarbonate types. Nitrate concentrations ranged from 10 to 15 mg/l, less than the MCL of 45 mg/l for public water supplies. Boron concentrations ranged from about 0.4 to 0.5 mg/l, suitable for irrigation of most crops.

HISTORICAL WATER BUDGET

CCID canal water deliveries to 3,600 acres of crops in the study area averaged 11,000 acre-feet per year during 2003-16. The estimated average urban and rural consumptive use for the

TABLE 9- CHEMICAL QUALITY OF WATER FROM CCID WELLS

Constituent (mg/l)	Well No. 22B	Well No. 57
Calcium	75	120
Magnesium	46	50
Sodium	100	120
Potassium	3	<1
Bicarbonate	380	330
Sulfate	99	170
Chloride	130	180
Nitrate	15	10
pH	7.6	7.7
Electrical Conductivity (micromhos/cm @ 25°C)	1,400	1,500
Total Dissolved Solids (@ 180°C)	820	950
Boron	0.38	0.51
Date	7/25/17	7/25/17
Perforate Interval (feet)	60-190	70-190

Chemical analyses by BSK Associates.

period was 9,400 acre-feet per year. There was an estimated canal seepage of 1,100 acre-feet per year from a 2.5-mile long reach of the Main Canal (average of 0.68 cfs for 330 days a year). There was an estimated 1,600 acre-feet per year of deep percolation from irrigated crops in the CCID (11,000 minus 9,400 acre-feet per year). The amount of groundwater inflow above the Corcoran Clay was previously estimated to be about 2,850 acre-feet per year. The average deep percolation from urban irrigation is estimated to have been about (625 minus 450 acre-feet per year, or about 175 acre-feet per year. The pond seepage and deep percolation associated with City effluent averaged 20 percent of the effluent amount, or about 125 acre-feet per year.

The total recharge (excluding groundwater inflow below the Corcoran Clay) thus averaged about 5,950 acre-feet per year for 2003-16. The average pumpage in the study area was about 3,900 acre-feet per year for 2003-16. There was no significant change in groundwater storage in the study area during 2003-20016. The difference between 5,850 and 3,900, or 1,950 acre-feet per year, was made up by the groundwater outflow above the Corcoran Clay and the difference between the groundwater inflow and outflow below the Corcoran Clay.

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Appendix S. Hydrogeologic Conceptual Model, Groundwater Conditions, and Water Budget for the City of Los Banos GSA

HYDROGEOLOGIC CONCEPTUAL MODEL, GROUNDWATER CONDITIONS, AND WATER BUDGET FOR THE CITY OF LOS BANOS GSA

prepared for
Central California Irrigation District
City of Los Banos
Grassland W.D.
San Joaquin River Exchange Contractors
Water Authority
San Luis Water District
Los Banos, California

by
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June 2019

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June 11, 2019

Mr. Chris White, General Manager
Central California Irrigation District
P.O. Box 1231
Los Banos, CA 93635

Re: City of Los Banos GSA

Dear Chris:

Submitted herewith is our hydrogeologic report on the City of Los Banos GSA. We appreciate the cooperation of the City of Los Banos, CCID, Grassland Water District, and San Luis Water District in providing information for this report.

Sincerely yours,

Kenneth D. Schmidt
Geologist No. 1578
Certified Hydrogeologist
No. 176

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HYDROGEOLOGIC CONCEPTUAL MODEL, GROUNDWATER CONDITIONS, AND WATER BUDGET FOR THE CITY OF LOS BANOS GSA

INTRODUCTION

This report is intended to satisfy Sections 354.14 (Hydrologic Conceptual Model), Section 354.16 (Groundwater Conditions), and Section 354.18 (Water Budget) of a Groundwater Sustainability Plan (GSP) for the City of Los Banos Study Area. This area includes a study area previously developed for an evaluation of the City of Los Banos groundwater conditions. This area extends beyond the City Urban Growth boundary, and includes an upgradient area termed the Los Banos Subarea (Figure 1). The area includes lands in the City, the Central California Irrigation District (CCID), the Grassland Water District (GWD), the San Luis Water District (SLWD), and in white areas of Merced County.

The City of Los Banos is an expanding urban area that relies entirely on groundwater. Hexavalent chromium concentrations in water from City wells exceed the proposed maximum contaminant level (MCL), of 10 parts per billion (ppb). Also, there are concerns about this supply in terms of adequacy for future growth. This evaluation is the result of a cooperative effort between the CCID, the San Joaquin River Exchange Contractors Water Authority, the City of Los Banos, the GWD, and the SLWD to further evaluate the sustainable groundwater supply for the urban area and adjacent areas. There are three districts that provide water to the rural part of the study area. The CCID extends from near Mendota northward to near Crows Landing,

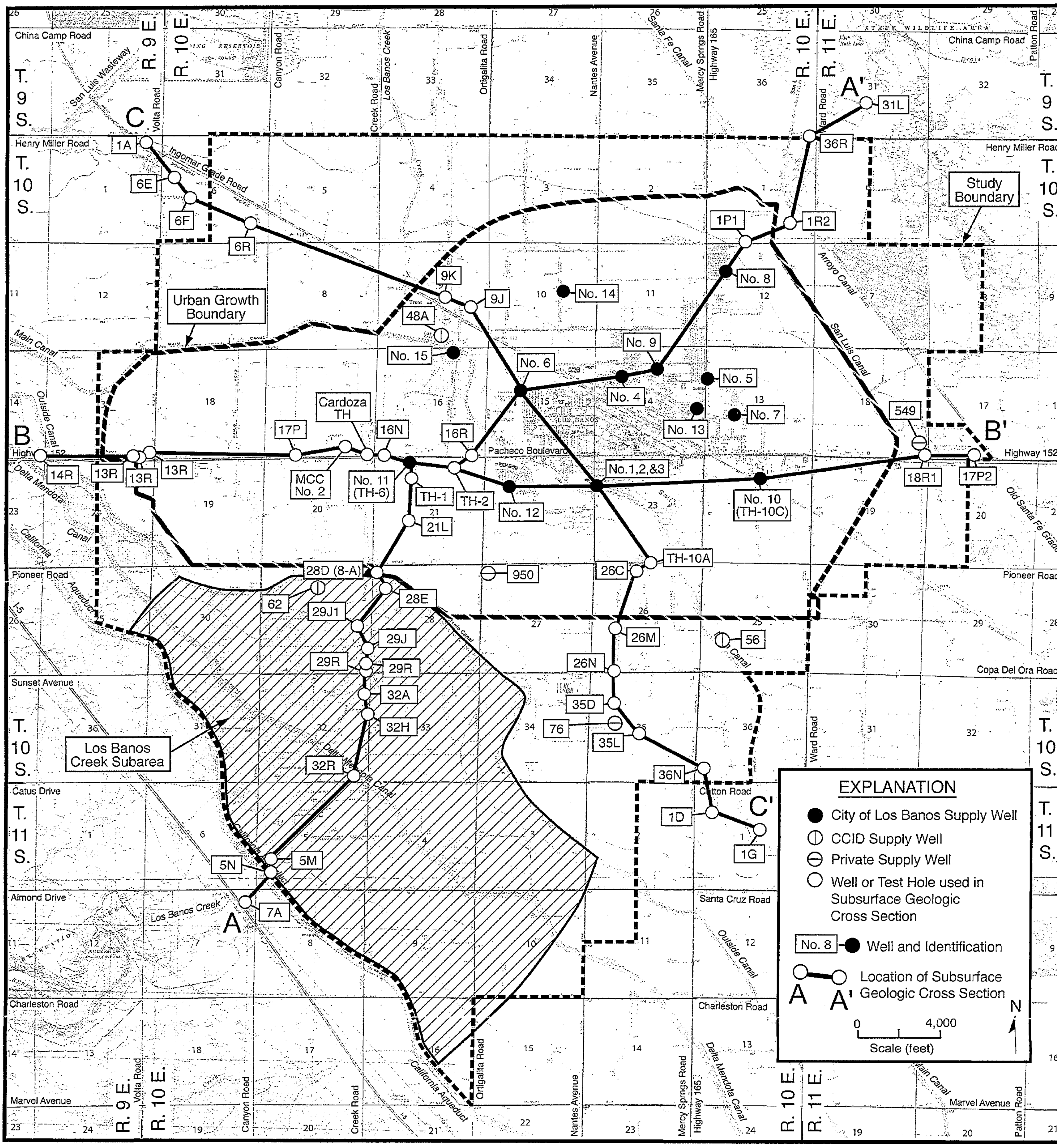


FIGURE 1 - TOPOGRAPHIC MAP OF STUDY AREA AND LOCATION OF SUBSURFACE GEOLOGIC CROSS SECTIONS

and surrounds a number of urban areas, including the City of Los Banos. Both District (CCID) and private wells are used in the CCID to supplement San Joaquin River water and imported water from the Delta Mendota Canal (DMC) that is used for crop irrigation. The GWD has two divisions, one essentially north of Highway 152 and the other south of this highway. The GWD supplies imported water from the DMC to numerous duck clubs. The CCID wheels water through its facilities to the GWD. The SLWD extends from near Santa Nella south to south of Little Panoche Creek and delivers water from the California Aqueduct and DMC. Private wells are used to supplement this water for irrigation in the part of the District near Los Banos.

Part of this study is an update of three earlier hydrogeologic evaluations prepared by Kenneth D. Schmidt and Associates (KDSA). The first two were for the CCID and City in 1991 and in 1998. The third evaluation was done in 2010 for the CCID, City of Los Banos, and U.S. Bureau of Reclamation. The latter report also focused on water transfers in the area upgradient (southwest) of the City.

Information on regional groundwater conditions in the vicinity was provided by Hotchkiss and Balding (1971), Swanson (1990), and KDSA (1997). The latter of these references described a detailed evaluation of the groundwater conditions in the CCID.

The study area for this evaluation includes lands within the City of Los Banos Urban Growth Boundary (UGB), upgradient lands to the southwest, and adjacent lands to the northeast in the GWD. In the 2010 evaluation, the Los Banos Creek subarea was delineated. This subarea is primarily outside of the CCID and up-gradient of the City (Figure 1). Groundwater pumpage from private irrigation wells in this subarea provides most of the water supply, and this subarea has experienced significant water-level declines during dry periods. Due to the upsloping topography and thinner alluvium to the southwest, changes in groundwater elevation are amplified within the western part of this area. Historically, minor amounts of groundwater have been transferred out of this subarea.

SURFICIAL CHARACTERISTICS OF THE LOS BANOS STUDY AREA

Topography

Figure 1 shows the topography of the study area. Lands south-west of Interstate 5 (I-5) are primarily in the foothills of the east edge of the Coast Range. Lands in and southwest of Los Banos and east of I-5 are on the alluvial fan of Los Banos Creek. Land surface elevations range from about 220 feet above mean sea level near I-5 to less than 100 feet above sea level near the northeast edge of the area. Lands slope gently in the northeast in the GSA.

Surficial Geology

Figure 2 is a surficial geologic map, modified from the California Division of Mines, San Jose Sheet (Rogers, 1966). Three types of alluvial deposits are shown. The older deposits are to the southwest near I-5 and are termed the Pleistocene non-marine (Qc). The deposits near

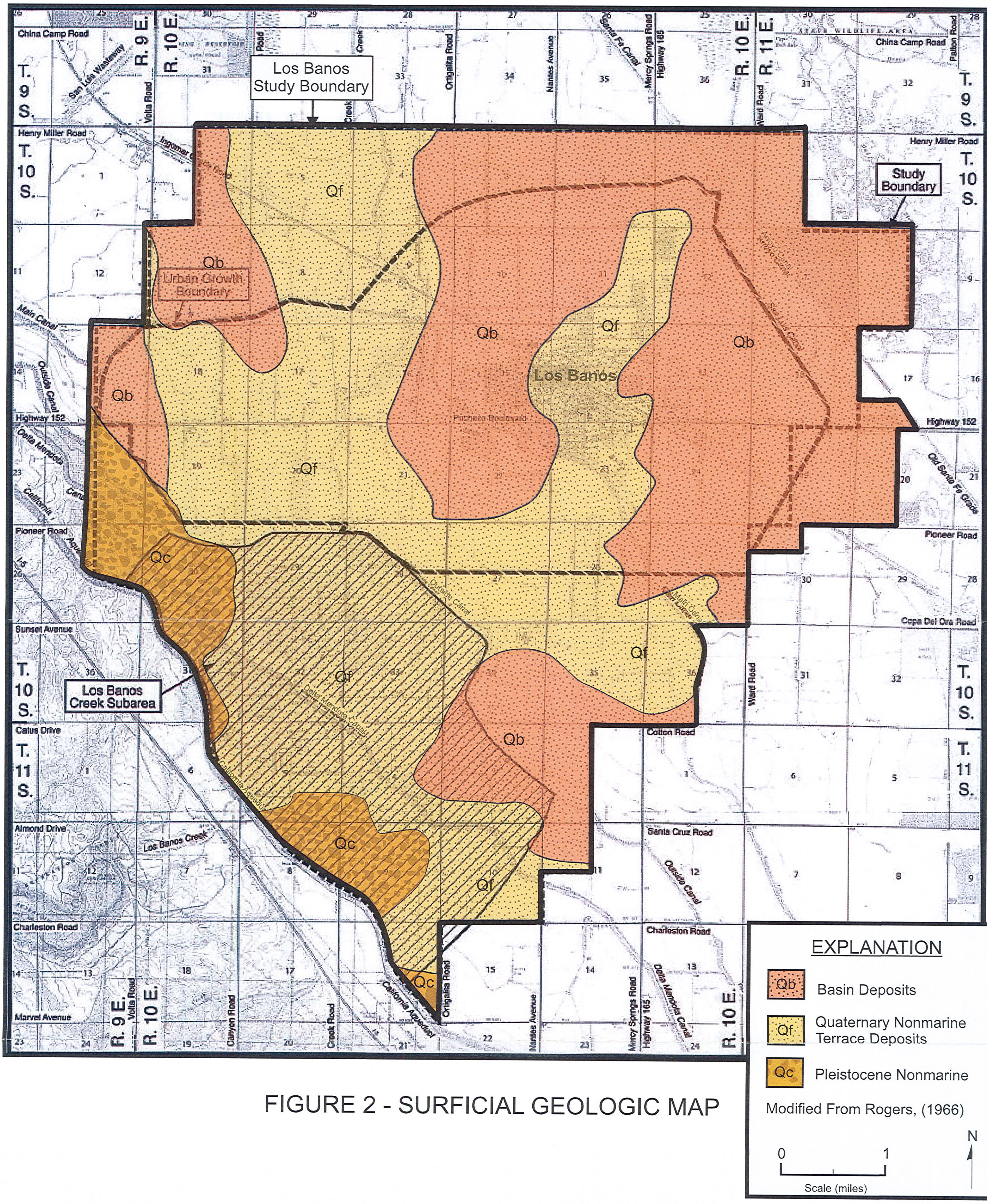


FIGURE 2 - SURFICIAL GEOLOGIC MAP

Los Banos Creek and its alluvial fan are termed Quaternary non-marine terrace (Qf). The deposits away from the creek are termed basin (Qb).

Topsoils

Figure 3 shows the major types of topsoils in the area. The U.S. Soils Conservation Service map of soils in the Los Banos area (Cole, 1952) was modified. The topsoils have been grouped into: 1) coarse-grained (sand), 2) fine-grained (clay and silty clay), and 3) intermediate texture (sand clay and clayey sand). Coarse-grained soils are limited to along Los Banos Creek, south of Sunset Avenue. The fine-grained soils are predominant in the rest of the area. Intermediate topsoils are present both to the northwest and southeast of the coarse-grained soils, and along Los Banos Creek in the area north of Highway 152. They are also present south and southeast of Los Banos.

