KINGS RIVER WATER QUALITY COALITION

A Comprehensive Groundwater Management Plan to address issues identified within the Kings River Water Quality Coalition' Groundwater Assessment Report as Required by the General Order of Waste Discharge for the Tulare Lake Basin, R5-2013-0120

Comprehensive Groundwater Management Plan

November 20, 2014

This Page Intentionally Left Blank

This Comprehensive Groundwater Management Plan is being prepared in accordance to the requirements specified in the Waste Discharge Requirements General Order for Growers within the Tulare Lake Basin Area that are Members of a Third Party Group, R5-2013-0120. The Comprehensive Groundwater Management Plan option was selected due to the widespread distribution of the primary Constituent of Concern identified within the Kings River Watershed Coalition Authority's (KRWCA) Groundwater Assessment Report of November 2014 and the size of the High Vulnerability Area defined within the report.

TABLE OF CONTENTS

Executive Summary 6

Introduction and Background 7

COC's Subject of Plan 10

Objectives 10

Region Covered by CGMP and How Determined 11

Previous Work Conducted 13

Land Use 14

Potential Sources 17

Beneficial Uses 17

Baseline Inventory of Management Practices 17

Applicable Groundwater Data 21

Soil Types, Geology, and Hydrology 22

Groundwater Basins 26

Water Chemistry 26

Known Water Bearing Zones 26

Water Bearing Zones and Uses 28

Aquifer Characteristics 28

Water Sources and Chemistry 29

Management Plan Strategy 30

Prioritization of COCs 30

Actions Taken 31

Compliance with Receiving Water Limitations 31

Education and Outreach 31

Identification and Validation of Practices that Reduce Loading . . . 31

Identification of Individuals Involved 32

Strategies to Implement Management Plan Tasks. 34

Management Practices Used 34

Outreach Strategies 35

Schedule and Milestones for Implementation 35

Monitoring Methods 36

Data Evaluation. 37

Reporting 37

Appendix 38

LIST OF FIGURES

Figure 1: KRWQC Boundary Map 8

Figure 2: KRWQC Groundwater Vulnerability Map 12

Figure 3: KRWQC Land Use Map 15

Figure 4: KRWQC Land Use and Groundwater Vulnerability Map . . 16

Figure 5: KRWQC Map showing Alta ID and DACs 18

Figure 6: KRWQC Map with Known Clay Layers 23

Figure 7: General Geologic Cross-Section of Southern San Joaquin Valley . 24

Figure 8: 2014 Depth to Groundwater Map 27

EXECUTIVE SUMMARY

This Coordinated Groundwater Management Plan (CGMP) was prepared according to the requirements set forth within the General Order of Waste Discharge for Growers within the Tulare Lake Basin who are Members of a Third Party Group, R5-2013-0120.

The Kings River Water Quality Coalition (KRWQC), upon receipt and review of the Groundwater Assessment Report (GAR) prepared for the KRWQC by GEI Consultants, Inc., elected to prepare a singular Groundwater Management Plan for the areas designated as High Vulnerability plus those areas that have shown a nitrate exceedance within the KRWQC service area. It was felt that given the single constituent of concern (nitrate) that can affect public health (Total Dissolved Solids (TDS) is a secondary water quality standard, and a naturally occurring component of groundwater), and the single source of the constituent of concern, a single plan for the designated area was better suited than multiple smaller plans.

The GAR looked at intrinsic factors to groundwater vulnerability, plus available water quality data that showed where drinking water standards had been exceeded. This plan will present a strategy incorporating grower outreach, systematic groundwater quality monitoring, management practice evaluations and adjustments, and a pilot study on specific isotopes present within the groundwater to determine the impacts of irrigated agriculture on groundwater, and the sources of contamination for those areas that already show exceedances of the drinking water standards. Lands that are covered by the Dairy General Order are not included within this CGMP. Available data from this Order will be considered as the GAR is revised, but corrective actions are not to be studied as part of this plan.

The specifics for the management practice evaluations will be determined under a group agreement with other third-party groups within the Tulare Lake Basin. The Isotope Study is planned in cooperation with Laurence Livermore National Laboratory, and the groundwater monitoring plan will be developed following the acceptance of the GAR/CGMP submission.

INTRODUCTION AND BACKGROUND

Groundwater is an important resource to many constituencies within the Kings River Basin. Many of the communities and isolated domestic systems are reliant upon groundwater as their primary domestic water supply, while the majority of the surface water supply within the basin has been diverted for agricultural uses. Agriculture relies on groundwater to make up for (1) shortfalls in surface deliveries, (2) as the primary source of water where surface deliveries do not exist, and (3) as an "on-demand" supply for those who use drip/microsprayer systems, which require water more frequently than surface water delivery schedules permit.

Prior to the development of irrigated agriculture within the Tulare Lake Basin, the major rivers within the basin (Kings, Kaweah/St. Johns, Tule, and Kern) would bring considerable volumes of Sierra snowmelt into the valley and flood vast tracts of land with very clean (low hardness and EC) waters, which would eventually percolate into basin and become groundwater. In areas where the uplifted marine deposits were more dominate (west of the valley trough), salts washed from these soils would also be deposited. The shallow nature of the water tables during this time would bring these dissolved salts back to the surface through capillary action as the Tulare Lake receded, thus leaving a "ring" of saline soils along its western and southern perimeters. These regions are still present today, but the land has been made productive through the use of drainage technologies such as tile drains and salt tolerant cropping.

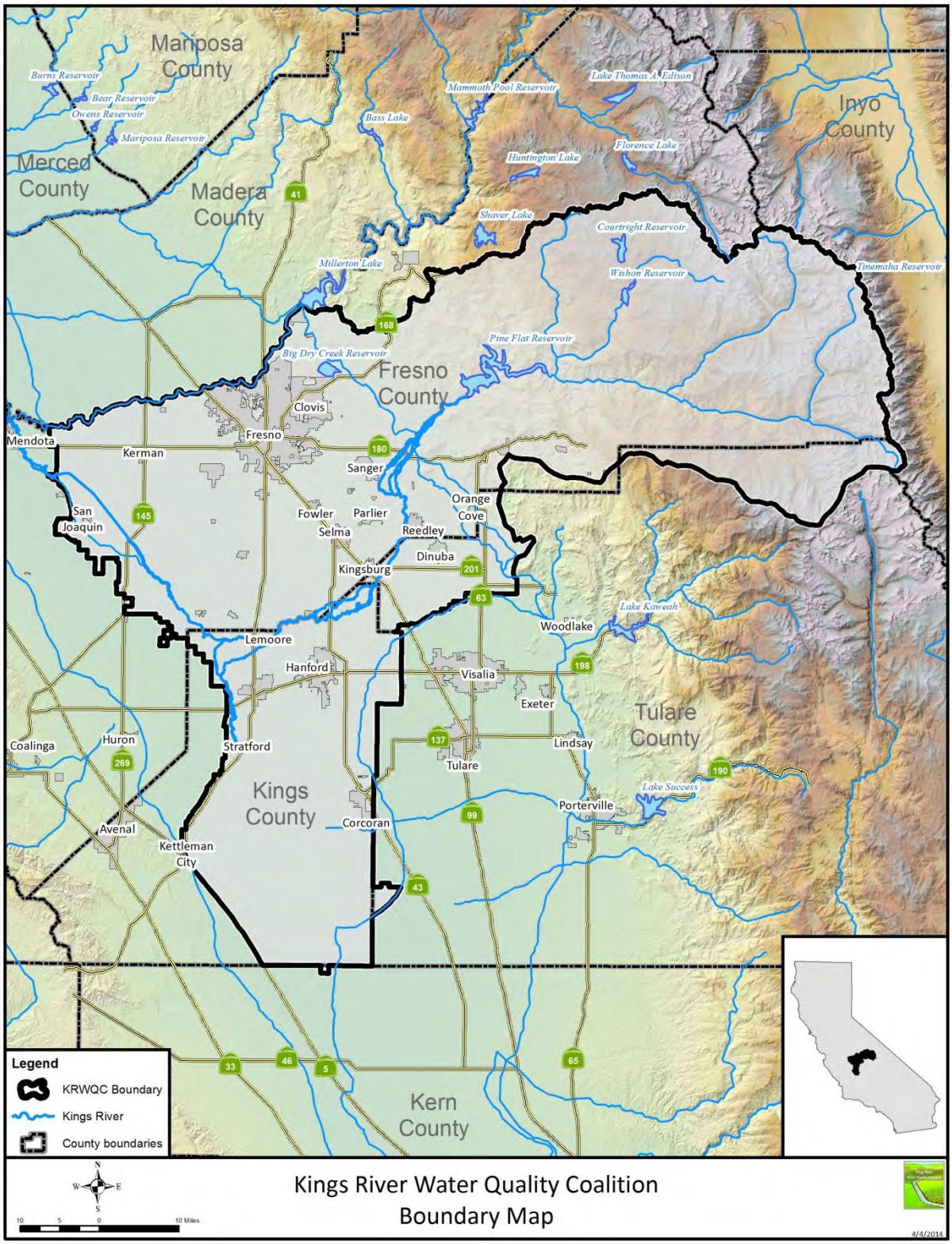
Irrigation supports approximately 49 major crops within the three counties covered by the KRWQC (plus some minor ones), which for 2013 had a gross value of over $12 billion. This represents the total crop value (excludes livestock and milk) for the three counties (Fresno, Kings, and Tulare); the total value within the KRWQC would be less due to only portions of Fresno, Kings, and Tulare Counties being covered by the KRWQC (2013 Agricultural Commissioner's Reports).

The Kings sub-basin is divided along political lines into the "Upper" and "Lower" basins. The Upper basin consists of the Fresno Irrigation District, Alta Irrigation District, and Consolidated Irrigation District, plus some smaller entities. These districts overlay a region with higher soil permeability, and due to superior water rights, have a generally higher reliance on surface water than on groundwater for irrigation. The Lower River has much lower soil permeability (finer textured soils), inferior water rights, and a greater reliance on groundwater for irrigation. The western portions of the basin (outside of the irrigation district boundaries near the North fork of the Kings) are entirely dependent upon groundwater.

Irrigation practices for the multitude of crops grown within the Kings Basin have evolved as greater understandings of crop-water relationships have occurred. Knowing that crop growth can be beneficially influenced by the application or withholding of irrigation water at critical times, growers have successfully increased crop yields and quality using less water than in years past.

Changes in cropping patterns over the years has promoted the conversion of irrigation systems from the regularly scheduled surface water deliveries to a more intensely managed micro irrigation system that allows for the maintenance of optimal soil moisture conditions (reduced or eliminated anaerobic soil conditions common to surface irrigation) and the matching of applied water to actual crop usage rates. This balancing of the water applied to the water used has led to a significant reduction in deep percolation of excess irrigation water during the growing season, and has increased the available soil capacity to absorb winter rainfall before erosion can take place. Many growers rely on winter rains to handle the leaching requirements needed to remove harmful salts from the rootzone (or to remove them from the soil surface back into the lower reaches of the active rootzone and away from the more active roots near the soil surface). As a consequence of this higher management level, in-lieu recharge that resulted from previous flood irrigation practices has been reduced, and the overall rate of groundwater replenishment

Figure 1: KRWQC Map



has decreased. The flip side of this is that there is less opportunity for unused nutrients or other soil-applied chemistries to migrate out of the root zone and eventually into the underlying aquifer.

It would appear from the available data that the agricultural practices of the past, while scientifically and economically justified at the time, may have created some degradation in the underlying groundwater. The primary constituent of concern that has triggered this management plan, nitrate, has multiple sources within the basin (application of fertilizer (commercial and home), dairy or other confined animal operations, and septic systems). This constituent has generally not been detected in surface waters used for irrigation.

Nitrate is one form of nitrogen that a plant must translocate into its roots to produce proteins (ammonium being the other), and is highly mobile within soil water. The State Water Resources Control Board, along with the UC Davis report on Nitrate Contamination within the Tulare Lake Basin (Harter et. al. 2012), determined that animal operations and septic systems are minor inputs; that the majority of nitrate could be traced back to irrigated agricultural operations. Preliminary data from the Regional Board regarding confined animal operations suggest that they have localized impacts upon groundwater, and the KRWQC suspects that septic systems behave in a similar fashion.

TDS (Total Dissolved Solids, aka salts) is addressed within the Groundwater Assessment Report for the Kings Basin, but this constituent can be heavily influenced by natural geologic conditions, and is therefore being considered as a low priority. High TDS waters can be found at greater depths within the Tulare Lake Basin hydrologic region (below the Corcoran Clay layer), and these layers are typically avoided by the users of groundwater. The regions where nitrate is an issue is the focus of this CGMP. TDS issues will be addressed through the KRWQC's participation in the CV-SALTS process as needed.

Because of the depth and impermeable nature of the Corcoran Clay, aquifers below this layer are not being addressed by this CGMP.

The KRWQC has expressed concerns with the findings of the Harter report, primarily the age of the data used along with other issues. It is felt that some septic systems may have a greater impact upon groundwater quality on a local basis, given the proximity of domestic wells and septic leach fields. Such a relationship would require further study to verify. This type of study would be included within the management plan.

It is also felt by the KRWQC that *current* agricultural practices *are* protective of groundwater quality, primarily because of the adoption of more sophisticated irrigation scheduling and application techniques, changes in recommended cultural practices, better nutrient management (crop needs and pest management relationships), and the economics of input costs versus increased yield or value (return on investment). If it is proven that current practices are protective, then the issues seen within the groundwater basin must be due to past practices, and thus are legacy issues. Harter indicated that in such cases, conventional remediation would be economically impractical, but long term improvements in groundwater quality would occur. The analysis of the Farm Evaluation Template data combined with the proposed MPEP studies will determine whether the surface activities are protective or are in need of adjustment.

COCs SUBJECT OF PLAN

Nitrate in groundwater is the primary focus of this groundwater management plan. As stated above, nitrogen (either as nitrate or ammonium) is essential for plant growth through the synthesis of proteins. Only legumes can supply their own nitrogen needs (through a symbiotic relationship with certain bacteria species), all other crops must have supplemental nitrogen applied to produce an economic yield. Climatic and soil conditions within the KRWQC service area (as well as many other areas of the valley) do not support the accumulation of sufficient supplies of organic matter to provide a reliable nitrogen source.

Nitrogen demands are known to vary during the growing season, and many growers pre-load the soil with an available nitrogen source just prior to the peak demand by the crop. Additional supplies are made available (either as soil/irrigation water applied or foliar) as crop conditions dictate, if necessary. Permanent plantings may see a post-harvest application to enhance the performance of the crop for the next crop year. The practice of supplying a majority of the nitrogen demand for a crop prior to planting is rapidly disappearing.

The varied sources of this constituent plus the potential for future increases in constituent concentration in groundwater before decreases occur make this plan an exceptionally long term one. The EPA has set a Maximum Contaminant Level of 10 mg/L NO_3-N (nitrate as N) or 45 mg/L as nitrate and a number of wells tested have shown levels in excess of that amount. The exact source of this nitrate has not been determined (naturally occurring, septic, confined animal operations, other discharges, or agricultural runoff), but the fact remains that it is there and irrigated agriculture is a possible source.

Total Dissolved Solids (TDS) is a measure of the amount of dissolved materials within a water sample. Any pumped groundwater is going to have some level of TDS within it; the question is the source and what level is present. Because it is naturally occurring, no actions are being proposed under this CGMP, but it will be addressed through our involvement with the CV-SALTS process.

OBJECTIVES

Under the Water Quality Control Plan for the Tulare Lake Basin (updated January 2004), the objective for nitrate within the basin is tied to its beneficial uses. Nitrate is not a serious issue for agricultural uses, although its presence in water at the wrong time of year can impact yield quality. Other users can remove the nitrate from the water supply, with the exception of Rec-1 and Rec-2 uses. The majority of the basin lists MUN as a beneficial use (a study to amend the Basin Plan to remove the MUN beneficial use for the Tulare Lake region is underway), and as such, the beneficial use must be protected. Larger communities have the resources necessary to remove nitrate from the water supply (or have sufficient other sources (deeper wells e.g.) that can blend the water to below the MCL. Smaller communities and individual domestic wells may not have sufficient resources to treat the water supply, and may need to secure alternate drinking water supplies (bottled water). The MUN designation provides the most restrictive water quality standards, and thus will be used as the objective for this CGMP.

The TDS standard for AGR is set at 450 mg/L, a narrative standard based on agricultural research. TDS is a secondary standard, related more to the aesthetic quality of the water (clarity, taste) than an actual health standard. Salty tasting water is related to chloride based salts (sodium or potassium), while bitter tasting water is related to carbonate/bicarbonates associated with calcium or magnesium. The secondary standard is typically set at 500 mg/L. High TDS values can be an indicator of the presence of other minerals (arsenic, copper, aluminum) as well as other anions (nitrates). The CV-SALTS process is looking at the standard for possible revision.

REGION COVERED BY CGMP AND HOW DETERMINED

The region covered by this CGMP has been determined by the results of the GAR analysis conducted for the KRWQC. The region will consist of the following land areas as determined by the GAR:

1. Sections identified as High Groundwater Vulnerability, excluding sections located underneath the Tulare Lake Basin's MUN de-designation study
2. Sections identified as having an nitrate exceedance, unless those sections are within identified city boundaries (county islands that may still have irrigated agriculture are left in the program)

Some lands will be excluded from the program because of potential coverage under another WDR program (specific WDR for a particular site or Dairy Order). The KRWQC has excluded these due to existing regulatory coverage and resource prioritization. The impacted sections may still be monitored once a dedicated groundwater quality monitoring network is established.

Areas designated as "High Vulnerable" from the GAR analysis were found to be that way through the use of a proprietary "GAR Analyst Tool" developed by GEI Consultants, Inc. This application took intrinsic conditions (fixed values) and combined them with assorted vulnerability (variable) factors to create GIS layers that totaled the assorted risk indices for each category and then calculated the top 15 percent of values has high vulnerability. The values considered are shown in Table One.