Surface Water Bodies

Figure 4 shows surface water bodies in the area. Los Banos Creek passes through the area from the southwest near the California Aqueduct to the north at the Henry Miller Road crossing. The Los Banos Creek Detention Reservoir is located upstream and to the southwest of the area. The California Aqueduct, DMC, and CCID Main and Outside Canals are all southwest of Los Banos. The Arroyo Canal (Santa Fe Canal), Mud Slough, and former San Luis Drain are northeast of Los Banos. Extensive water bodies are

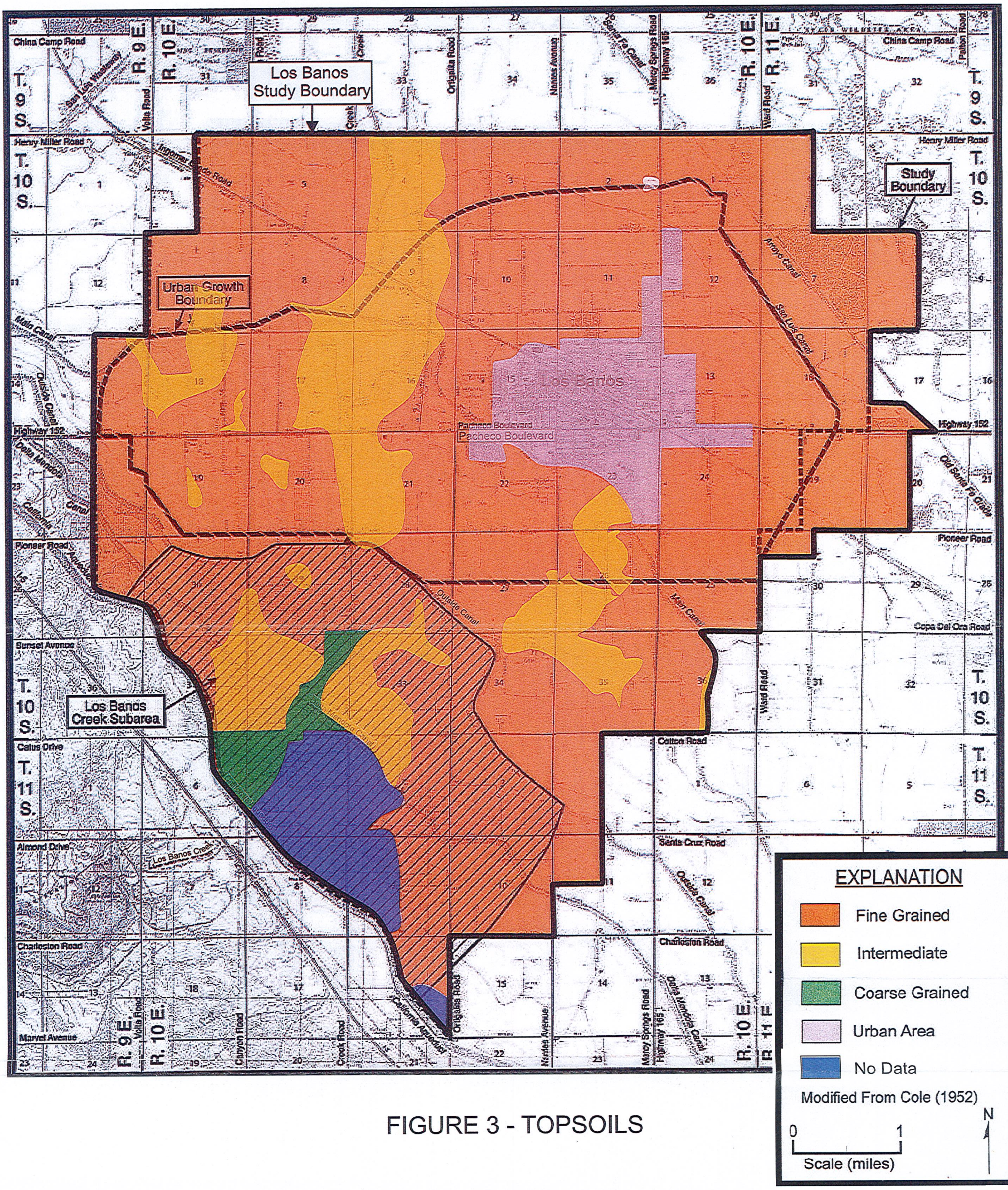


FIGURE 3 - TOPSOILS

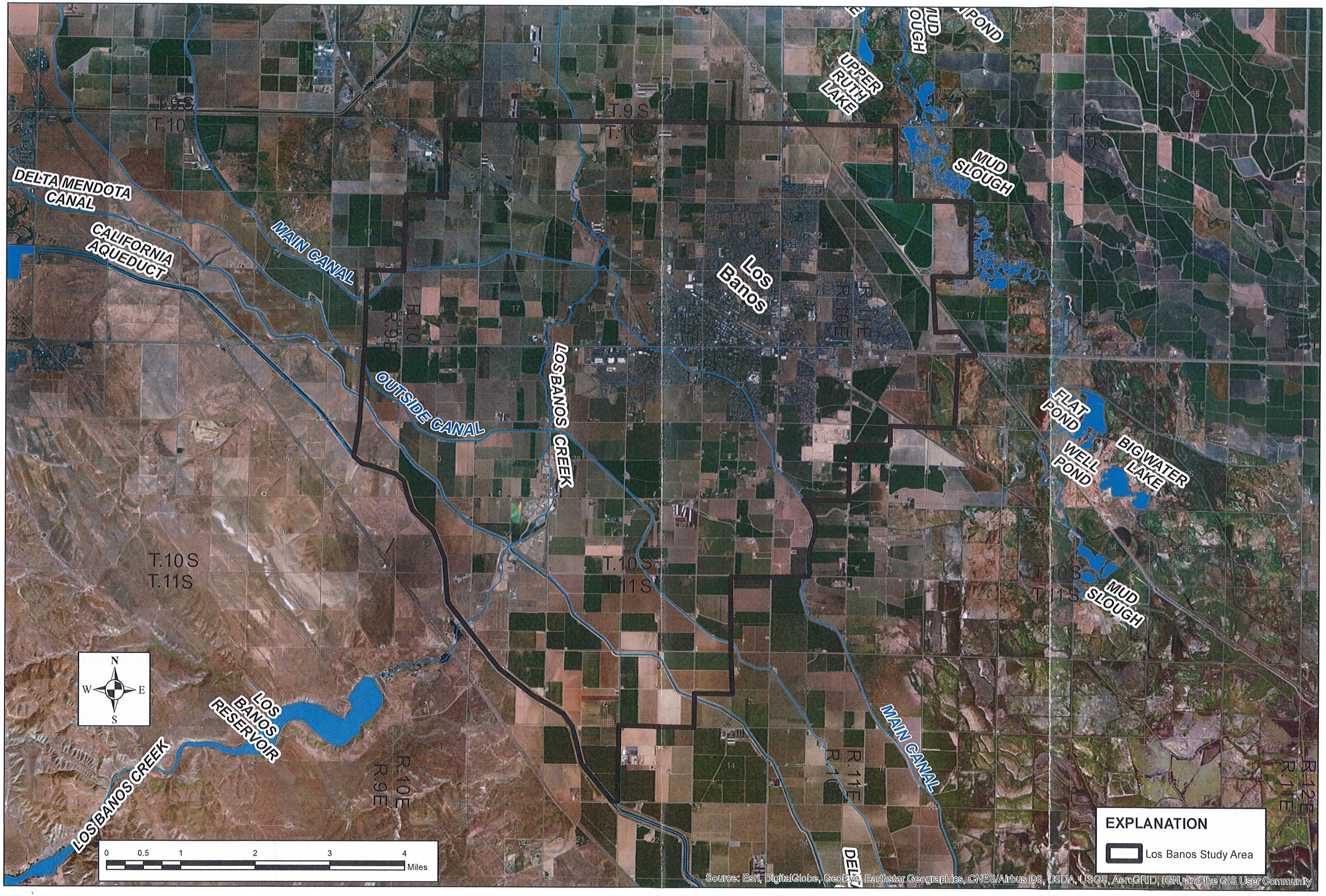


FIGURE 4 - SURFACE WATER BODIES

created seasonally in the GWD for duck clubs.

SUBSURFACE GEOLOGIC CONDITIONS

Regional Geologic and Structural Setting

The GSA is within west part of the San Joaquin Valley, which is a topographic and structural trough bounded on the east by the Sierra Nevada fault block and on the west by the folded and faulted Coast Ranges. Both mountains blocks have contributed to marine and continental deposits in the Valley. In the west-central part of the valley, more than 12,000 feet of sediments are present. In the Los Banos vicinity, groundwater is present in alluvial deposits that dip slightly toward the trough of the valley (the San Joaquin River).

Lateral Basin Boundaries

Figure 5 shows the study area boundaries and various GSAs. The north, west, and south boundaries of the study area were determined for the 2010 cooperative study of the Los Banos Area by KDSA. The northeast boundary was subsequently extended to cover additional land in part of the GWD. This Los Banos GSA is located within the San Luis-Delta Mendota Sub-basin. Land of the southwest in the study area (green color) are in the San Luis Water District. Lands in the area west and south of Los Banos Area are in the CCID (yellow color) and in the SJREC GSA boundary. White areas near Los Banos, particularly to the northwest and southeast (blue in color) are

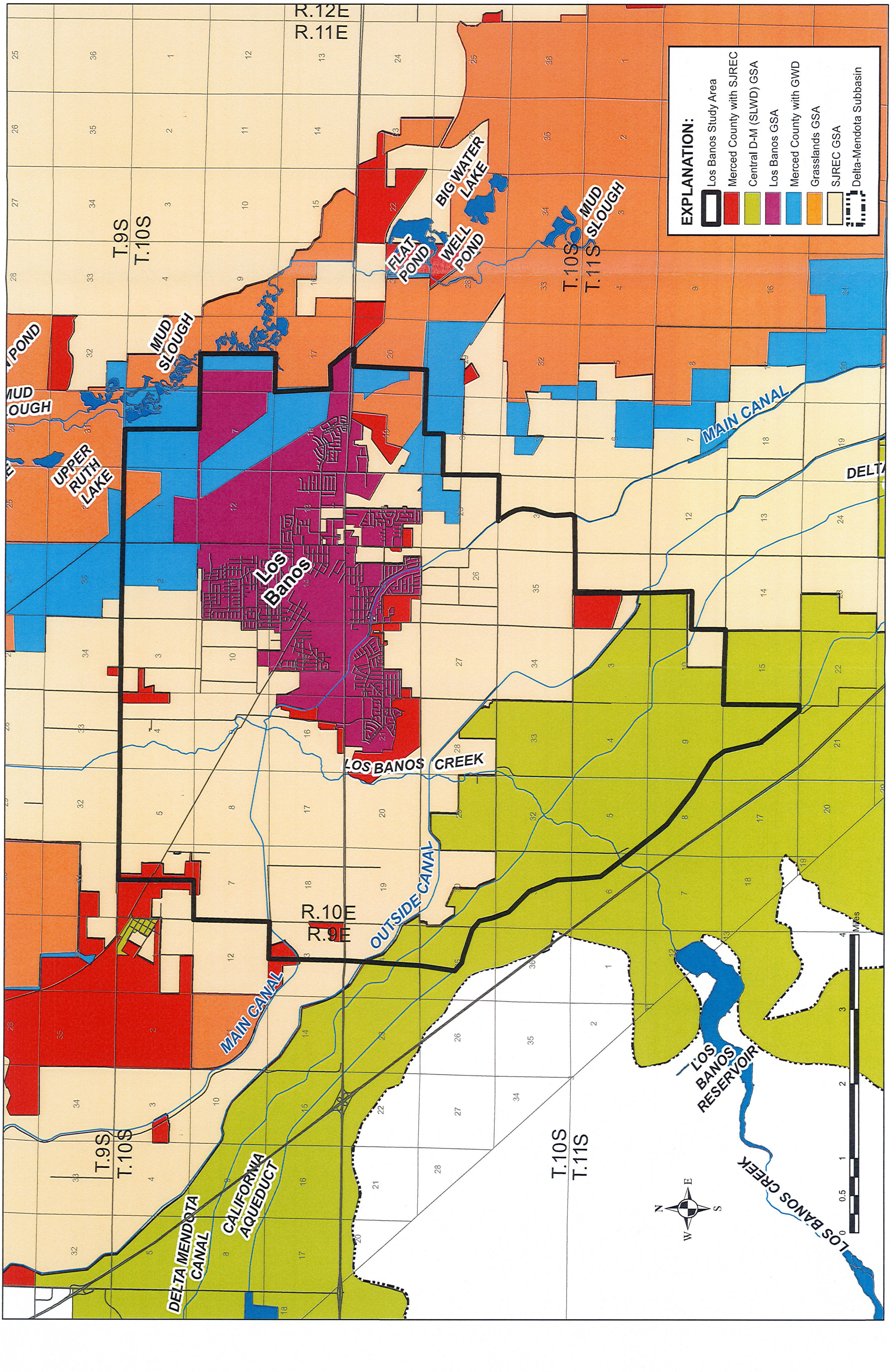


FIGURE 5 - LOCATION OF VARIOUS GSA's

in the Merced County GSA.

Definable Bottom of the Basin

Figure 6 shows the definable bottom of the area. Historically, the U.S. Geological Survey (Page, 1973) used an electrical conductivity of 3,000 micromhos per centimeter at 25°C to delineate the regional base of the fresh groundwater in the San Joaquin Valley. The underlying groundwater is termed "connate water" and is of higher salinity. Page indicated that the base of the fresh groundwater ranged from about 600 to 800 feet deep in most of the area. As part of this evaluation, electric logs for a number of deep holes were obtained from the California Division of Oil, Gas, & Geothermal Resources and interpreted to determine the bottom of the basin in more detail. The bottom of the basin in the area ranges from about 500 to 800 feet deep, and is generally deeper beneath Los Banos and the central part of the area.