Table One: Factors Considered by GAR Analyst for Vulnerability Designations

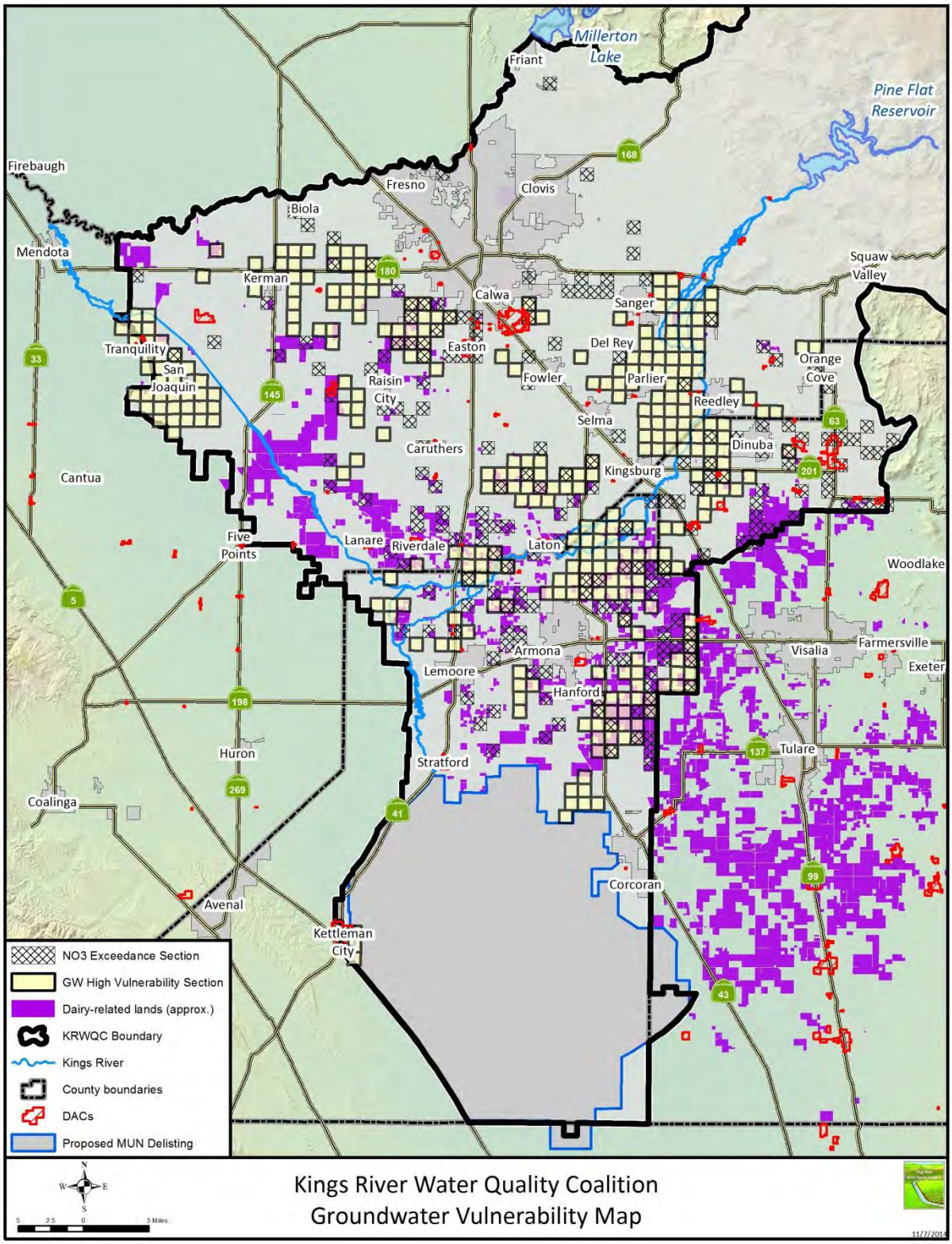
Intrinsic Values	**Vulnerability Values**
Soil Permeability	Regional Vulnerability (artificial recharge, conjunctive uses, imported water, reservoir operations). May also include septic systems, wastewater recycling, surface or groundwater treatment plants
Soil Transmissivity	On-Farm Vulnerability (nutrient application and timing, methods of application, irrigation system, and cropping
Depth to Groundwater	Drinking Water Vulnerability
Aquifer Thickness	
Clay Layer Thickness	
Natural Streamflow	

Each characteristic is assigned a value, and the layers are tabulated. For example, soils with low permeability would be ranked low (value set at 1) where high permeability soils would be ranked higher (value set at 5 or greater, depending on the number of categories). Greater depths to groundwater would rank low; shallow or perched groundwater would rank higher. Some characteristics may not be present within a particular study unit (square mile), and that characteristic would receive a rank of zero.

Like any other GIS output, the final determination of vulnerability can be adjusted for those factors that on a subjective level can be either factored in or factored out. In the case of determining the which areas are to be considered high vulnerability, it was determined that the impacts of Dairy operations needed to be included within the GAR Analyst Tool's output, as additional layers. This data, supplied by the Regional Board staff, showed that some, but not all, of the nitrate exceedances could be tied to Dairy operations. As these are covered by a separate Order, these sections were removed from the vulnerability area.

The geographic layout of the GAR Analyst's vulnerability area is not one that can be contained within a simple polygon. The high vulnerability areas are defined as square mile blocks, which makes identification of the affected parcels more efficient, since parcel boundaries generally don't cross section

Figure 2: KRWQC Map with HV areas, Nitrate exceedances, Dairy influences, DACs



lines. The blocks do tend to group together, but some are islands or linked by single sections. The largest area of concern is located in an arc from northeastern Fresno County through northwestern Tulare County and northern Kings County. This is essentially the area east of Sanger to the area around Parlier but west of Reedley and Dinuba, circling southwest towards Hanford and westward to Laton, north of Lemoore (following a path almost parallel to the current river channel). Isolated areas west-southwest of Fresno (between Fresno and Kerman, around Biola) are also identified.

Another area is around San Joaquin/Tranquility, but this is likely due to the influence of perched water tables common to Westlands, and is being considered for a lower priority within the KRWQC area. Any studies within this region will be considered at a later date. The area north of the proposed MUN de-designation for the Tulare Lake Basin is also known to have perched water of marginal quality (high TDS), and is also known to be permitted for dairy operations.

The last area is located within Lakeside Irrigation District (west of the Kings County line) which is also heavily influenced by dairy operations.

Other regions of interest are areas of nitrate exceedances that do not overlay geographic areas that the GAR Analyst has identified as vulnerable or the Regional Board has identified as being under the Dairy Order. These regions are home to several Dis-Advantaged Communities (DACs (rural, low income communities)), and will be the subject of a specific testing program.

The total area covered by the CGMP is 299 sections (191,360 acres). This was arrived at in the following manner:

Category	Sections	Acres
High Vulnerability Sections	337	215,680
NO_3 Outside of HV Sections	157	100,480
NO_3 Impacted by Dairy	111	71,040
Dairy Impacted Sections outside HV Area	84	53,760
Totals	299	191,360

The total area is calculated by adding impacted High Vulnerability sections (HV Sections plus NO_3 Outside of HV Sections) and deducting those sections impacted by Dairy operations (NO_3 Impacted by Dairy plus Dairy Impacted Sections outside of HV Area). This was done because Dairy operations are not covered by this General Order. The KRWQC is mandated to address issues related to irrigated agriculture, and this CGMP is designed to address those issues.

PREVIOUS WORK CONDUCTED

Much of the Central Valley has been studied by the USGS and the groundwater flow patterns analyzed by the Central Valley Hydrologic Model (CVHM). This grid was the basis for the GAR Analyst, once the orientation of the study blocks was corrected to surface survey lines (Township/Range/Section). The data used in the GAR utilized all publically available data sources (outlined in Chapter 3 of the GAR), and extensive QA/QC review of the data was performed prior to analysis. Other work performed regarding groundwater quality is outlined in the GAR.

LAND USE

The following section includes maps of land use within the KRWQC. The last map will include the overlaid vulnerability data. The data is the most current available.

Cropping patterns within the KRWQC are generally zonal. Fruit tree crops (citrus, deciduous trees) are generally located in the eastern portions of the KRWQC (primarily in the Kings Basin), where winter weather patterns (fog layers, risk of frost or freezing temperatures) are minimized due to natural cold air drainage or elevation. Citrus dominates the highest portions of the irrigated lands in order to avoid hard freezes. There are orchards in other regions within the central part of the Kings Basin, but as the topography becomes more flat, field crops begin to dominate.

Deciduous nut trees (almonds, pecans, pistachios, walnuts) are more common in the western portions of the Kings Basin, with expanding almond acreages in the central basin areas where fewer salty soils are present and higher quality water (both surface and groundwater) are available.

Vines dominate the lighter textured soils in the central portion of the basin, where conditions are optimal for raisin production. Table grapes and wine grapes are also grown in this area.

The remaining lands are divided into various field crops (cotton, corn, alfalfa, hay, tomatoes, etc.). Many of the crops are grown in support of the large dairy industry present within the basin, and the lands are capable of multiple crops per growing season. A grower may plant wheat in November, harvest it as silage in March, and plant the first of potentially two corn crops immediately afterward. Cotton and tomatoes dominate the cropping in the Tulare Lake area. Permanent crops are not planted in this region due to the continuing possibility of flooding.

Irrigation practices vary according to crop type, topography, grower preference, and crop value. In lands that are primarily flat, gravity/flood systems (basin flood, furrow) dominate. Permanent plantings are more likely to have drip/micro sprinkler systems, as the value of the crop can support the initial capital investments. Buried drip lines in tomatoes are becoming increasingly common as growers learn how to use the technology properly. Experiments into using this technology in other field crops (cotton, corn, alfalfa) are progressing.