Formation Names

Hotchkiss and Balding (1971) divided the unconsolidated deposits in the Tracy-Dos Palos area (west of the San Joaquin River) into flood basin deposits (normally less than 50 feet thick), Quaternary alluvium (usually less than 200 feet thick), and the Tulare Formation (up to almost 1,000 feet thick). The

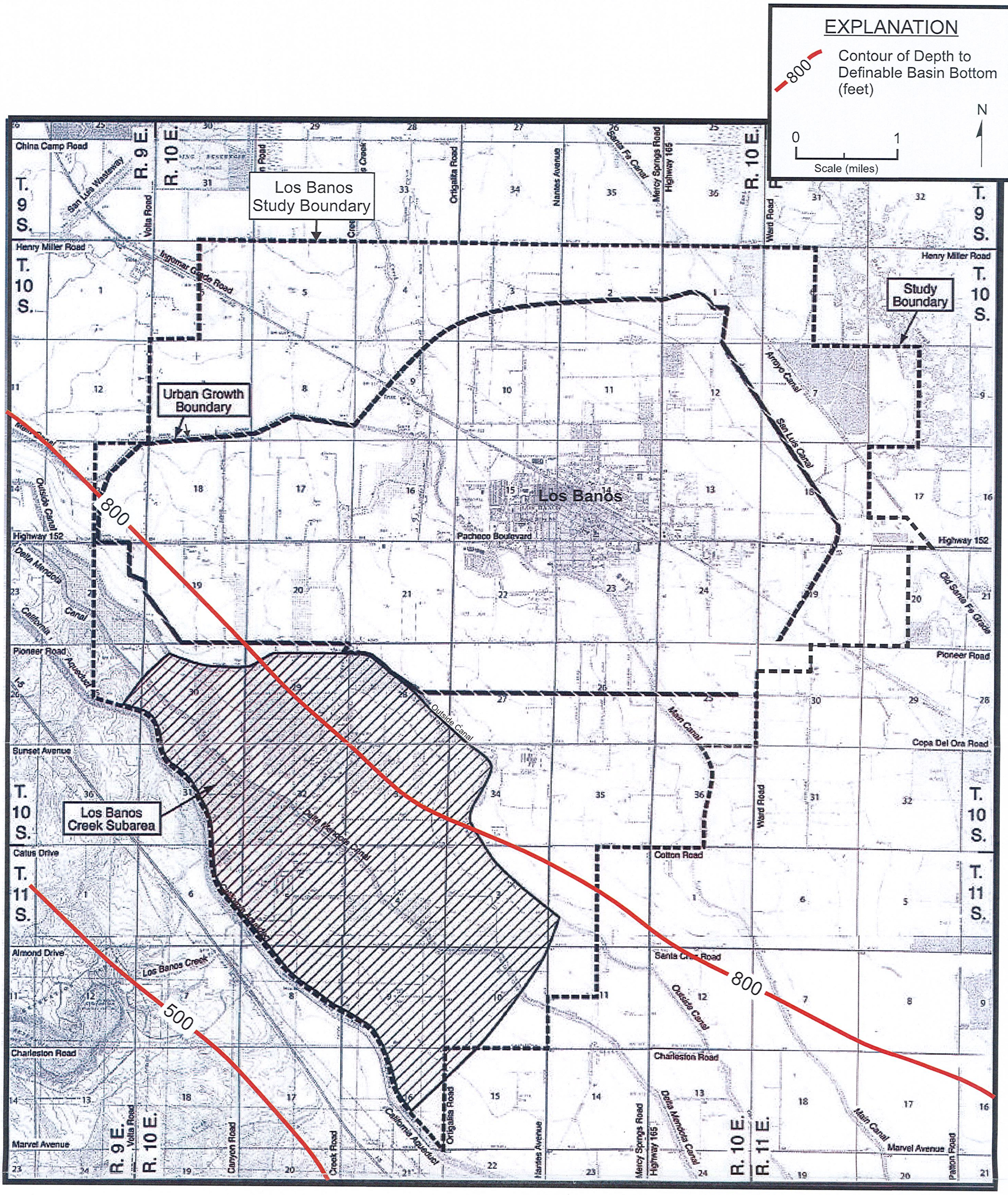


FIGURE 6 - DEFINABLE BOTTOM OF BASIN

Tulare Formation has an upper, thinner section which is above the Corcoran Clay, and a thicker, lower section below the clay. The Corcoran Clay is a regional confining bed, which divides the groundwater into an upper aquifer and lower aquifer. Deposits in most of the area are generally tan in color and are termed the Diablo Range deposits. These deposits are shown on several subsurface geologic cross sections that are presented later in this report.

Confining Beds

There is only one confining bed that is important beneath the area: the Corcoran Clay (also termed the E-Clay). Figure 7 shows the depth to the top of the Corcoran Clay, which was mapped by KDSA (1997a). The Corcoran Clay has been deformed since its deposition. The top of the clay in the area is shallowest (about 50 feet deep) near I-5 and deepest (about 300 feet) near Los Banos. The Corcoran Clay thickens to the northeast in the area. The clay is about 40 feet thick near the California Aqueduct and about 120 feet thick near the northeast edge of the area.

Principal Aquifers

The principal aquifer tapped by most wells in the area is the upper aquifer (above the Corcoran Clay). A secondary aquifer is the lower aquifer (below the Corcoran Clay). One City well,

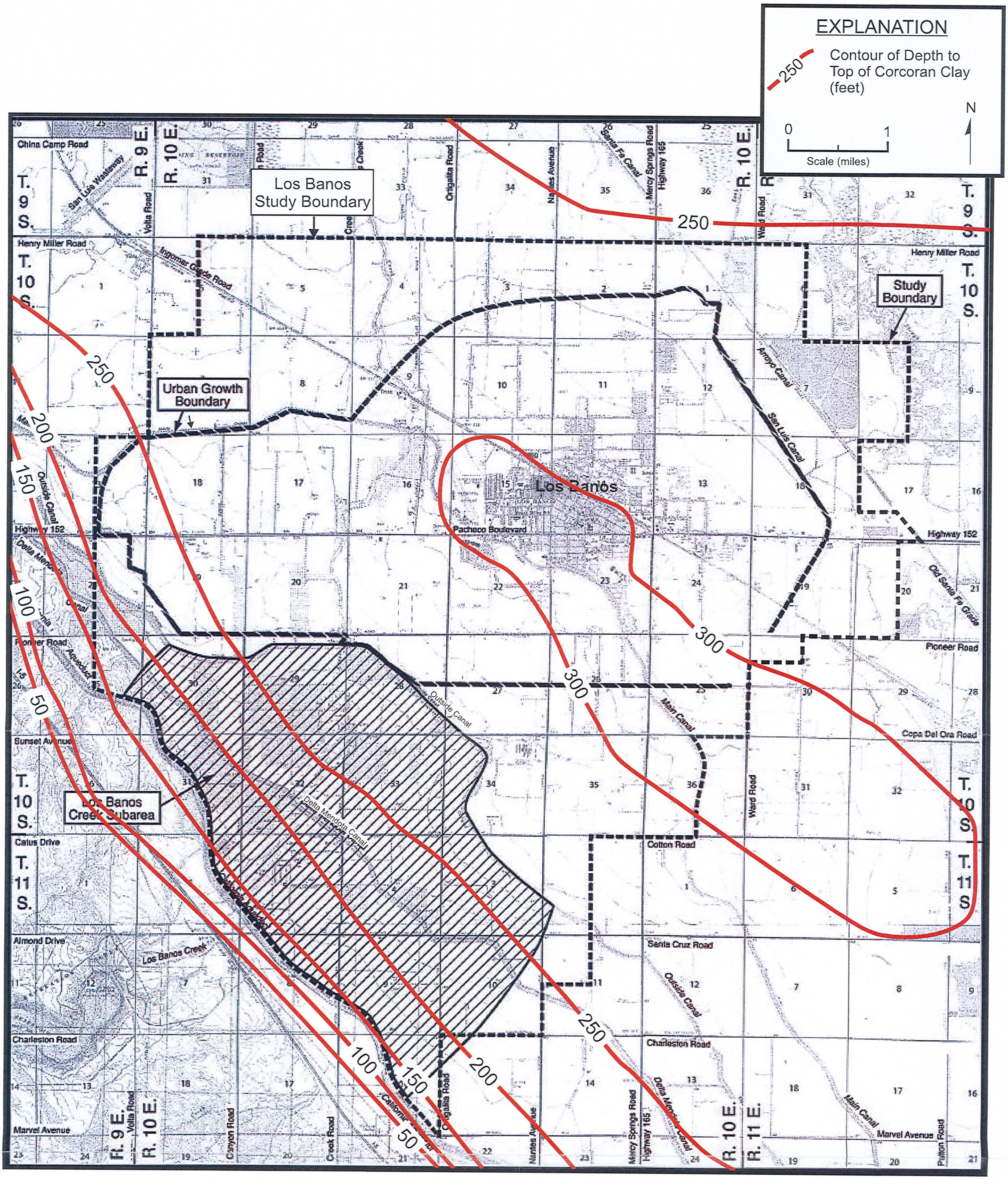


FIGURE 7 - DEPTH TO TOP OF CORCORAN CLAY

one CCID well, and a number of private irrigation wells in the study area tap the lower aquifer.

Subsurface Geologic Cross Sections

Figure 1 shows the locations of wells and test holes for which geologic information is available, and the locations of these cross sections. Besides electric logs, drillers logs for water wells were obtained from the California Department of Water Resources (DWR) in Fresno for use in developing these cross sections. Non City wells are identified by their 40-acre designation in a section, following the convention of the U.S. Geological Survey.

Subsurface Geologic Cross Section A-A' (Figure 8) extends from near I-5 on the southwest to near Henry Miller Avenue and Ward Road on the northeast. This section generally extends along the inferred dip of the alluvial deposits (to the northeast). Electric logs are available for six wells or test holes along this section. Included are a 710-foot deep test hole that was drilled near City Well No. 4, a 425-foot deep test hole that was drilled near Well No. 8, Well No. 9, which is 300 feet deep, and a 528-foot deep test hole drilled near Well No. 11. Drillers logs are available for the remaining wells along this section. Twenty-two of the wells or test holes along this section appear to have reach the top of the Corcoran Clay. The top of this clay ranges from about 60 feet deep near Well 5N to about

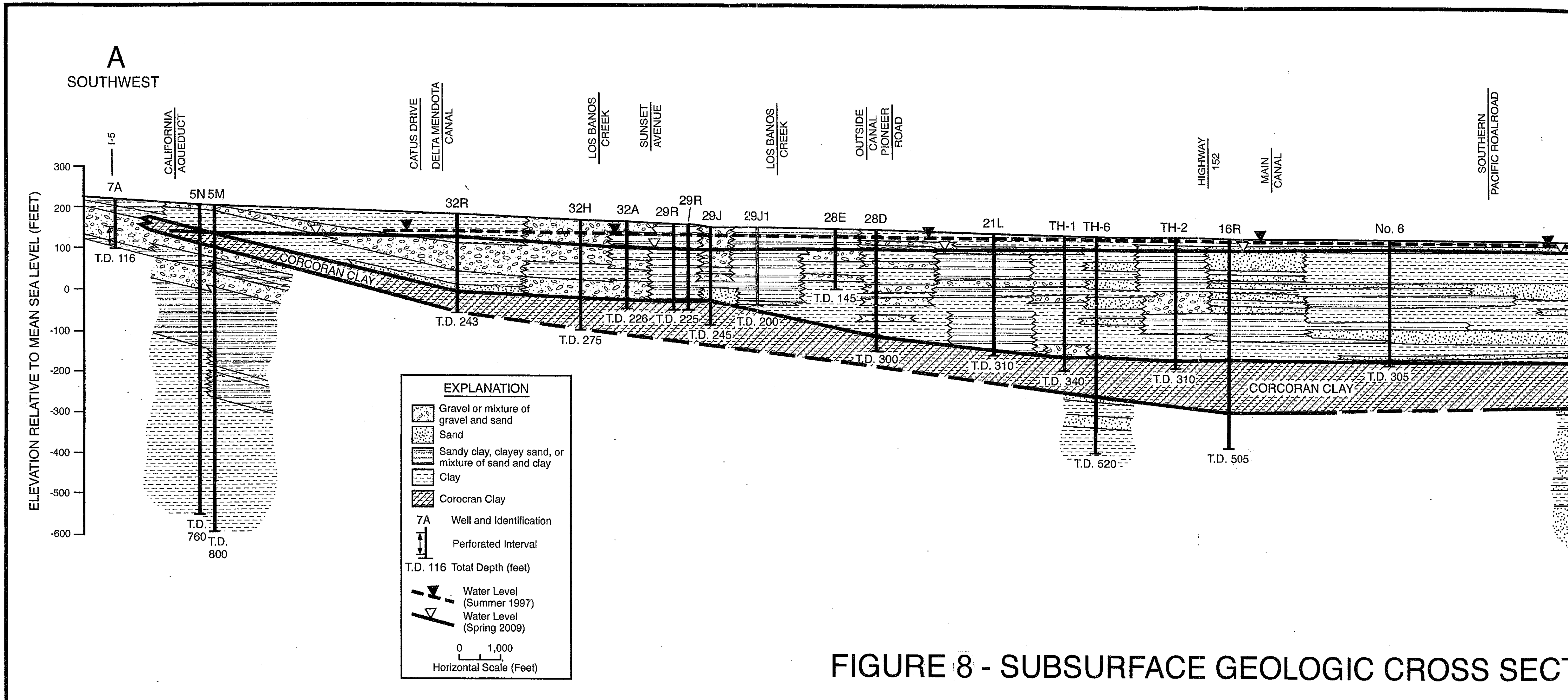
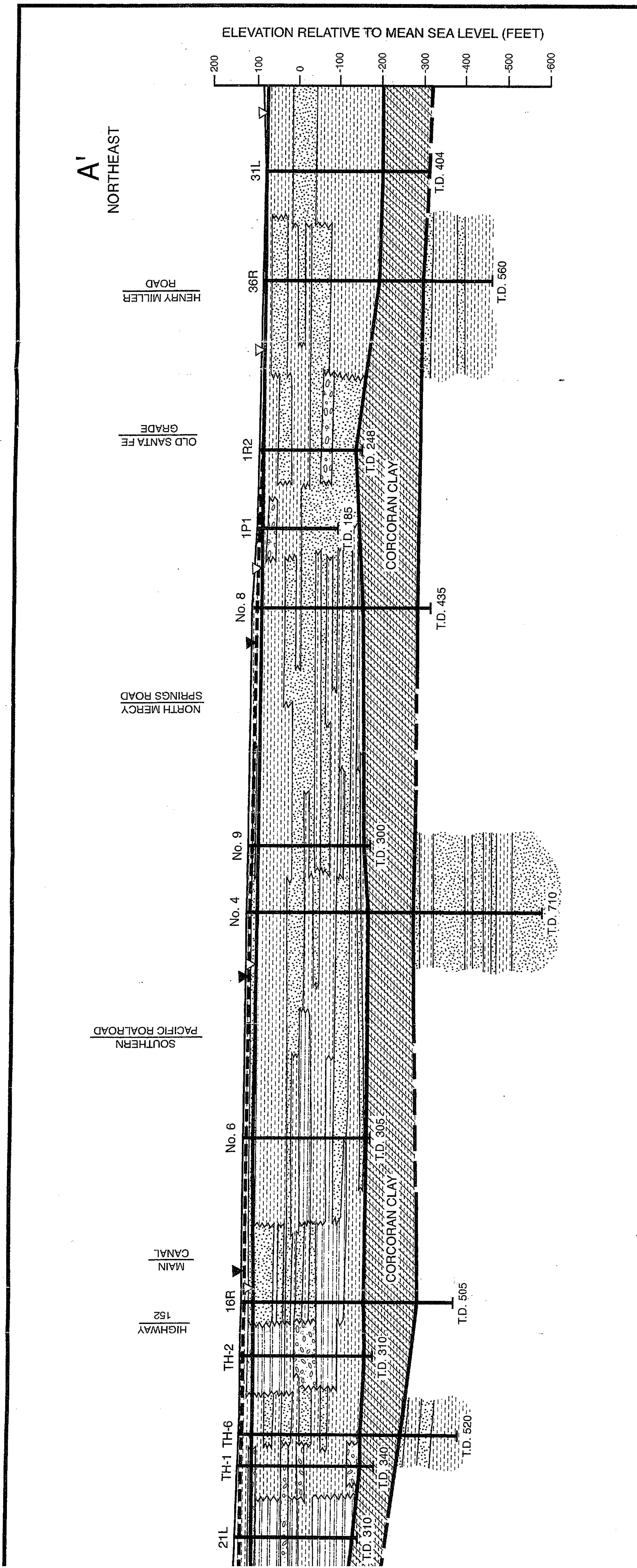


FIGURE 8 - SUBSURFACE GEOLOGIC CROSS SECT



- SUBSURFACE GEOLOGIC CROSS SECTION A - A' about 310 feet at Well 31L. The test holes near City Wells No. 4, 8, and 11 and Wells 5M, 16R, and 36R penetrated the base of the Corcoran Clay. The Corcoran Clay is about 90 feet thick near City Well No. 11, 110 feet thick near Well No. 4, and almost 130 feet thick near Well No. 8. The clay thins toward the southwest along this section and apparently pinches out between I-5 and the California Aqueduct.

Sand and gravel layers are more common in the upper aquifer beneath the southwest part of the study area (i.e., at Wells 32H and 32R). The permeable strata tapped by most City Wells are primarily in the interval between 100 and 300 feet in depth. City Wells No. 4, 9, 8, and 11 all appear to tap a laterally extensive coarse-grained layer about forty feet thick, the top of which is about 100 feet deep. Another a really extensive coarse-grained layer appears to be present at a depth of about 220 to 230 feet along the central part of this cross section. This layer ranges from about 10 to 20 feet in thickness. A coarse-grained layer about ten feet thick and just above the Corcoran Clay is fairly extensive along this section. Fine-grained strata are more predominant to the northeast along this section (i.e. Wells 31L and 36R).

The base of the Corcoran Clay is 415 feet deep at Well T10S/R10E-16R, 402 feet deep near City Wells No. 4 and 11, and 394 feet deep near City Well No. 8. Thick coarse-grained, permeable deposits are present below the Corcoran Clay near City Well No. 4 to a depth of 710 feet. More than 200 feet of such deposits are present below the Corcoran Clay at this location. City Well No. 11 encountered three permeable layers between 407 and 514 feet in depth, totaling about 60 feet in thickness. Well 5M encountered several sand and gravel layers below the Corcoran Clay.

Subsurface Geologic Cross Section B-B′ (Figure 9) extends from the west, near Highway 52 and the Outside Canal, generally along Highway 152 to the east near the Old Santa Fe Grade. The strata along the Corcoran Clay are predominantly clay along the part of the section west of Los Banos Creek. Between the creek and Ortigalita Road, interbedded coarse-grained strata are more common, including stream channel deposits (coarser than sand). Clay strata are predominant above the Corcoran Clay beneath much of the City. However, the relatively thin interbedded coarse-grained strata at some locations produce adequate amounts of water for City wells. Sand strata above the Corcoran Clay thicken to the east along this section, particularly east of Mercy Springs Road. A number of coarse-grained stream channel deposits were encountered at City Well No. 1, near Center Avenue.

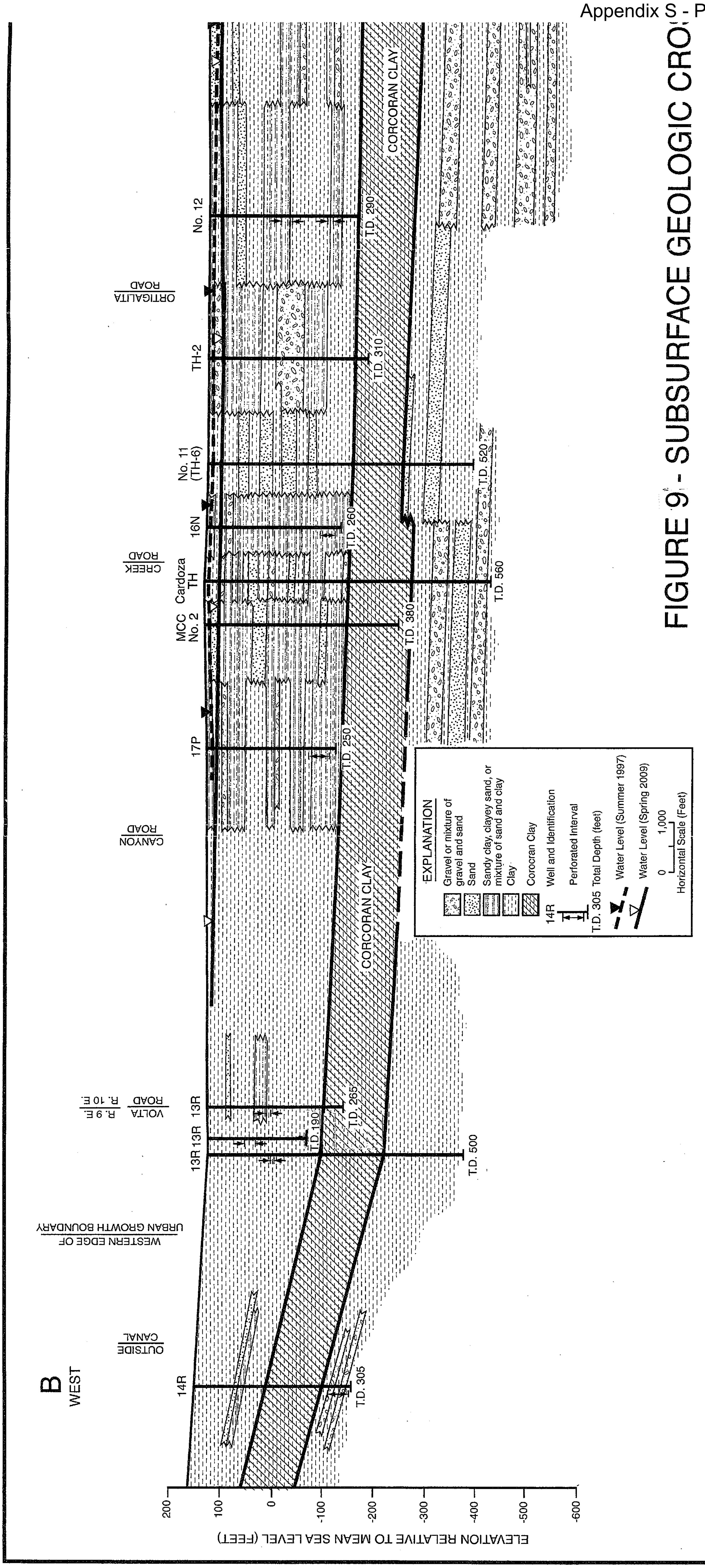
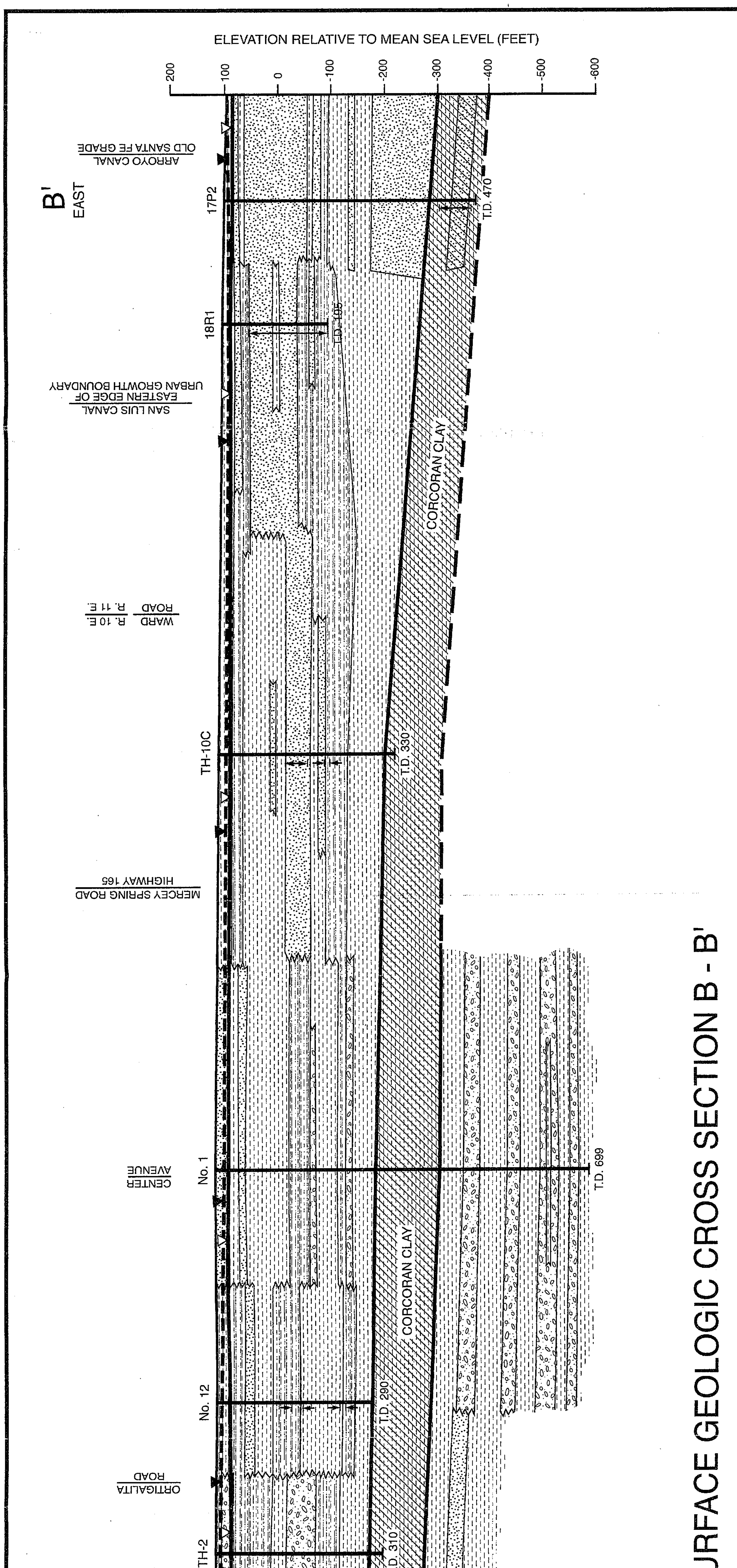


FIGURE 9 - SUBSURFACE GEOLOGIC CRO


ELEVATION RELATIVE TO MEAN SEA LEVEL (FEET)
200
100
0
-100
-200
-300
-400
-500
-600
B'
EAST
OLD SANTA FE GRADE
ARROYO CANAL
17P2
T.D. 470
18R1
T.D. 105
SAN LUIS CANAL
EASTERN EDGE OF
URBAN GROWTH BOUNDARY
WARD
ROAD
R. 10 E.
R. 11 E.
TH-10C
T.D. 330
CORCORAN CLAY
MERCEY SPRING ROAD
HIGHWAY 165
No. 1
CENTER
AVENUE
T.D. 699
CORCORAN CLAY
No. 12
T.D. 290
ORTIGALITA
ROAD
TH-2
T.D. 310
URFACE GEOLOGIC CROSS SECTION B - B'

Subsurface Geologic Section C-C' (Figure 10) extends from Volta on the northwest (Well 1A), through City Wells No. 6, 1, and Test Hole No. 10-A, to Well 1G, near the southeast boundary of the GSA. This section is generally oriented perpendicular to the inferred dip of the alluvial deposits, and thus the strata appear relatively flat. Well No. 1 was drilled to a depth of 697 feet. The top of the Corcoran Clay ranges from about 280 feet in depth at Test Hole No. 9 to 306 feet at Well No. 1. City Well No. 1 and Well 35L along this section penetrated the base of the Corcoran Clay. The Corcoran Clay is about 110 feet thick at City Well No. 1 and about 120 feet thick at Well 35L. Test Hole No. 10-A encountered five relatively thin and poorly developed water-producing strata between 95 and 280 feet in depth, and a production well was not completed at this site. The coarse-grained permeable deposits in the lower aquifer appear to be much thinner at Well No. 1 than at Well No. 4. Fine-grained deposits are predominant along this section between the northerly extension of Canyon Road and City Well No. 6.

CONSTRUCTION DATA FOR WELLS

City of Los Banos Wells

There are presently 13 active City Wells, all of which tap strata above the Corcoran Clay. Well No. 14 is the only active City

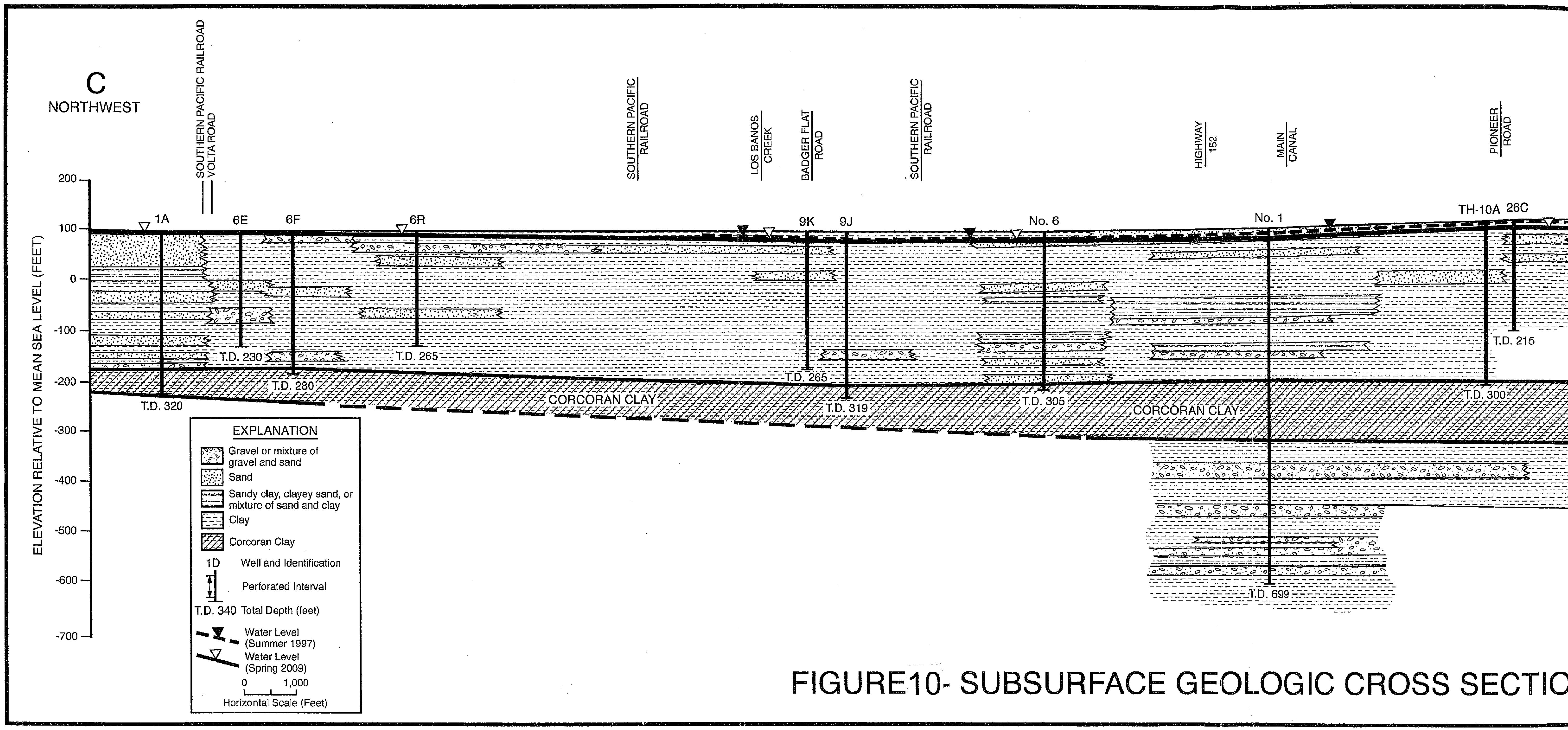
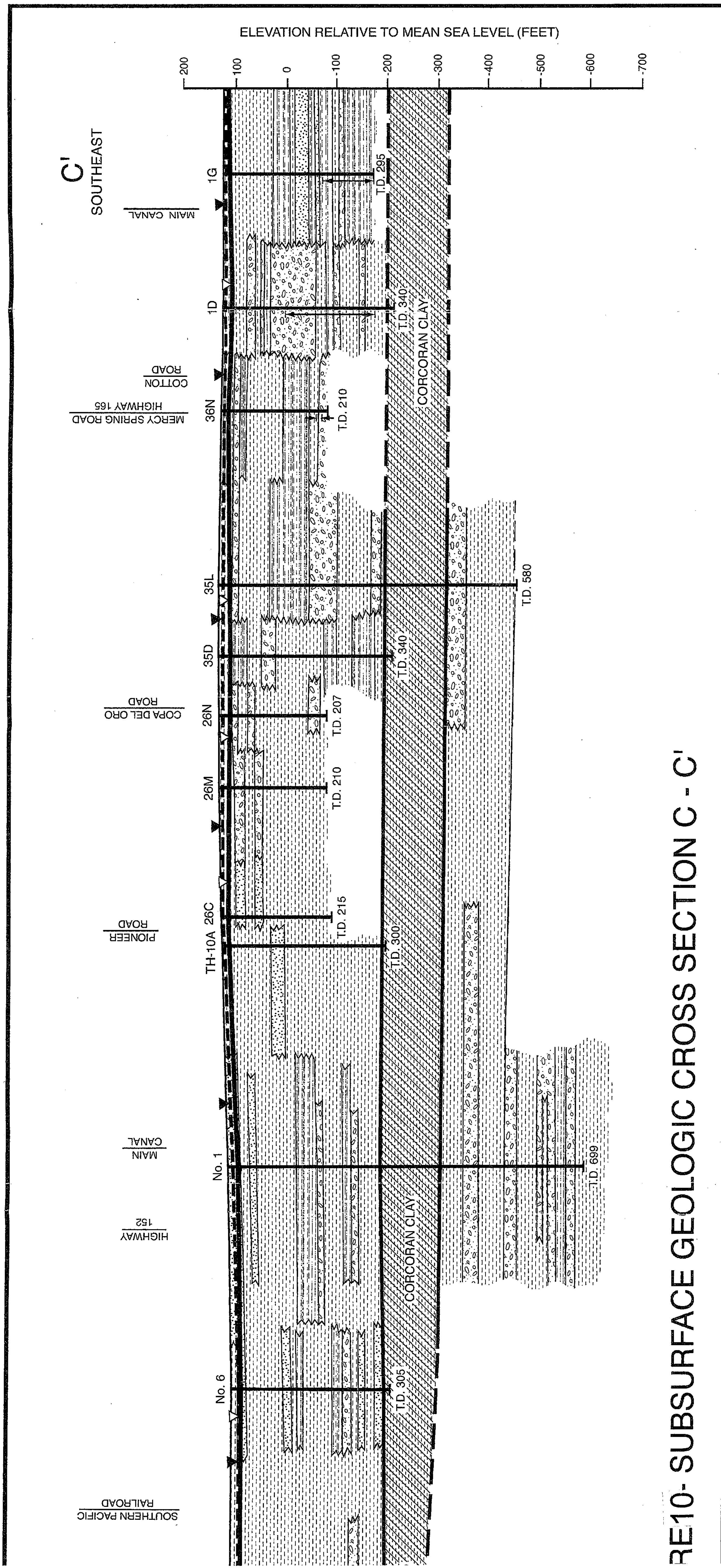