Drip/micro irrigation is very common in vineyard systems, and increasing popular in orchard situations. Such systems can be automated to run based on crop water usage or other weather factors, allowing for more precise water management. It also allows the grower to resume irrigations after harvest much sooner, thus reducing the induced stress on trees and vines.

Figure 3: Land Use

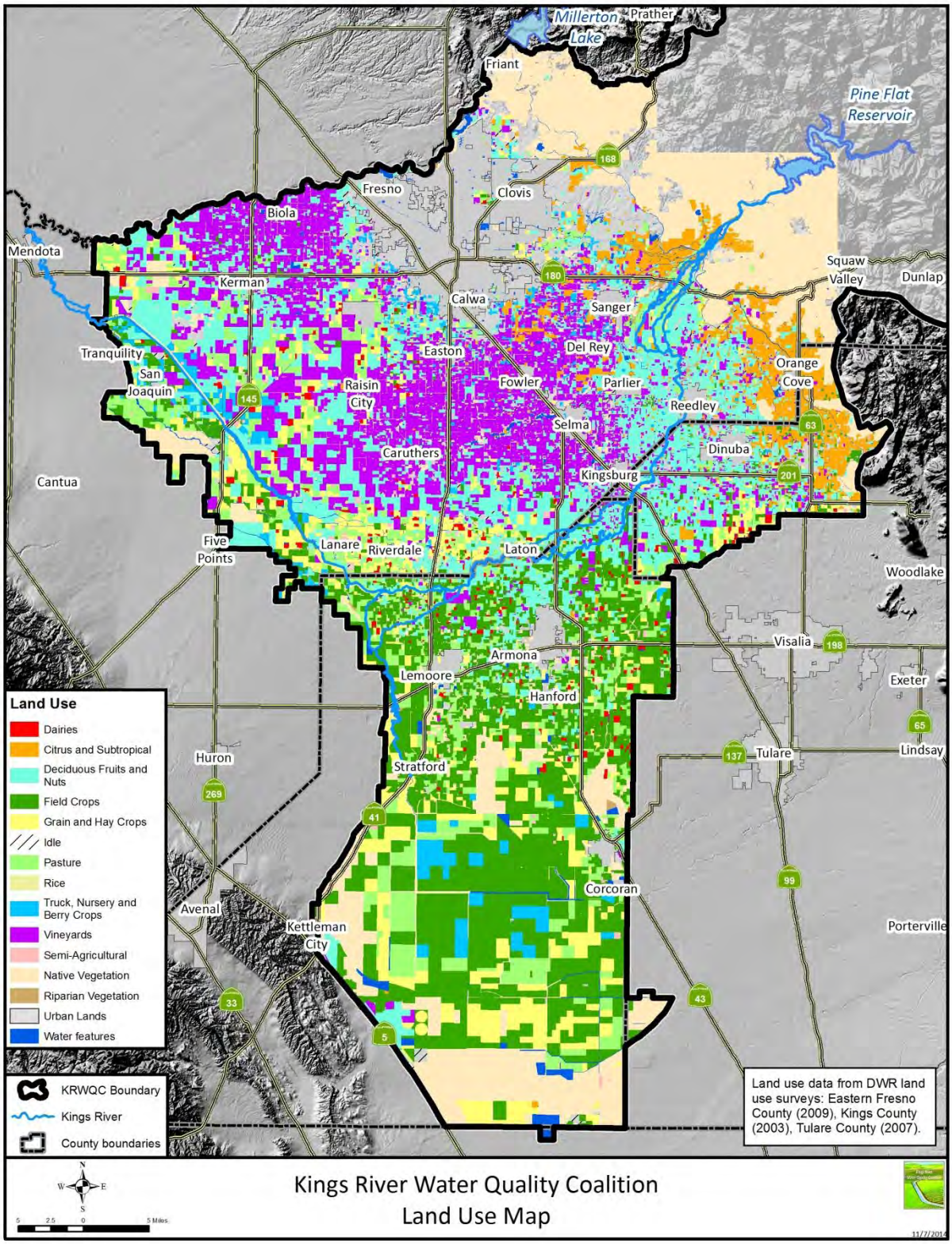
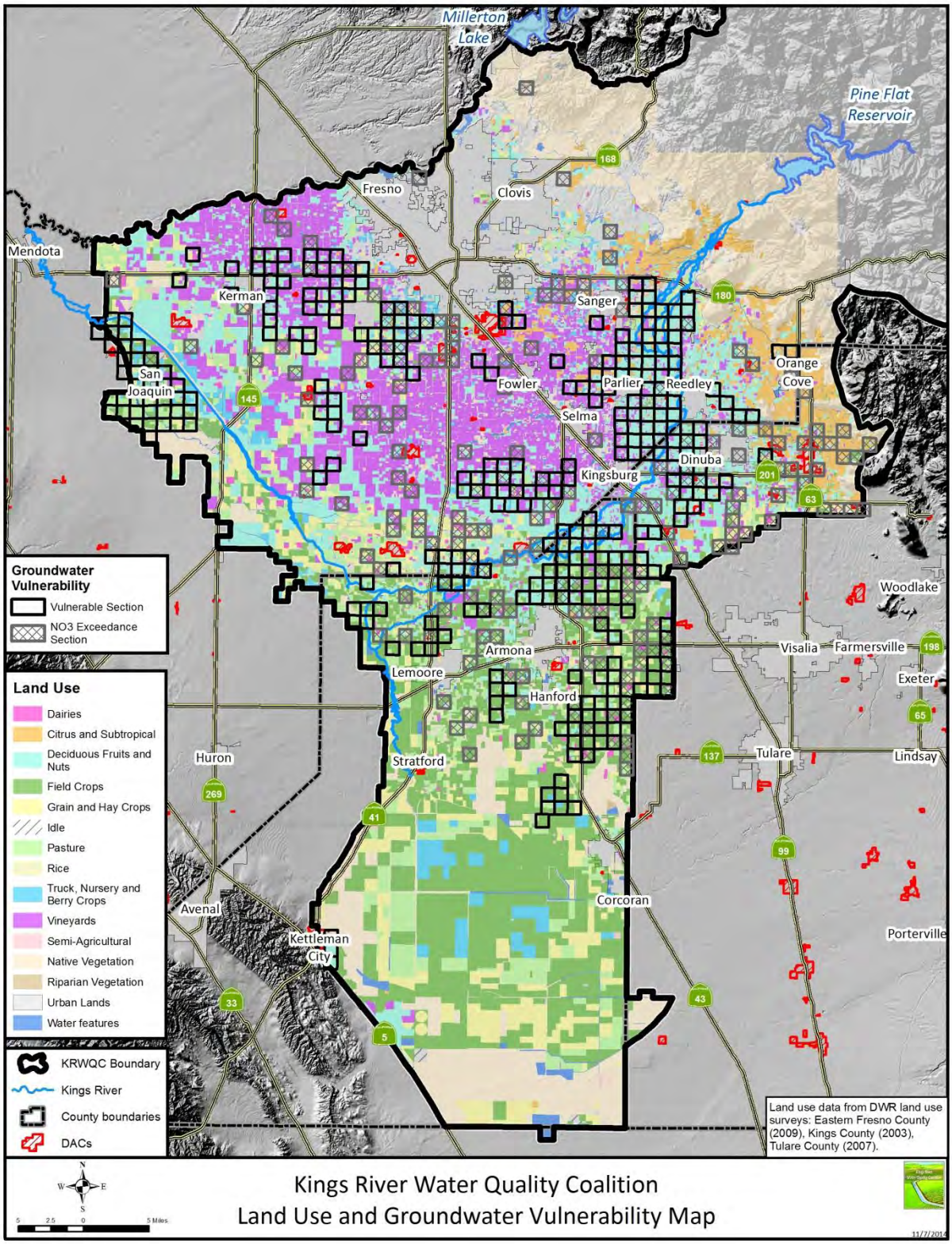


Figure 4: Land Use with HV sections, Nitrate sections, Dairy Land, DACs



POTENTIAL SOURCES

Nitrates are present from multiple sources within the valley. There is naturally occurring nitrate from mineral deposits and decaying organic material, leached nitrate from confined animal operations, leached nitrate from poorly designed or older septic systems, and leached nitrate from the synthetic fertilizers used in irrigated agriculture. According the Harter report, naturally occurring and septic sourced nitrates are minor contributors to the overall nitrate levels within valley aquifers. Agricultural sources (animal operations and synthetic fertilizer use) are theorized to be the dominant sources.

The KRWQC will be submitting a request to conduct a Source Identification Study (isotope studies) for nitrates within the area serviced by the Alta Irrigation District. This district is located in the eastern portion of the KRWQC service area, has several DACs located within its boundaries, and has both regions defined as high vulnerability according to the GAR and numerous nitrate exceedances that are currently not explained. The pilot study would be designed and conducted by Lawrence Livermore National Laboratory, with staff support from the KRWQC. Additional elements required by the General Order would be addressed by the KRWQC. The KRWQC hopes to pin down the source/age of the nitrate detected (natural, animal, septic, synthetic), thus determining the course of corrective actions. Should the method be proven valid, the KRWQC will consider an expansion of the testing over a broader area.