FIGURE10- SUBSURFACE GEOLOGIC CROSS SECTION



RE10- SUBSURFACE GEOLOGIC CROSS SECTION C - C' well with perforations extending below the Corcoran Clay. Table 1 provides information on dates drilled, depth, and perforated intervals for these wells. Drillers logs are available for all of these wells. Electric logs are available for Old Well No. 1, Wells No. 1 and No. 4, and Wells No. 7 through 15.

CCID Wells

Table 2 shows construction data for the four CCID supply wells in the Los Banos area. Cased depths of three of these wells range from 220 to 300 feet and the tops of the perforations range from 25 to 220 feet deep. These wells tap strata above the Corcoran Clay. Well No. 56 is 600 feet deep and is perforated from 400 to 600 feet deep. This well taps strata below the Corcoran Clay.

GROUNDWATER USE AND WELL DATA

Primary Uses of Each Aquifer

The primary use of the upper aquifer is for public supply and irrigation, and a secondary use is for wetlands and domestic use. The primary use of the lower aquifer is for irrigation use. A secondary use in for public supply and wetlands.

TABLE 1-CONSTRUCTION DATA FOR ACTIVE CITY OF LOS BANOS WELLS

No.	Date Drilled	Drilled Depth (feet)	Cased Depth (feet)	Casing Diameter (inches)	Perforated Interval (feet)	Annular Seal (feet)
1	03/51	699	310	16	-	-
2	01/58	310	310	16	164-310	0-70
3	07/63	310	310	16	115-134 145-305	0-60
5	06/64	302	159 301	16 14	108-154 223-270	0-61
6	04/76	305	302	-	205-235 240-245 290-295	0-50
7	11/77	300	180	16	104-114 140-170	0-50
9	09/90	300	255	16	180-190 225-245	0-163
10	03/91	242	218	16	125-165 198-208	0-50
11	09/94	290	265	16	130-140 170-185 215-225 245-255	0-50

Continued:

TABLE 1-CONSTRUCTION DATA FOR ACTIVE CITY OF LOS BANOS WELLS
(Continued:)

No.	Date Drilled	Drilled Depth (feet)	Cased Depth (feet)	Casing Diameter (inches)	Perforated Interval (feet)	Annular Seal (feet)
12	10/95	290	266	16	140-160 230-240 250-256	0-75
13	01/99	300	261	16	135-160 193-203 241-251 134-154 180-200	0-60
14	08/98	555	470	16	134-154 180-200 260-270 440-460	0-70
15	02/02	540	285	16	135-160 175-185 240-275	0-90

TABLE 2-CONSTRUCTION DATA FOR CCID WELLS

No.	Date Drilled	Drilled Depth (feet)	Cased Depth (feet)	Casing Diameter (inches)	Perforated Interval (feet)	Annular Seal (feet)
8-A	03/94	230	220	16	75-220	0-50
48-A	11/96	305	300	18	220-260 280-295	0-50
56	01/99	610	600	18	400-600	0-50
62	04/03	255	250	21 16	25-125 150-240	0-25

Data from well completion reports.

Depths of Water Supply Wells

City of Los Banos Wells

Cased depth of the City upper aquifer wells range from 180 to 310 feet. Except for Wells No. 7 and 10, the cased depths of these wells range from 255 to 310 feet. The only active City well tapping the lower aquifer (No. 14) is a composite well, cased to a depth of 555 feet. This well is perforated from 134 to 460 feet in depth (top and bottom of perforations).

CCID Wells

Cased depths of the CCID upper aquifer wells range from 220 to 300 feet. Well No. 56 taps only the lower aquifer, and the cased depth is 600 feet and the casing is perforated from 400 to 600 feet in depth.

Other Wells

Most private irrigation well in the study area tap only the upper aquifer, and are thus generally cased above a depth of about 300 feet. There are some shallow private domestic wells that are cased to depths of less than 150 feet, and thus tap the upper part of the upper aquifer. Some irrigation wells are composite wells (tapping both aquifers), and others only tap the lower aquifer. The composite and lower aquifer wells are generally cased to depths ranging from about 450 to 700 feet.

WATER LEVELS

Water-Level Depths

KDSA (1998, Figure 4) provided a depth to water map for Spring-Summer 1997. Many of the measurements were for shallow observation wells measured by the CCID. Several were for shallow monitor wells at the City Wastewater Treatment Facility. There are less such wells southwest of the Outside Canal, and in part of that area, measurements for water supply wells were used. In addition, water-level measurements were obtained for six monitor wells for the Triangle Rock gravel plant. Depth to water ranged from less than five feet beneath the northwest and southeast parts of the study area in Spring-Summer 1997, to more than 20 feet in most of the area southwest of the Outside Canal. In most of the City of Los Banos, depth to the shallowest groundwater ranged from 10 to 15 feet. The depths that were shown for the urban area were more representative of the shallowest groundwater, as opposed to those for City supply wells, many of which aren't perforated near the water level, but much deeper.

KDSA (2010, Figure 5) provided a depth to water map for Spring 2009. This map showed the greater depth to water during a dry period, particularly in the Los Banos Creek subarea. Depth to water ranged from less than 10 feet beneath the northwest, northeast, and southeast part of the area, to more than 80 feet in the area west of the DMC and south of Los Banos Creek. Depth to water exceeded about 40 feet in most of the Los Banos Creek sub-area.

Water-Level Elevations and Direction of Groundwater Flow

Upper Aquifer

KDSA (1998, Figure 5) provided a water-level elevation and direction of groundwater flow map for Spring-Summer, 1997. This map was also based on shallow wells in some areas. The highest water-level elevations (exceeding 140 feet above mean sea level) were southwest of the DMC. The lowest water-level elevations (less than 90 feet) were to the northeast. Recharge mounds were indicated near Los Banos Creek (southwest of the Outside Canal) and near the City WWTF to the northeast. This water-level map indicated that most of the lateral groundwater inflow into the City came from the southwest.

KDSA (2010, Figure 6) prepared a water-level elevation and direction of groundwater flow map for Spring 2009. This was based on data in the DWR water-level data base and CCID data. At this time this map was prepared, water-level measurements weren't available for City wells. Since that time they have become available, and the map has been revised to include water-level elevations for City wells (Figure 11). Water-level elevations

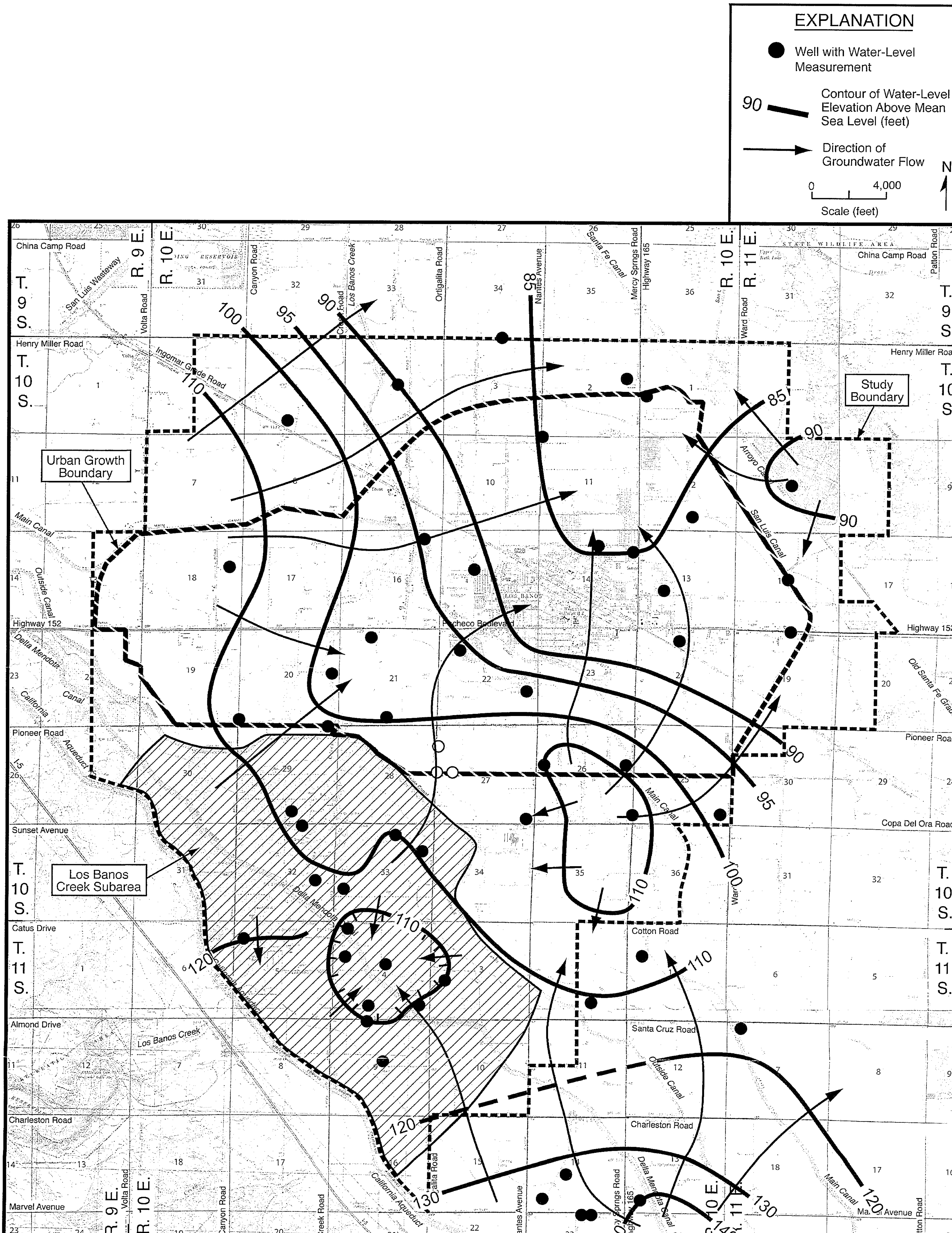


FIGURE 11 - WATER-LEVEL ELEVATIONS AND DIRECTION OF GROUNDWATER FLOW ABOVE CORCORAN CLAY (SPRING 2009)

ranged from more than 140 feet near the DMC and Merced Avenue to less than 85 feet northeast of Los Banos. A cone of depression was indicated beneath the City, and this depression extended at least two miles to the north of the City. A similar overall direction of groundwater flow was generally indicated as in 1997. However, the most significant change was the lack of a recharge mound along most of the reach of Los Banos Creek for the Spring 2009 map. This was due to minimal streamflow in the creek prior to and during Spring 2009, and also due to the use of measurements for deeper wells (i.e. supply wells). The recharge mound associated with the WWTF (east of the San Luis Canal) was indicated to still be present in Spring 2009. There was a localized cone of depression in Spring 2009 in the area southeast of Los Banos Creek along the DMC. This area coincided with a number of private wells that were used for irrigation of land in the study area.