BENEFICIAL USES

Groundwater within the KRWQC has several beneficial uses outlined within the Water Quality Control Plan for the Tulare Lake Basin (second edition, January 2004). Primary among the uses is MUN. Groundwater is the primary source of drinking water throughout the KRWQC, although the use of treated surface water is increasing in the Fresno area and soon to be available within Alta Irrigation District. Domestic drinking water is typically in the unconfined aquifer above the Corcoran Clay formation (where present), with municipal supplies typically coming from the deeper confined aquifer (below the Corcoran Clay). Multiple aquifers exist below the Corcoran Clay formation level (approximately 500 ft. below the surface), and the water quality varies considerably between each layer.

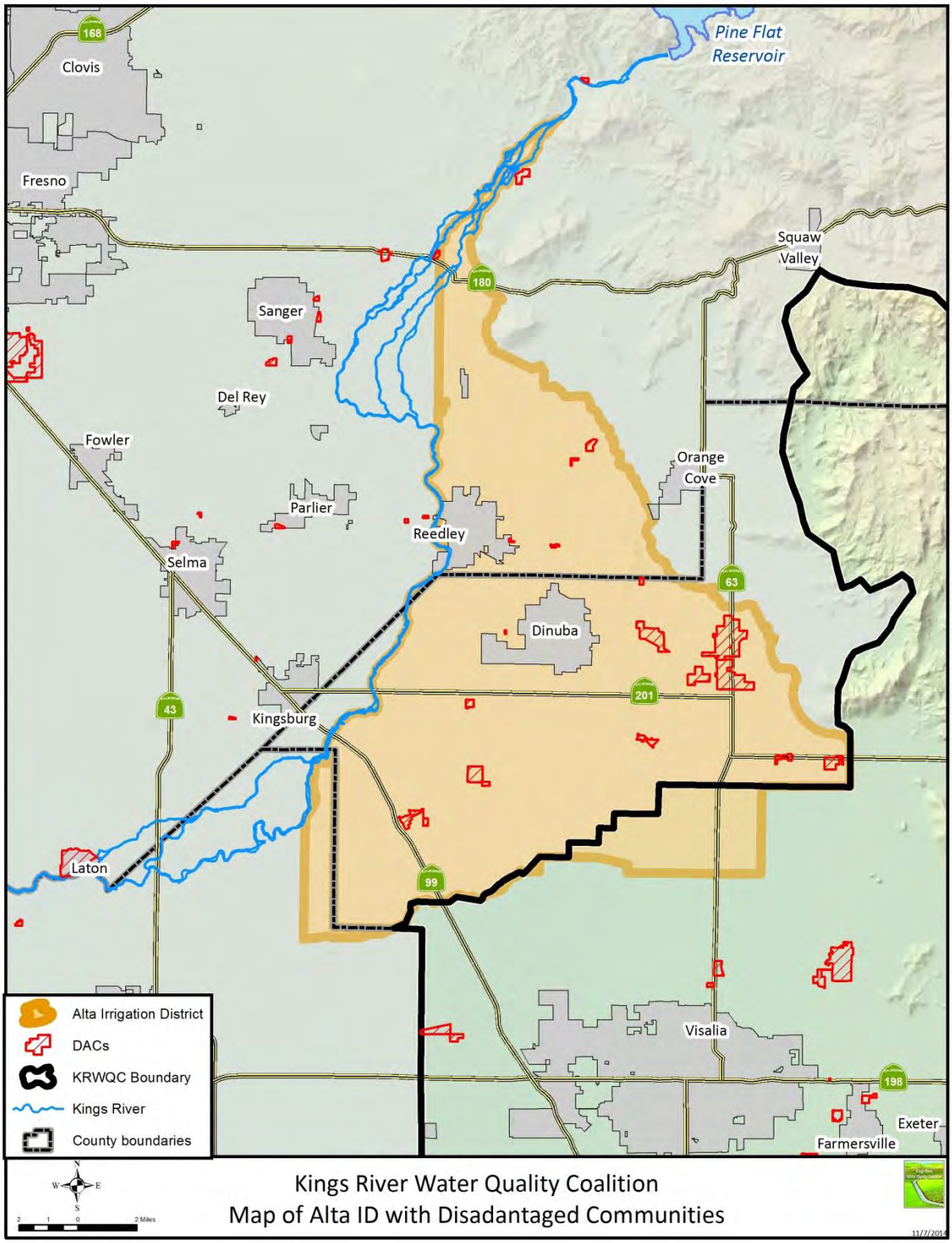
Other beneficial uses within the Tulare Lake Basin plan include AGR, IND, PRO, REC-1, and REC-2. REC-1 and REC-2 are of limited value, as pumped groundwater is generally too expensive for use as lake water for swimming or other recreation under normal circumstances. AGR and PRO are more common, and IND is only used on a limited basis.

BASELINE INVENTORY OF MANAGEMENT PRACTICES

Management practices on agricultural operations vary according to what each individual farmer has found to work best for their operation. Generalized practices can be grouped according to crop type, and an approximate list can be prepared for this management plan. The completion of the Farm Evaluation data analysis will further define the practices used, as well as provide location data for each practice.

Herbicides, which are not currently a Constituent of Concern (COC) within the KRWQC, are typically applied in two phases: pre-emergence and post-emergence. Pre-emergent materials are applied to cropland to control weeds before they have a chance to germinate by creating a chemically treated layer at the surface that either kills the weed seeds or kills the weeds as they emerge. Rainfall is a popular method of incorporation, as the herbicide is kept within the top inch of soil. Mechanical incorporation is used just prior to planting if the grower is unsure of what crop will be planted or the amount of available irrigation water for the upcoming season.

Figure 5: KRWQC Map showing Alta ID and DACs



Post-emergent materials are used once the weed species is identified, so that appropriate control chemistries can be selected (grass or broadleaf species, contact or systemic mode of action).

Nutrients are applied using a variety of methods. The most common is a dry soil application (band or broadcast) that is later incorporated by irrigation water. Such materials can be tailored to the needs of the crop (more or less nitrogen, phosphorus, or potassium). Broadcast is common for field crops prior to soil tillage in the winter while the soil is still dry; the applied fertilizer prills are kept in the top 6 inches of soil for the next season's crop. Band applications are used in orchards where a thin strip of fertilizer is placed on the berm, and irrigation water dissolves a small portion of the fertilizer and carries it into the rootzone for the tree roots to absorb. Applications occur either in the late fall before the post-harvest irrigation takes place (thus providing nutrients for the tree before it goes dormant for the winter) or in the spring as the nutrient demand of the trees increases following leaf out. Another method of band application is the direct injection of fertilizer into the rootzone (similar to band applications) during either the pre-plant operations or as a side-dress (post-emergent) application in field crops.

Growers with drip/micro irrigation systems can add fertilizers directly to the irrigation water and insure that fertilizer is applied with high uniformity throughout the field. The application can be set up to distribute the fertilizer such that once the desired amount is applied, the system is shut off and the fertilizer remains in the top soil where the majority of roots exist. In field crops, the fertilizer can be added to the irrigation water, thus covering the entire irrigated field with nutrients for the roots.

Foliar applications are available to apply micro-nutrients (those nutrients needed in small quantities) in situations where a nutrient deficiency is noted mid-season. The nutrients are applied directly to the leaves where it is absorbed. These are typically combined with pesticide applications for efficiency.

Crop: Tree Fruit (Citrus, Deciduous Tree Fruit)

Task	Action	Timing	Why	Risks
Weed Control	Pre-emergent application	Late Fall to Early Winter	Use natural rainfall for incorporation of weed control material without soil disturbance, leaves material in top ¼ to ½ inch of soil surface	Runoff from high intensity rain fall, use of water soluble materials could leach
	Post-emergent application	As Needed	Frost Issues, Insect/Disease Host	Low unless excessive rain after
Nutrients	Soil Applied	Post-Harvest (previous year), Pre-Plant/Early Season	Replenish nutrients prior to next crop cycle	Runoff from high intensity rain, leaching
	Fertigation	As Needed with irrigation water	Adjust nutrient status based upon better than expected weather, crop growth	Low, unless insufficient safeguards in place at pump
	Foliar	As Needed	Emergency nutrient deficiency correction	Low, overspray into surface water
Pesticides	Pest Control	As Needed, when target pest reaches economic damage thresholds, preventative applications	Protect cosmetic quality of fruit, tree health and yield	Overspray into surface water

Crop: Deciduous Nut Crops (Almonds, Pistachios, Walnuts, Pecans)

Task	Action	Timing	Why	Risks
Weed Control	Pre-emergent application	Late Fall to Early Winter	Use natural rainfall for incorporation of weed control material without soil disturbance, leaves material in top ¼ to ½ inch of soil surface	Runoff from high intensity rain fall, use of water soluble materials could leach
	Post-emergent application	As Needed	Insect/Disease Host	Low unless excessive rain after
Nutrients	Soil Applied	Post-Harvest (previous year), Pre-Plant/Early Season	Replenish nutrients prior to next crop cycle	Leaching
	Fertigation	As Needed with irrigation water	Adjust nutrient status based upon better than expected weather, crop growth	Low, unless insufficient safeguards in place at pump
	Foliar	As Needed	Emergency nutrient deficiency correction	Low, overspray into surface water
Pesticides	Pest Control	As Needed, when target pest reaches economic damage thresholds, preventative applications (fungicides)	Protect cosmetic quality of fruit, tree health and yield	Overspray into surface water

Crop: Field Crops

Task	Action	Timing	Why	Risks
Weed Control	Pre-emergent application	Late Fall to Early Winter, Early Spring prior to planting	Use natural rainfall for incorporation of weed control material without soil disturbance, leaves material in top ¼ to ½ inch of soil surface (Spring – mechanical incorporation)	Runoff from high intensity rain fall, use of water soluble materials could leach
	Post-emergent application	As Needed	Insect/Disease Host	Low
Nutrients	Soil Applied (band or deep injected)	Post-Harvest/Pre-Plant	Replenish nutrients prior to next crop cycle	Leaching
	Fertigation	As Needed with irrigation water	Adjust nutrient status based upon better than expected weather, crop growth	Low, unless insufficient safeguards in place at pump
	Foliar	As Needed	Nutrient deficiency correction	Low, overspray into surface water
Pesticides	Pest Control	As Needed, when target pest reaches economic damage thresholds, preventative applications (fungicides)	Protect cosmetic quality of fruit, crop health, and yield	Overspray into surface water

Nutrient applications have been refined considerably over the previous 20 years as increased research and economic pressures (material cost) have encouraged growers to become more aware of the amount of material applied. Excess nitrogen, for example, has been shown to increase pest pressure in certain crops

(cotton e.g.). The higher protein content of the plant sap supports higher pest populations, forcing the grower to use additional control measures. The control measures also reduce the beneficial insect populations, thus making it easier for the remaining pest population to recover to previous or higher levels. Growers who utilize Integrated Pest Management (IPM) practices look at the entire picture (nutrient and water stresses, pest and beneficial insect populations, crop growth stage, damage potential) before action is taken. An imbalance in any of these factors negatively affects the others. Excess nutrient levels in a crop can also have a negative impact on yield quality.

Fertilizer costs have risen in response to the costs of the energy necessary to produce the fertilizer (oil, natural gas). Other input costs (water, labor) have risen as well. Growers must now choose what inputs they can afford and what their return on that investment will be. In many cases, a grower can fertilize for maximum crop yield, but the cost of the inputs necessary are not recovered by the increased yield obtained (a dollar's worth of input returns less than a dollar of yield increase). Many growers now aim for maximum economic yield, where the cost of the inputs yields maximum return on investment (one dollar of input yields greater than a dollar of yield return).

These considerations have led to growers reducing their nutrient inputs or changing the timing and methods of inputs so as to match crop need (yield potential, nutritional status of the crop). Bulk applications in early spring are no longer standard practice, as growers realize that much of what is applied can be lost due to leaching from excess water application (irrigation or rainfall) or that the plant did not utilize the inputs because it was not needed yet (stage of growth). Growers are also becoming aware of the nutrient content of their pumped groundwater, and thus factoring that into their nutrient decisions. This will eventually lead to decreases in nutrient concentrations within the groundwater within the affected or high vulnerable areas. It is hoped that the data collected by the Farm Evaluations, Nutrient Management Plans, and the Management Practice Effectiveness Program (MPEP), when combined with groundwater monitoring data, will accelerate this process.

APPLICABLE GROUNDWATER DATA

The majority of the analysis of available groundwater data was performed during the preparation of the GAR (Chapter 3). The data is reflected in the defined areas of vulnerability and those areas that show nitrate exceedances. The KRWQC plans to create and monitor a groundwater quality network throughout the Coalition area in order to create a dataset of current water quality data, measured at fixed points on a regular schedule. Such a grid does not currently exist, although previous monitoring efforts did have similar goals. The data from such a study will help consolidate where the vulnerability areas actually are within the basin. Regions with documented exceedances will have higher densities of monitored wells, more frequent sampling, or both.

The available data was reviewed for appropriate QA/QC, and data that lacked sufficient levels of review were examined again. The time scale of the available data was also reviewed, so that the most current data available would be used in the analysis.

The available data was subdivided into a variety of categories for analysis, and then the data sources were ranked as to quality. CVHM-ModFlow data consistently scored highest as to quality of data, availability, and usefulness for the overall evaluation of the groundwater basin. Groundwater data from CV-SALTS, GeoTracker, Harter Report, and GAMA also scored high.

SOIL TYPES, GEOLOGY, AND HYDROLOGY

The affected areas of the groundwater basin have been evaluated using the GAR Analyst developed by the KRWQC's consultant, and each of the identified sections has been identified as having a number of intrinsic characteristics that could lead to groundwater being vulnerable. These characteristics include soil permeability, soil transmissivity, depth to groundwater, aquifer thickness, clay layer thickness, and natural streamflow. When combined with vulnerability values such as regional vulnerability (proximity to artificial recharge, imported water use, etc.), on-farm vulnerability (farm management practices), and drinking water vulnerability, individual sections of land could be identified as being higher risk to groundwater than others.

The KRWQC regions where this management plan will be applied consist of the irrigated lands located within the valley portion of the KRWQC service area. This region is composed of alluvial materials of various textural classes that have been deposited over millennia. The sloping nature of these deposits has created aquifer zones of varying thicknesses, with shallow, easily recharged aquifers lining the eastern boundaries, and deeper aquifers being present further west in the deeper alluvium.

The valley was once an inland sea, with fresh water coming from the rivers that originated in the mountains to the east (the current Sierra Nevada and the ranges that existed previously). As uplift continued and the sediments that compose the Coast Ranges were raised out of the shallow sea, fresh water began to dominate the valley and the nature of the deposits changed. The valley divided into two basins, the Sacramento-San Joaquin River basins which naturally drained out to sea via the delta, and the Tulare Lake Basin which found itself cut off except in periods of extreme flooding. This cutting off of the Tulare Lake from the balance of the valley led to very thick clay deposits and relatively impermeable soils and strata.

The deposition of the alluvium was not a constant process, and long periods of stagnant waters were evidently present which created clay lenses of varying thicknesses within the valley. Some layers are only a few inches to a few feet thick and generally do not restrict water movement to any great degree. Some regions have much denser clay layers that actually prevent water movement through them, thus creating a perched water table that moves horizontally until the edge of the clay layer is found before moving downward again.

Within the valley floor portion of the KRWQC, three major clay layers are recognized to exist. The first is the "A" clay, which exists in some regions at a depth of approximately 60 feet below the soil surface. This layer is fairly thick and can impede water movement to such a degree that a shallow aquifer is created. This is known to exist north of the Kings River in the region around Lemoore and out towards Five Points and Helm. This layer is frequently fractured (discontinuous), and water above will move laterally until an edge or crack is found, after which it resumes its downward travels.

The second layer is the "C" clay, which is found around 250 feet below the soil surface. This layer is much like the A clay above it, and holds a considerable volume of water above it. It is found in the same areas as the A clay. The aquifer above the C clay is one of the most utilized within the basin due to its great well yield characteristics and ease of access. The A and C clays have higher amounts of sand and silt than other layers, which contributes to their limited permeability.