Figure 12 shows water-level elevations and the direction of groundwater flow for the upper aquifer in Spring 2017. This map is based on measurements for water supply wells as opposed to shallow monitor wells. For this map, measurements were also available for the City wells. Water-level elevations ranged from more than 115 feet above mean sea level to the southwest to less than 80 feet to the northeast. A well developed cone of depression was present beneath the Los Banos urban area. Otherwise, the direction of groundwater

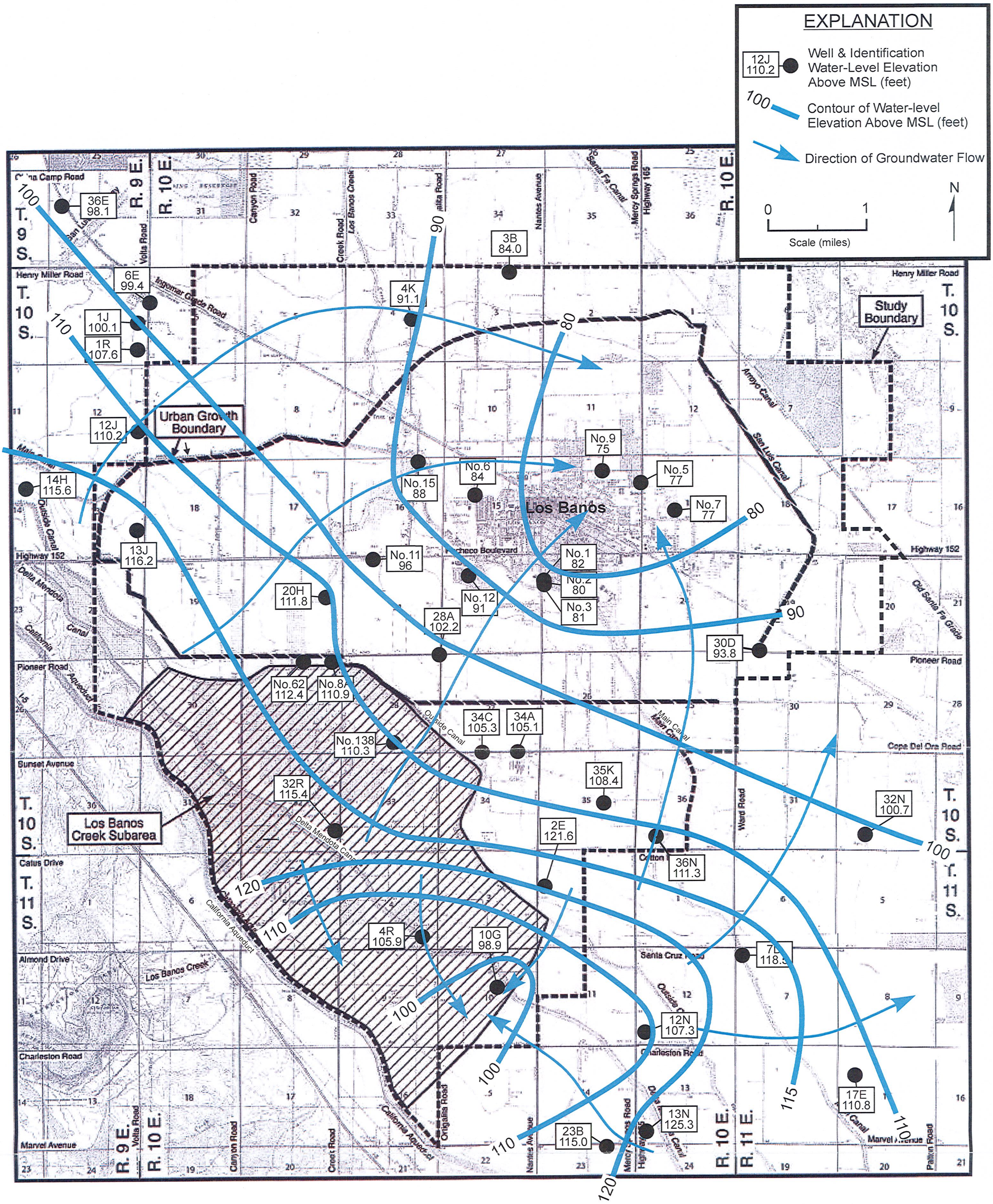


FIGURE 12 - WATER-LEVEL ELEVATIONS AND DIRECTION OF GROUNDWATER FLOW ABOVE CORCORAN CLAY (SPRING 2017)

flow was to the northeast, except in an area southeast of Los Banos Creek and upslope of the Outside Canal, where groundwater was flowing toward a depression in the area south of Cactus Drive in the SLWD. Little indication of a recharge ridge was indicated along Los Banos Creek by the supply well water-level measurements. Such a ridge would be indicated by water-level measurements for shallow observation wells or monitor wells.

Lower Aquifer

Water-level measurements for wells tapping the lower aquifer in the area are inadequate to determine the direction of groundwater flow. However, regional maps prepared for the San Joaquin River Exchange Contractors Water Authority (SJRECWA) have indicated a southeasterly direction of flow toward the Panoche W.D.

Water-Level Fluctuations

Upper Aquifer

KDSA (2010) evaluated water-level hydrographs for wells in the area from the DWR website (presented in Appendix A of that report). Water levels in wells in most of the area were stable or rising through Spring 2009. However, in the area near and southwest of the Outside Canal, and east of the south part of the canal in the study area, water levels fell between 2006 and 2009. Records for twelve wells in Sections 19, 20, 22, 26, 29, 33, 34, and 36 of T10S/R10E showed this decline, which ranged from seven to 29 feet. The greatest declines (20 feet or more) were in Wells 19R1, 29A1, 29N2, 29Q2, 33H1, 34A1, and 34C1.

Updated water-level hydrographs (through early 2017) are provided in Appendix A of this report. Figure 13 is a representative long-term water-level hydrograph for the part of the study area northeast of the Outside Canal. Well T10S/R10E-12Q1 is located in the northeast part of Los Banos. Water levels in this well generally rose between 1975 and 1987, then fell during 1988-1994 during the drought. The water level then rose from 1996-1999 and was stable through 2006. The water level fell about nine feet during 2006-08, rose about five feet by 2010, then fell about 13 feet in 2015. Overall, water levels have been stable except for temporary declines during dry periods. Figure 14 is an updated water-level hydrograph for a well in the Los Banos Creek subarea. Well T10S/R10E-33H1 is located about a mile east of Los Banos Creek. The water level in this well fell about 20 feet between 1987 and 1993. The water level then rose about 24 feet by 2002. The water level fell about 27 feet between 2007 and 2009, then rose about 18 feet by 2012. The water level then fell about 78 feet by the end of 2014, and more recent measurements aren't available. Water-levels in this well were relatively stable prior to 2009. Water levels declined between 2009 and 2015.

Appendix A also contains water-level hydrographs for 12 City of Los

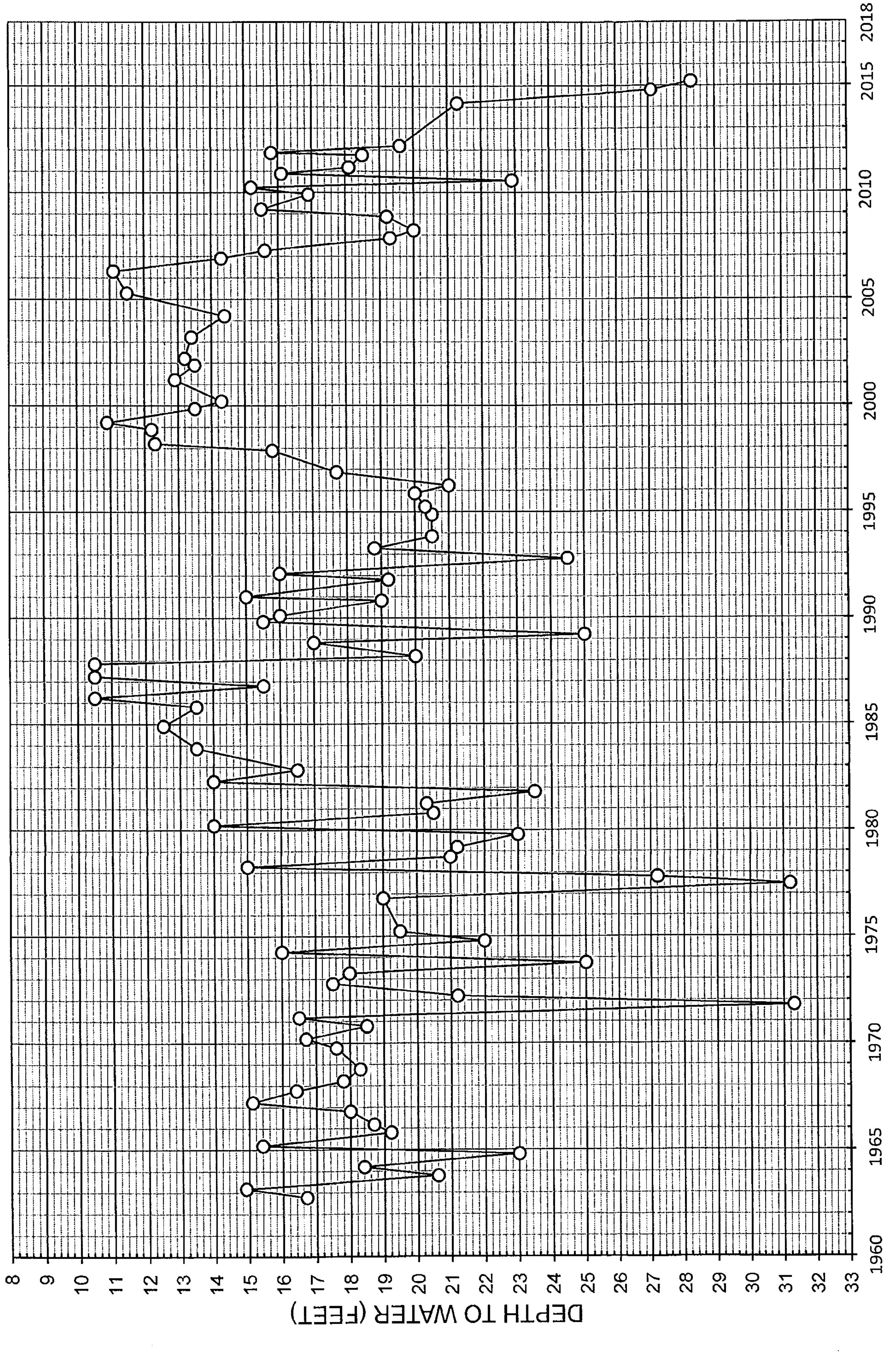


FIGURE 13 - LONG-TERM WATER-LEVEL HYDROGRAPH FOR WELL T10S/R10E-12Q1

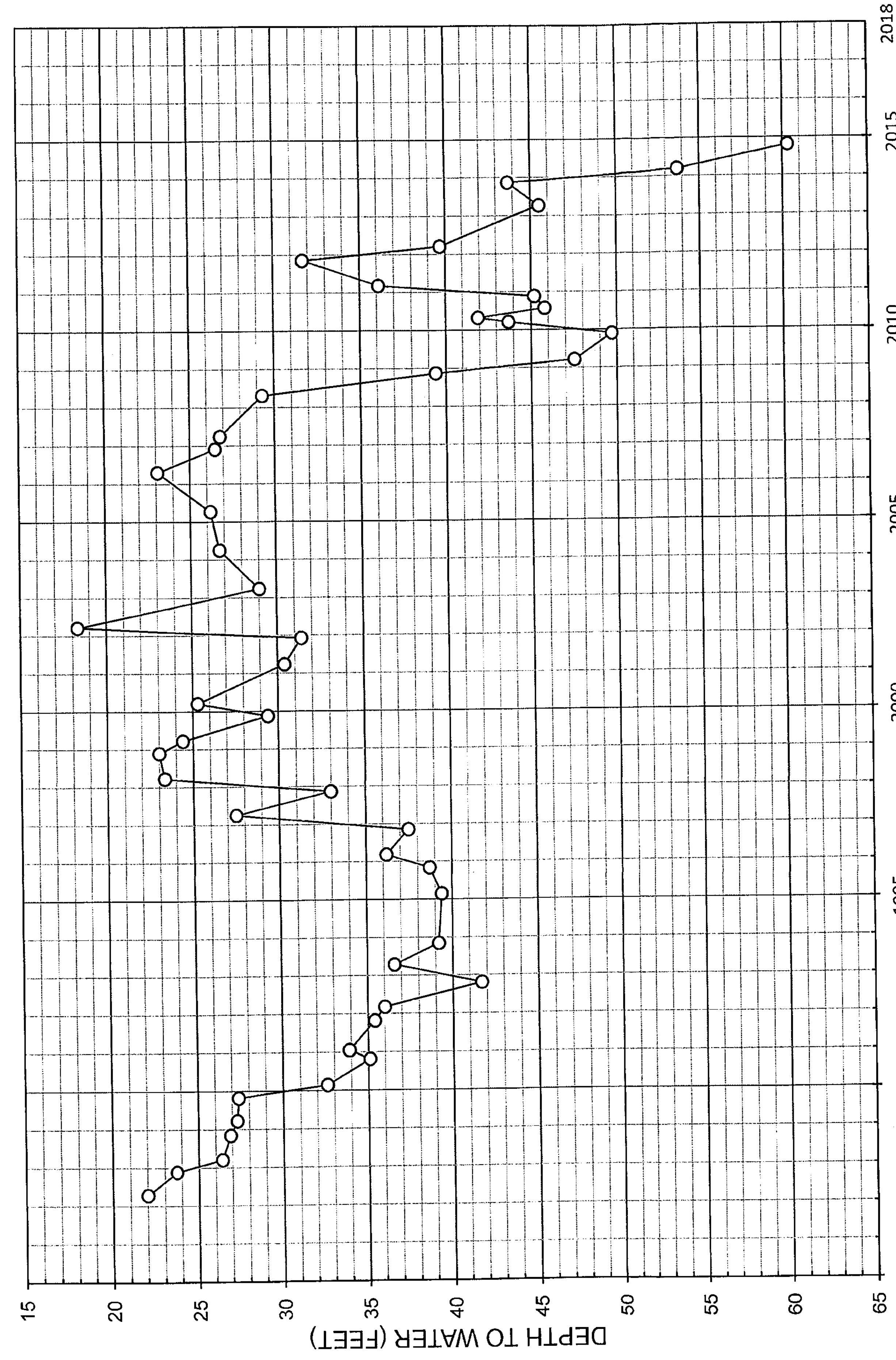


FIGURE 14 - LONG-TERM WATER-LEVEL HYDROGRAPH FOR WELL T10S/R10E-33H1

Banos wells for Spring 1997-Spring 2017. The City measures static (standing) water levels in the wells on a monthly basis when possible. Well No. 14, which is perforated above and below the Corcoran Clay, is included, because its water-level trends are consistent with those for the other wells. Figure 15 is a water-level hydrograph for Well No. 5, which is considered representative of average trends. Water levels were shallower during the winter and deeper during the summer, and seasonal variations often ranged from about 20 to 30 feet. A review of these hydrographs indicates water-level declines, ranging from no decline in two wells to 0.7 foot per year (at the well No. 1 site) between 1997 and 2012-14. The average water-level decline in the City wells during this period was 0.2 foot per year. Water-levels declines during 2013-17 ranged from 0.9 to 3.8 feet per year and averaged 2.0 feet per year.