Figure 6: KRWQC map with known clay layers

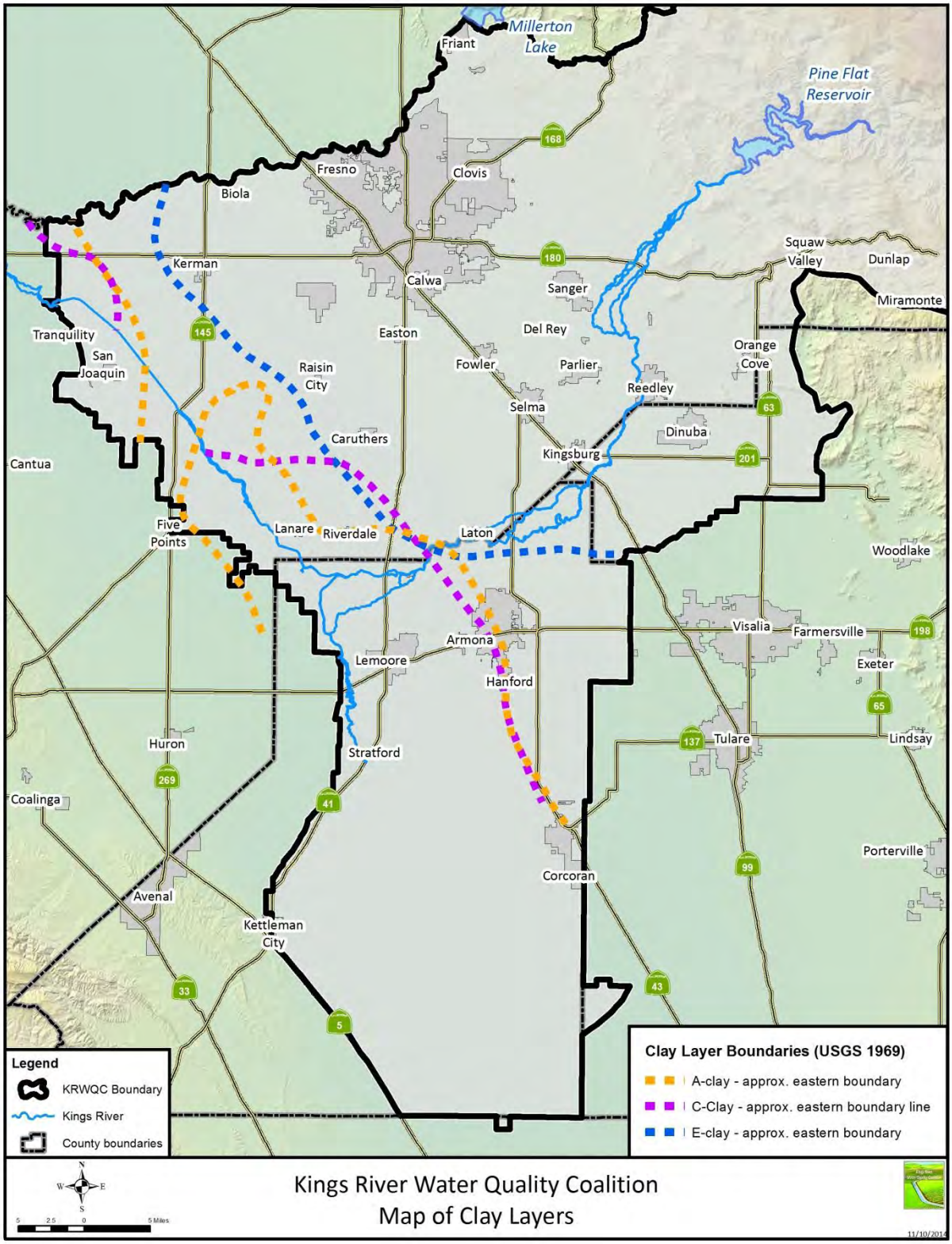
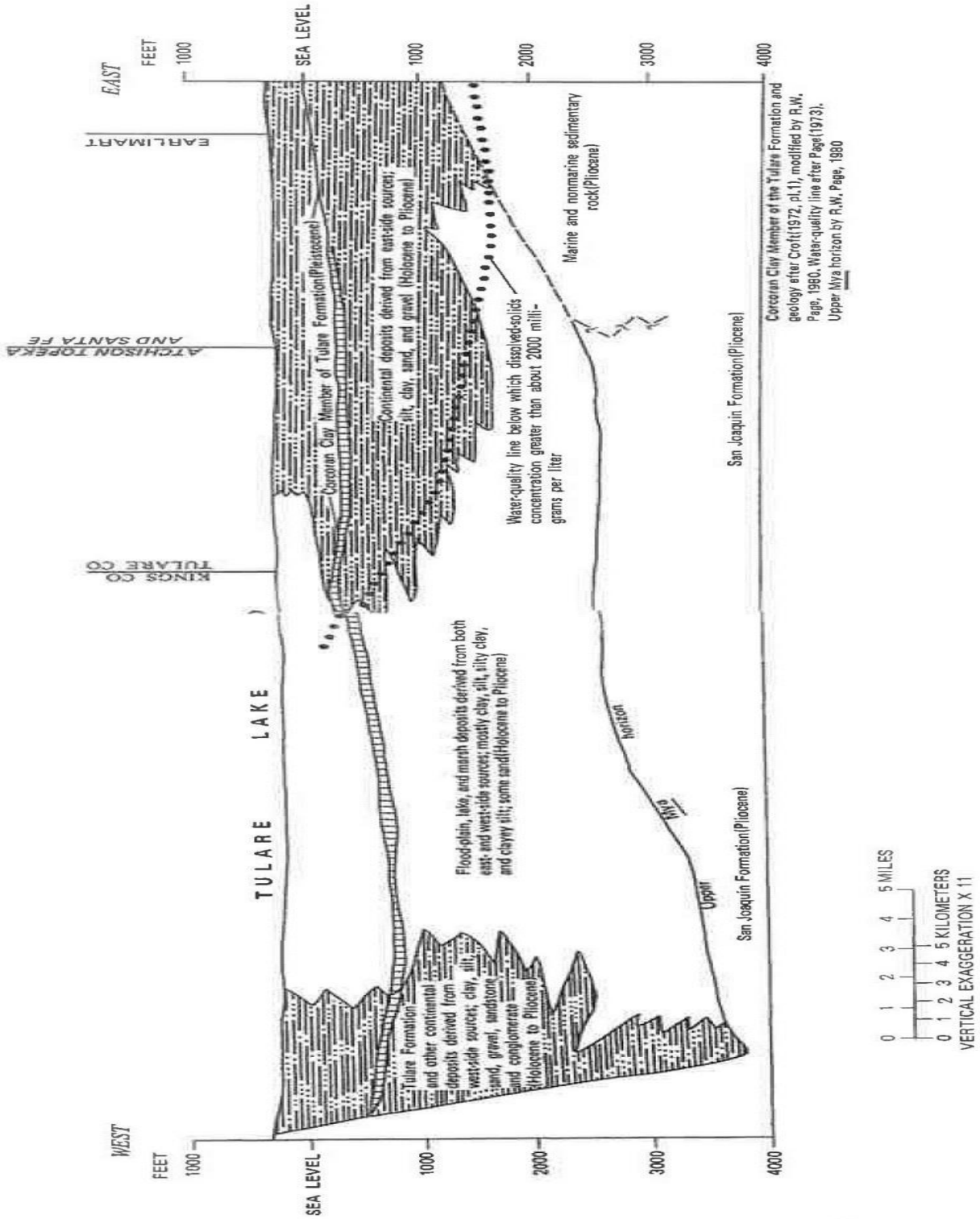


Figure 7: General Cross section of Valley



The last layer is the "E" clay or Corcoran Clay layer at about 500-600 feet below the soil surface. The Corcoran Clay is the most restrictive clay layer in the valley, and is the boundary between the unconfined aquifers above and the vast amounts of water in the confined aquifers below. The Corcoran Clay layer is typically sought out because of its restrictive nature, thus insuring that water extracted below it is protected from surface activities. Many major municipalities extract their water supply from below this layer (when present, it does not cover the entire valley), while many agricultural users have wells only as deep as the Corcoran Clay.

A large number of aquifers exist below the Corcoran Clay with varying levels of water quality, many of which are saline (a reflection of the conditions when the sediments were laid down). Very few users tap water from these aquifers due to the cost of well construction and the dissolved constituents found within these ancient waters. These aquifers are not being addressed by this management plan.

Groundwater is recharged via the Kings River channel (recorded by the Kings River Water Association as channel losses), seepage losses from irrigation district canals, dedicated recharge basins used during flood and above normal water years, and by those landowners that continue to use surface irrigation as their primary irrigation method, surface soil conditions permitting. Many landowners have converted to drip/micro irrigation, which is designed to match applied water to crop usage. When operated properly, this method of irrigation does not apply enough water to contribute to groundwater recharge (not to mention that most of these systems are supplied by groundwater, not surface deliveries).

The soils within the KRWQC were originally sourced from erosion of a previous eastern mountain range plus more recent deposits from the Sierra Nevada. As the Coast Ranges were uplifted, deposits that had previously been submerged in a marine environment began to erode into the forming trough that would become the Central Valley. The deposits from the east formed alluvial fans that terminated near the valley trough (near the north fork of the lower Kings River), meeting alluvial fans that formed from the eroding Coastal Ranges. The soils formed from the eastern fans were generally coarse grained soils, readily permeable, and low in salt content. Soils from the Coast Range are higher in clay content and loaded with salts accumulated from their formation in a shallow sea. They are generally less permeable, and more prone to having perched water tables due to dense clay layers.

The Tulare Lake formed in a depression within the lower portions of the southern valley, and the waters from the four major rivers (Kings, Kaweah, Tule, and Kern) plus the many smaller watersheds filled the basin with freshwater each year. The lake would be sufficiently stagnant for prolonged periods, allowing for the suspended clay particles to settle out, creating thick deposits at the bottom of the lake bed. These deposits are excellent farm land, have very high shrink/swell capacity, but have very low permeability.

GROUNDWATER BASINS

The KRWQC covers one Department of Water Resources (DWR) groundwater basin (Tulare Lake) and two sub-basins (Kings Sub-basin and Tulare Lake Sub-basin). This CGMP covers lands identified as vulnerable within the Kings Sub-basin, with the understanding that the current effort to remove the MUN beneficial use designation from the Tulare Lake Sub-basin places any designated vulnerable lands as low priority at present.

WATER CHEMISTRY

Groundwater chemistry is highly variable within the KRWQC. Depending upon where the sample is collected, the water ranges from odorless, low EC, low hardness, neutral pH to waters with elevated EC, strong sulfur smell, high hardness, and alkaline pH. The aesthetically poor water is generally found on the west side (near marine origin deposits), although deeper water can contain the same poor qualities anywhere within the basin.

A variety of metals are known to exist within the groundwater locally. Arsenic can exist at levels both below and above MCL levels; iron, magnesium, calcium, sulfur (as sulfide), carbonate/bicarbonates and other naturally occurring compounds are also present. Nitrates are found in various regions, with multiple possible sources. In those regions where it exceeds the MCL, future isotope testing (if expanded past the pilot program currently proposed) will attempt to pinpoint the source. A mapping of concentrations of major cations/anions, hardness, pH, TDS, and nutrients has not been conducted, but the trend testing mandated by the General Order will provide basin-wide data on such constituents.