The most frequent long-term water-level records available near Los Banos Creek and upstream of the Outside Canal are for six shallow monitor wells for the Triangle Rock facility near Pioneer Road and the creek. Water levels in these monitor wells were frequently measured during 1990-99 and from 2006-2017 (Figure 16). Records of outflow from the Los Banos Creek detention dam since 1967 are provided in Appendix B. In part of 2017, water was also discharged to the creek from the DMC, as part of a pilot recharge project. Water levels in these monitor wells

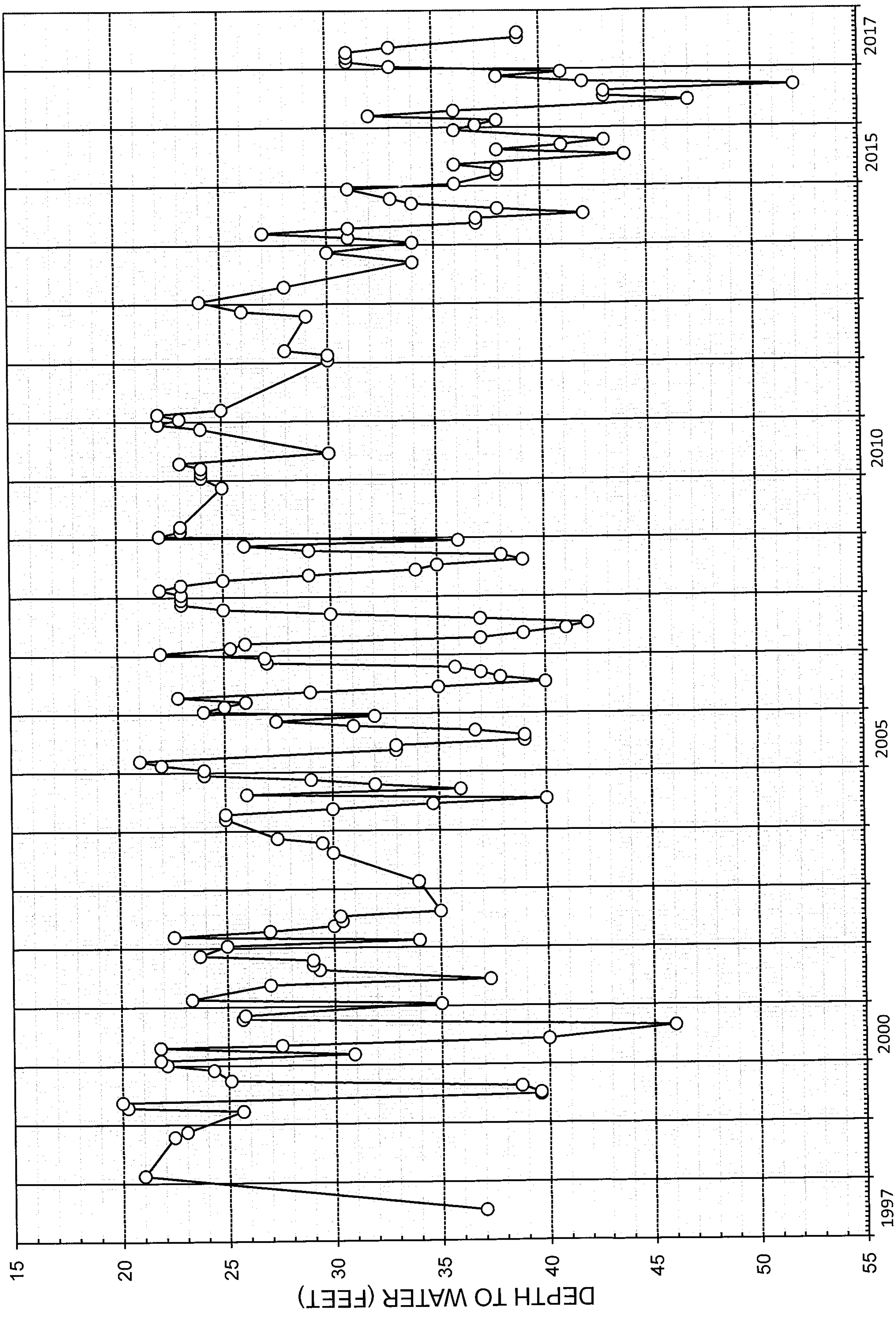


FIGURE 15 - WATER-LEVEL HYDROGRAPH FOR CITY OF LOS BANOS WELL NO. 5

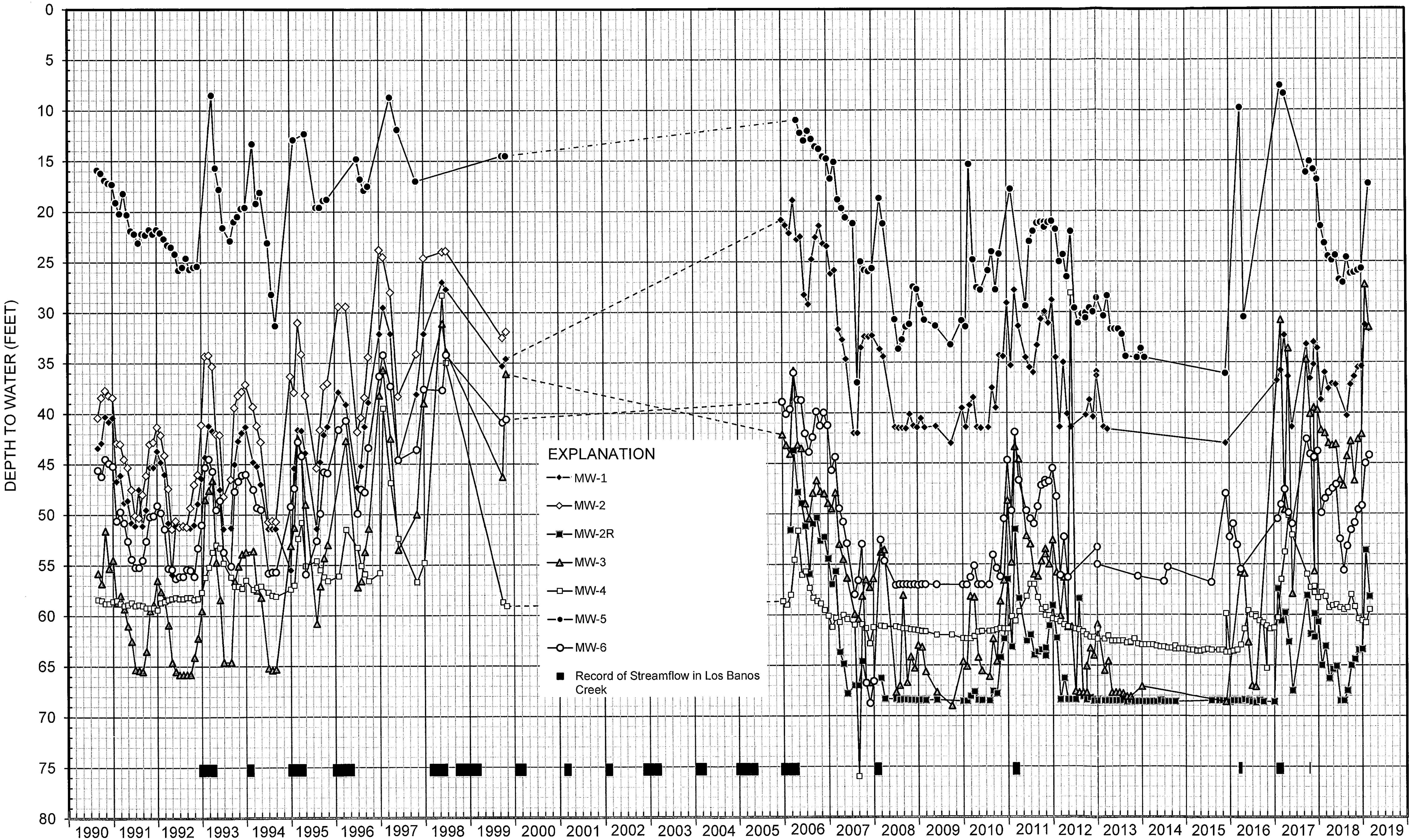


FIGURE 16-WATER-LEVEL HYDROGRAPHS FOR TRIANGLE ROCK MONITOR WELLS

have risen during and following periods of significant flow in Los Banos Creek, and have fallen during non-streamflow periods. Some of the deepest water levels in these monitor wells were during the drought of the early 1990's, and during 2006-09 and 2014-16. Average water-level declines in the monitor wells in the absence of streamflow in Los Banos Creek were about eight feet per year during May 2006-January 2009. Records for Los Banos Creek streamflow indicate that the longest period of no outflow from the Dam was between March 1987 and January 1993, or almost six years.

During the more recent drought, water levels in most of these shallow monitor wells were dry for several years, prior to early 2017. However, when there was flow in Los Banos Creek during 2017, the water levels in those wells rose significantly.

Nested monitor well T10S/R10E-32L is located near the DMC and Los Banos Creek. Figure 17 shows water-level hydrographs for two of the monitor wells at this site (32L5 and L6) that are perforated above the Corcoran Clay. The shallowest spring water levels for the upper aquifer at this site have normally ranged from about 48 to 52 feet. The deepest spring water levels have normally ranged from about 65 to 70 feet. In Spring 2017 depth to water in Well 32L6 was about 37 feet, the shallowest of record. Depth to water in Well 32L5 was 64 feet in Spring 2017,

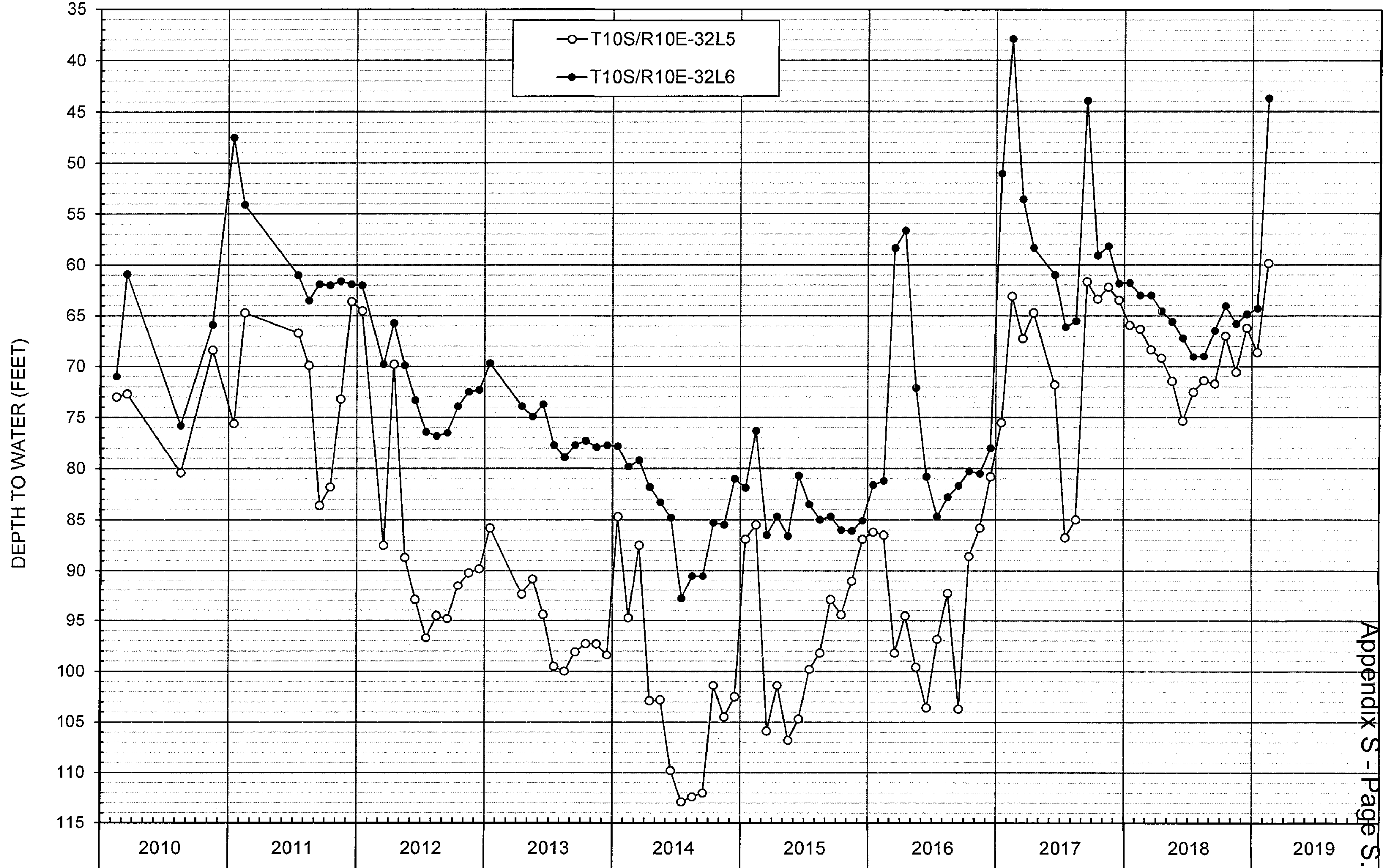


FIGURE 17 - WATER-LEVEL HYDROGRAPHS FOR OBSERVATION WELLS NEAR LOS BANOS CREEK AND THE DMC

near the shallowest of record. These shallow levels were during streamflow in the creek.

Lower Aquifer

One of the DMC monitor wells (T10S/R10E-32L4) is perforated only below the Corcoran Clay. Water levels in this well are much deeper than those in Wells 32L5 and L6, and have ranged from about 129 feet deep in Summer 2011 to 175 feet in July 2015. Water levels in this well are influenced by streamflow in the creek and by pumpage. There has been only limited pumpage below the Corcoran Clay in the immediate area. The nearest area where there is extensive lower aquifer pumpage is in the area northeast and east of the City.

SOURCES OF RECHARGE

The primary sources of recharge to groundwater in the Los Banos study area are deep percolation of irrigation return flow in areas irrigated with canal water, canal seepage, seepage of streamflow from Los Banos Creek, intentional recharge ponds, and seepage of water from wetlands supplied by DMC water (Figure 18).

Los Banos Creek Seepage

Historical streamflow records for the outflow from Los Banos Dam are provided in Appendix B. The annual flows since 1965

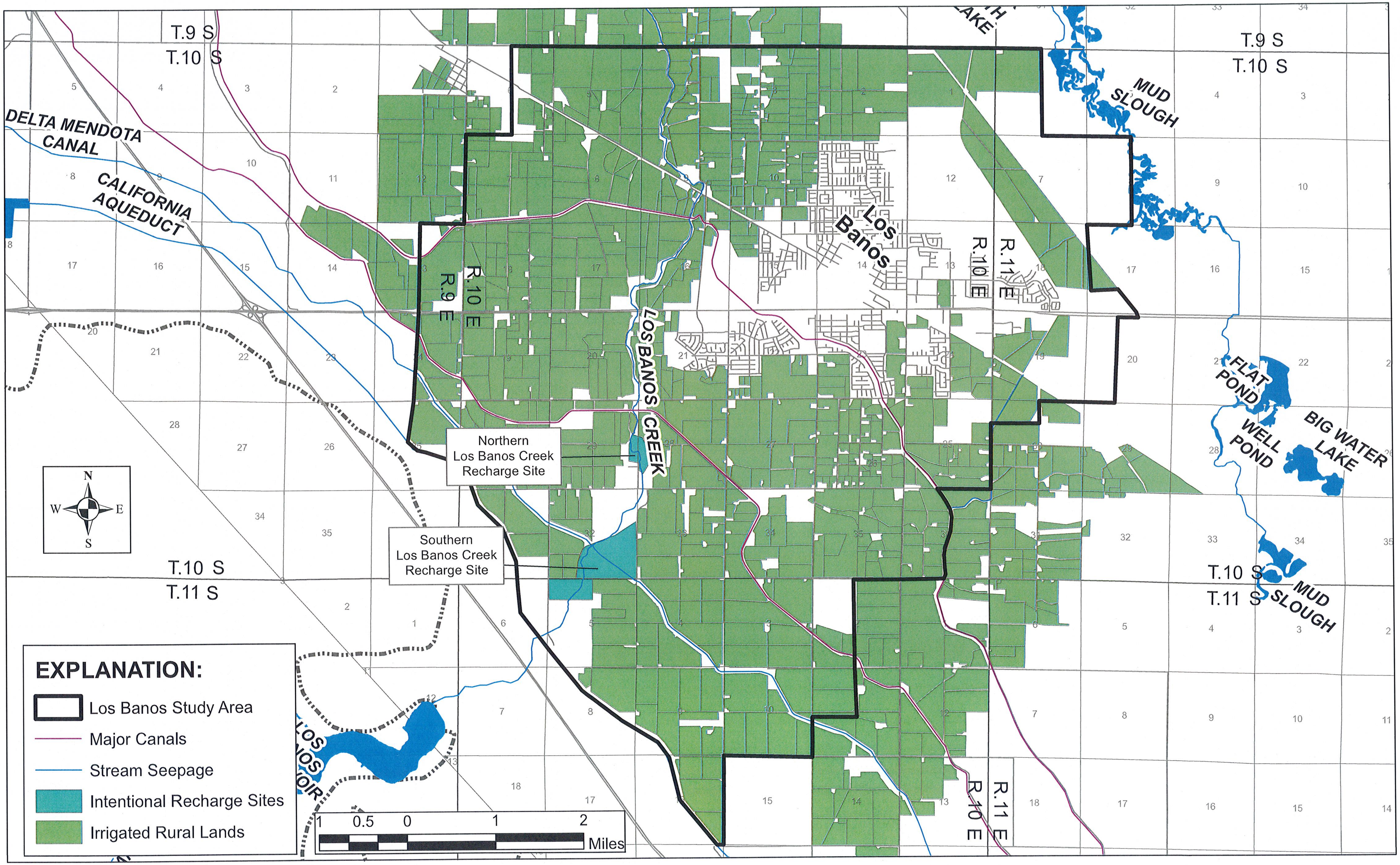


FIGURE 18 - POTENTIAL LOS BANOS GROUNDWATER RECHARGE AREAS

have ranged from less than two acre-feet to about 62,700 acre-feet in 1998. The average annual outflow from 1965-2016 was about 8,450 acre-feet per year. In early March 2010, the DWR released 200 cfs of water from the Dam. The CCID measured creek flow at two locations. At the Pioneer Road crossing, the flow was 156 cfs, indicating a seepage loss of about 44 cfs, or about 87 acre-feet per day, in the reach between the Dam and Pioneer Road. Measurements indicated another 6 cfs of seepage between Pioneer Road and the Main Canal. The creek flow at Highway 152 was 126 cfs, indicating a seepage loss of about 25 cfs, or 50 acre-feet per day, between Pioneer Road and Highway 152.

The CCID conducted an evaluation in August 2017, when about 40 cfs was released. Based on this information, the CCID has re-evaluated the seepage from Los Banos Creek within the Los Banos study boundary for 2003-17. The annual seepage ranged from none in 2007, 2009, and 2011-15 to 4,800 acre-feet in 2017. The seepage averaged 1,500 acre-feet per year during 2003-17.

Deep Percolation and Canal Seepage

The CCID determined that from 2003-16, an average of 48,500 acre-feet of water was delivered to the study area by the CCID and SLWD. The estimated crop consumptive use during this period averaged 29,600 acre-feet per year. The difference, or 28,900 acre-feet per year, is deep percolation to the groundwater. The

CCID estimated canal seepage as 0.68 cfs per mile during an average canal run of 330 days. Canal seepage is discussed in more detail later under the water budget section of this report. Seepage from wetlands in the GSA varies significantly depending on the soil type, and has been estimated to average about 0.5 acre-foot per year (Swanson, verbal communication, 2019).

Groundwater Inflow

Water-level elevation contour maps for the upper aquifer indicate that there has been groundwater inflow into the study area from the south and from the west, particularly in the area north of Los Banos Creek.

In Spring 2017, northeasterly groundwater inflow was occurring along the entire length of the study area at a location near the DMC, where the water-level elevation was about 115 feet above mean sea level. The average water-level slope along this nine-mile long segment was about seven feet per mile. Specific capacities have previously been mapped in the Los Banos area for the SJRECWA service area. Recent specific capacities for City upper aquifer wells averaged about 43 gpm per foot. Using a conversion factor of 1,500, the estimated average transmissivity in the City of Los Banos is about 65,000 gpd per foot. Transmissivities have been determined for aquifer tests in five upper aquifer sites within the area, and at two pits along Los Banos Creek. Values ranged from 35,000 to 168,000 gpd per foot. Most values ranged from about 56,000 to 70,000 gpd per foot.

Using an average transmissivity of 65,000 gpd per foot along the nine-mile segment, the annual lateral groundwater inflow was about 4,600 acre-feet per year. Another calculation was made for the groundwater inflow into the City of Los Banos. The average water-level slope was about seven feet per mile along a segment of flow of five and a half miles. The groundwater inflow from upgradient areas was about 2,800 acre-feet per year.

SOURCES OF DISCHARGE

The primary sources of groundwater discharge are well pumpage and groundwater outflow. Figure 19 shows the potential groundwater discharge area.

Pumpage

Pumpage in the area is from City wells, CCID wells, private irrigation wells, and other wells. The City of Los Banos provided records of City pumpage. As part of this evaluation, the CCID determined pumpage from CCID wells and private landowner wells in the study area. In addition, they estimated well pumpage in the Los Banos Creek subarea. Historical pumpage records are provided in Appendix C.

City Wells

Table 3 provides pumpage from the City of Los Banos wells for

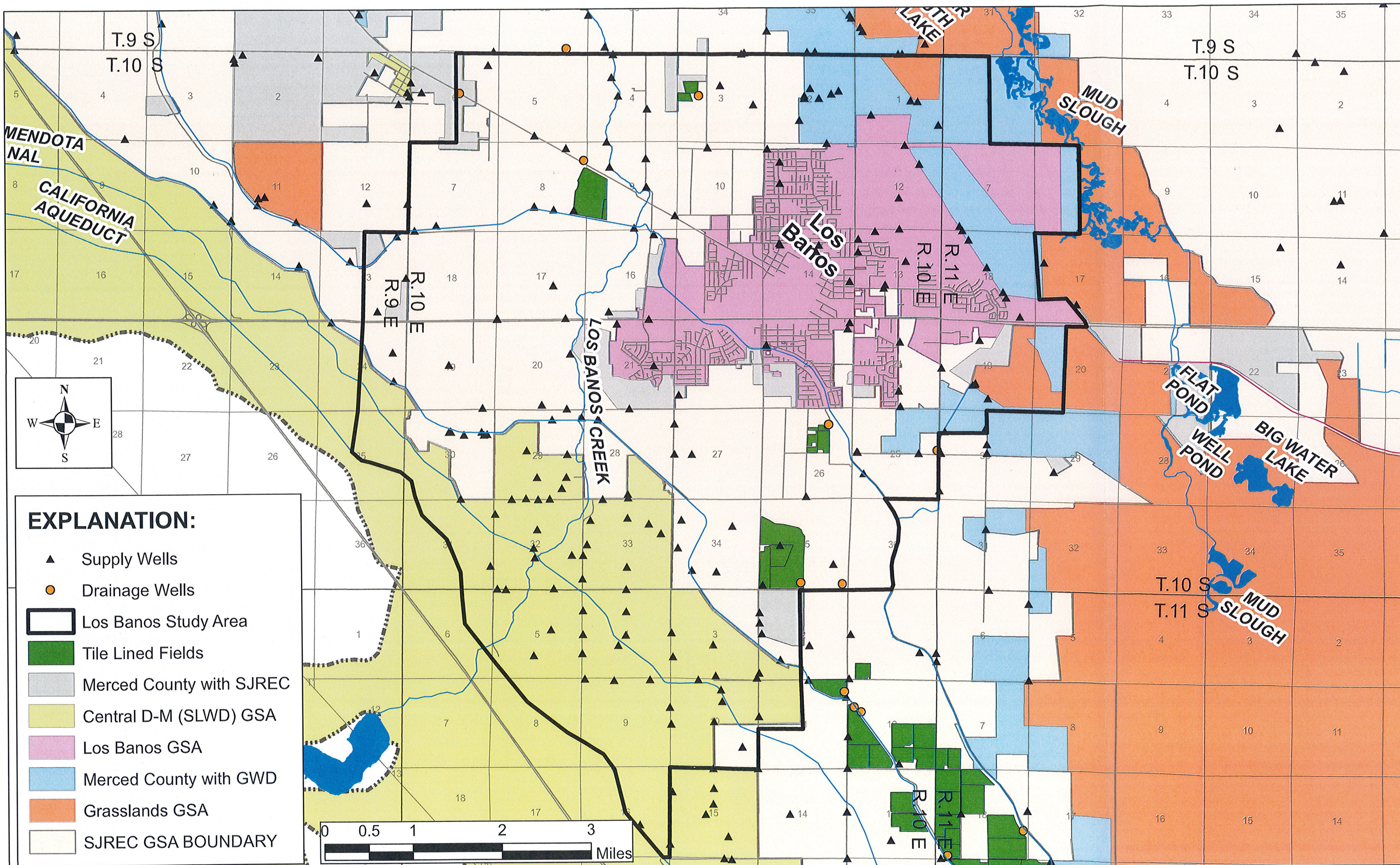


FIGURE 19 - POTENTIAL LOS BANOS GROUNDWATER DISCHARGE AREAS

TABLE 3-ANNUAL PUMPAGE FROM CITY OF LOS BANOS WELLS (1993-2016)

Year	Pumpage (Acre-Feet)
1993	5,073
1994	5,631
1995	5,307
1996	5,185
1997	6,045
1998	5,287
1999	5,343
2000	4,688
2001	5,461
2002	6,923
2003	6,434
2004	6,914
2005	7,152
2006	7,465
2007	9,113
2008	8,876
2009	8,258
2010	7,712
2011	7,776
2012	8,312
2013	8,486
2014	7,894
2015	6,657
2016	6,121
Average	6,715

1993-2016. Annual pumping gradually increased from about 5,100 acre feet in 1993 to about 9,100 acre-feet in 2007. The pumpage then decreased and was lower in 2010-11 and significantly lower during 2015-16, due to water conservation measures implemented during the recent drought. The average pumpage from City wells during 1993-2016 was about 6,700 acre-feet per year.

CCID Wells

Table 4 provides pumpage from CCID wells in the area for 1993-2016. The average pumpage of these wells was about 2,600 acre-feet per year. Of this, an average of 670 acre-feet per year was from wells inside the UGB.

Private Wells

Table 5 shows pumpage from private wells in the area for 1993-2016. An average of about 11,300 acre-feet per year was pumped from these wells. Of this amount, about 6,000 acre-feet per year were pumped from wells inside the UGB. An average of 4,900 acre-feet per year was pumped from private wells in the Los Banos Creek subarea, excluding water pumped for transfer, during 2007-16.

Records indicate that pumpage from private wells into the DMC/San Luis Canal for transfer of water out of the area ranged from about 1,300 to 5,200 acre-feet per year during 2007-16. The average pumpage

TABLE 4-ANNUAL PUMPAGE FROM CCID WELLS
IN GSA (1993-2016)

	Pumpage (Acre-Feet)		
Year	Inside UGB	Outside UGB	Total
1993	0	0	0
1994	0	1,008	1,008
1995	0	0	0
1996	0	841	841
1997	706	1,069	1,775
1998	0	0	0
1999	650	1,436	2,086
2000	859	2,112	2,971
2001	918	2,426	3,344
2002	637	2,396	3,033
2003	1,016	2,272	3,288
2004	1,247	2,590	3,437
2005	329	1,086	1,415
2006	21	0	21
2007	1,463	5,326	6,789
2008	922	3,720	4,642
2009	1,291	2,394	3,685
2010	589	685	1,274
2011	435	1,565	2,000
2012	1,490	4,851	6,341
2013	1,517	4,529	6,046
2014	1,093	3,245	4,338
2015	870	3,143	4,013
2016	130	174	304
Average	674		2,610

TABLE 5-ANNUAL PUMPAGE FROM PRIVATE WELLS
IN STUDY AREA (1993-2016)

	Pumpage (Acre-Feet)		
Year	Inside UGB	Outside UGB	Total
1993	12,818	14,201	14,812
1994	15,279	16,356	22,230
1995	11,081	11,967	16,782
1996	4,657	7,733	9,060
1997	4,289	9,479	8,586
1998	2,982	3,424	4,391
1999	6,923	8,317	8,660
2000	6,183	7,168	8,426
2001	6,923	8,317	12,031
2002	2,330	4,607	5,682
2003	5,595	8,439	11,872
2004	5,143	9,280	11,133
2005	4,104	6,006	8,882
2006	4,127	6,170	7,031
2007	4,221	10,142	9,970
2008	3,064	11,803	10,999
2009	6,460	5,127	14,887
2010	6,916	4,509	14,240
2011	6,000	5,125	14,017
2012	6,058	2,966	12,722
2013	2,161	6,444	9,251
2014	5,971	4,777	14,572
2015	6,852	4,012	13,585
2016	2,789	844	6,350
Average	5,955		11,257

was about 2,900 acre-feet per year during this period. The maximum annual pumpage from these wells during this period was in 2008. Pumpage from private wells in the CCID for transfer of water out of the area ranged from 0 to 1,654 acre-feet per year during 2000-16. The average pumpage from these wells was 990 acre-feet per year. Since 2010, transfers were curtailed when triggers for water levels were exceeded and new monitoring requirements were added to the Warren Act contract.

Groundwater Outflow

The Spring 2009 water-level elevation map shows groundwater outflow from the study area along the north boundary, between Volta Road and Ortigalita Road. The width of flow was about 1.5 miles and the average water-level slope was about 12 feet per mile. Using a transmissivity of about 65,000 gpd per foot, an outflow of about 1,300 acre-feet per year was calculated. The Spring 2017 water-level elevation map shows no lateral groundwater outflow from the study area. The average groundwater outflow for these two years was thus about 700 acre-feet per year (rounded).

AQUIFER CHARACTERISTICS

Pump Tests

Table 6 summarizes short-term pump test data for City wells in March 2015. Pumping rates ranged from about 490 to 2,140 gpm. The highest pumping rates were for Wells No. 5, 7, 10, 13,

TABLE 6-PUMP TEST DATA FOR CITY OF LOS BANOS WELLS

Well No.	Date Tested	Pumping Rate (gpm)	Static Level (feet)*	Pumping Level (feet)	Drawdown (feet)	Approximate Specific Capacity (gpm/ft)
1	3/3/15	852	35	56	21	41
2	3/3/15	887	38	63	25	35
3	3/3/15	660	36	65	29	23
5	3/2/15	1,243	38	69	31	40
6	3/2/15	490	-	168	-	-
7	3/2/15	1,430	39	60	21	68
9	3/2/15	910	-	129	-	-
10	3/2/15	2,140	43	88	45	48
11	3/2/15	945	-	171	-	-
12	3/2/15	820	-	95	-	-
13	3/2/15	1,500	-	101	-	-
14	3/2/15	1,300	-	128	-	-
15	3/2/15	911	47	-	-	-

* Static levels are for five or ten minutes of recovery after pumping stopped, and do not represent true static levels. Because of this, the actual values for specific capacity would be smaller, particularly for wells with large drawdowns.

and 14. Approximate specific capacities ranged from 23 to 68 gpm per foot. Short-term water-level recovery was measured, and opposed to true static levels (i.e., prior to pumping). True specific capacities are expected to be significantly greater for wells with pumping levels exceeding about 70 feet.

Table 7 summarizes short-term pump tests for CCID wells in 2015-16. Pumping rates ranged from about 1,147 to 1,909 gpm. Specific capacities ranged from about 22 to 161 gpm per foot. The highest specific capacity was for Well No. 8A, which is located near Los Banos Creek and the Outside Canal.

Aquifer Tests

During 1996-98, the CCID conducted aquifer tests on four wells in the study area. Locations of the tested wells are shown on Figure 1. In November 1996, a 24-hour constant discharge test was conducted on CCID Well No. 8-A. This well is located near Los Banos Creek and Pioneer Road, and is perforated from 75 to 220 feet in depth. The static level prior to pumping was 35.5 feet. The average pumping rate was 2,415 gpm. The drawdown at the end of pumping was 25.5 feet, and the specific capacity was 94.7 feet. Corrected recovery measurements indicated a transmissivity of 168,000 gpd per foot.