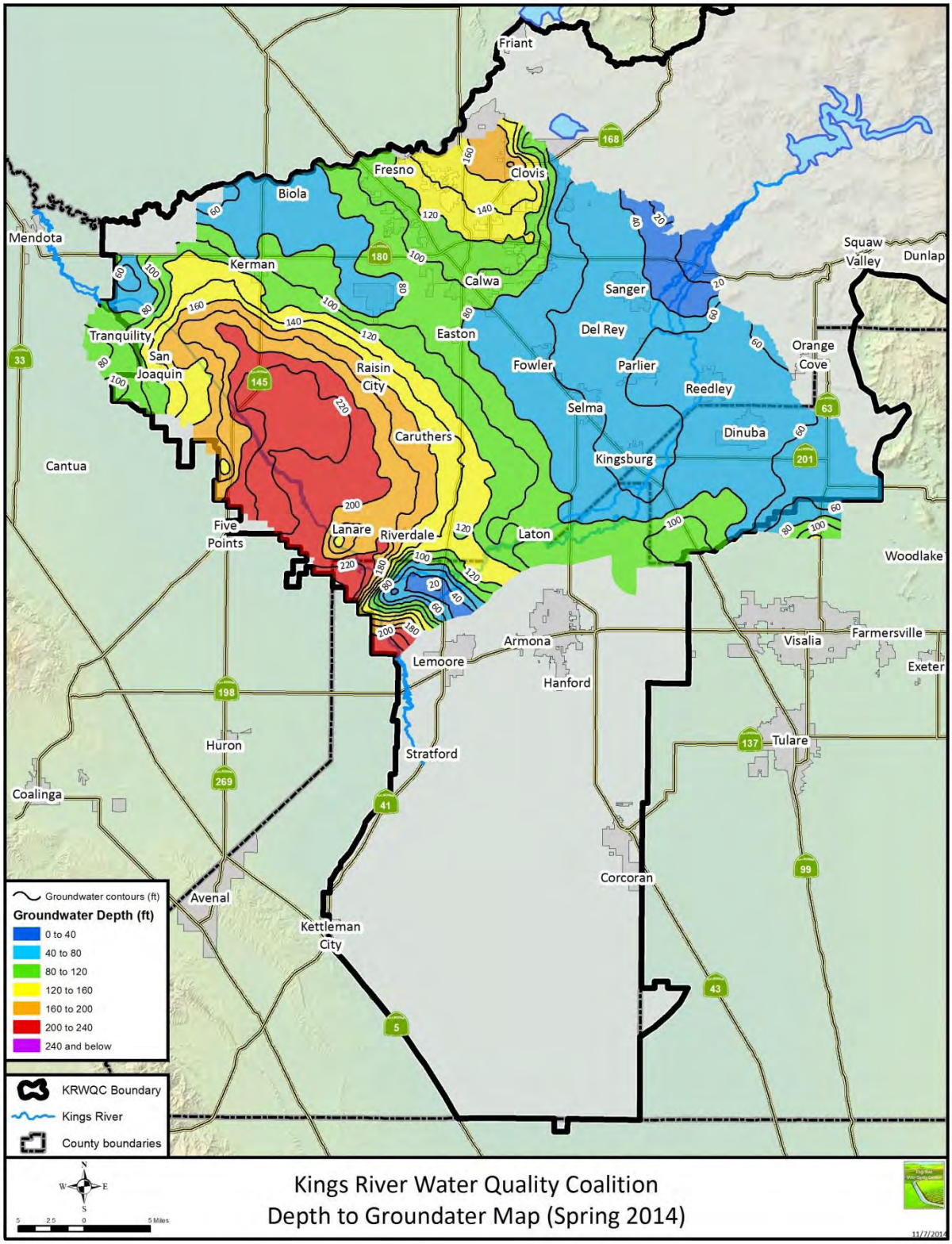
KNOWN WATER BEARING ZONES

Groundwater levels vary considerable throughout the KRWQC. It is generally shallower to the east (about 20 ft. below the soil surface) and considerably deeper as one moves towards Helm/Five Points (depths in excess of 225 ft. are common). A few groundwater facts regarding the basin are as follows:

1. Perched Water is typically found in the western portions of the basin where discontinuous clay formations near the soil surface inhibit the downward flow of applied irrigation water. Much of this has been corrected through the use of tile-drainage systems and conversion to micro irrigation systems.
2. Multiple unconfined aquifers exist around the Kings River channels. Water can be found above the A clay at 60 ft., in the aquifer between 60 and 250 ft. (C clay), and the aquifer between 250 and 500 ft. (E clay or Corcoran Clay). These layers are present north of Lemoore, but rapidly disappear as the clay content rises south of Lemoore. Perched water becomes a problem in this region, and salt deposits are visible at the soil surface.
3. Multiple confined aquifers exist beneath the Corcoran Clay layer. Some of these waters are usable for MUN or AGR, many are saline and unusable. Very few water wells are drilled below 2500 ft.

Recharge occurs in any surface water conveyance (river channel, ephemeral creek, irrigation district canals), and dedicated recharge basins throughout the KRWQC. The Kings River, under normal circumstances, has water present in the upper reaches of the river (Pine Flat to Hwy 99) year round. Additional recharge occurs when irrigation deliveries are made to lower river water rights holders, either

Figure 8: 2014 Depth to Groundwater Map



through the lower Kings River (Hwy 99 to the Tulare Lake (South Fork) or James Weir (North Fork)) or in the numerous irrigation district canals that pass through the region. Irrigation canals are typically active from May through October, depending on the water year and the irrigation district. With the exception of the Fresno Irrigation District's canals through Fresno, most of the irrigation canals within the KRWQC are unlined. Several segments of the Friant-Kern Canal are unlined as it passes through the KRWQC, but the soil permeability in these reaches is very low.

Fresno ID, Alta ID, and Consolidated ID maintain extensive recharge basins within their district boundaries. Fresno and Alta's basins are managed as water banks (meaning that only a portion of the recharged water can be withdrawn later); most of Consolidated's basins are managed for recharge only. Fresno's most famous recharge basins, Leaky Acres, are filled with the city's allocation of San Joaquin River water most years, and Kings River water when available. All three districts are looking at expanding their recharge capabilities (along with several other smaller lower river districts) to better capture available flood flows on the Kings River, thus addressing the chronic overdraft present within the Kings Basin.

WATER BEARING ZONES AND USES

Any of the aquifers present within the Kings Basin can be used for Domestic, Irrigation, or Municipal supply. The amount of water demand and the cost of the well's construction dictate which aquifer is preferred.

Domestic users typically tap into the shallowest available aquifer. During the current drought, many of these wells are going dry as the water tables fall below either the pump setting (how deep the pump itself is within a well), or the water falls below the drilled depth of the well. Domestic wells are typically no deeper than 100 feet in most of the eastern basin, and can be deeper than 150 ft. as one goes further west.

Irrigation wells are drilled to a depth of 300-400 ft. or more in order to produce the volumes needed for agricultural uses (typically 400 gallons per minute or more). The deeper wells allow for more slotted well casing (screens), thus allowing more water to enter the well and be pumped to the surface with a minimal amount of drawdown (the drop in water level caused by pumping). More drawdown means more lift is required, which reduces the volume a given pump can deliver.

Municipal wells are drilled much deeper, and have their well screens set as low as possible to avoid any contaminates from the surface. When wells are constructed in the regions where the Corcoran Clay is present, the well will be sealed at the clay layer, and pumping will occur below the clay layer only.

In regions where multiple aquifers are present, some wells are "composite" wells, meaning they draw from multiple aquifers. Such wells will need to be identified prior to any sampling program is initiated, because they do not behave in the same way as single aquifer wells.

AQUIFER CHARACTERISTICS

The Kings Basin is primarily reliant on the unconfined aquifer located above the Corcoran Clay layer. Water levels within the basin typically start at 20 ft. below the surface (east side) and falls at an increasing gradient until it bottoms out at 225 ft. or more near Helm and Five Points. The west side is almost totally dependent upon pumped groundwater for irrigation purposes, and as such, has created an extensive

groundwater depression in that region. Some recharge occurs during flood events (depending upon duration) from the Kings River channel, and several projects are underway to increase the utilization of this water supply for irrigation/recharge when available.

The general groundwater flow direction is (1) away from the river channels/canals and (2) from the northeast to southwest in response to the groundwater depression that has formed in the western basin. Some regions have groundwater flows in other directions (Alta ID groundwater can flow southeast towards Visalia), so the direction of flow can be highly localized in a direction other than in general trends.

Recent work for the Kings River Conservation District Groundwater Report has shown that the specific yields of the aquifer within the basin are more highly variable than originally thought. This may allow for faster groundwater movement in some areas, slower in others. This could explain why the groundwater gradients seen in the western basin are sharper than expected, and that recovery does not occur as much as anticipated during flood years.

WATER SOURCES AND CHEMISTRY

Surface water available within the majority of the basin is of exceptional quality, based upon ILRP testing since 2006. The water is very low in dissolved minerals, slightly acidic, and very low in electrical conductivity. The quality of the water does not vary greatly as one progresses from upstream to downstream, when the water is flowing. Once stagnant, it can quickly reflect the soil conditions present around it, becoming more alkaline and higher in EC.

Groundwater quality really depends upon where the water is collected from. Water goes from relatively pure (low EC, neutral pH) in the east to alkaline and higher in EC to the west. Hardness varies considerably within the basin. Depth of collection can also impact water quality, as deeper water has had much more time to dissolve naturally occurring metals from the surrounding formations (arsenic and magnesium e.g.). The closer the water source is to the marine deposits of the west side, the greater the chances of higher pH and EC values being found.

MANAGEMENT PLAN STRATEGY

The general Management Plan strategy is to conclusively identify the sources of nitrates (on a local and regional basis) and using the information gathered from the Farm Evaluation and Management Practice Evaluation Program (MPEP), suggest modifications to existing practices for those growers in the target areas. Effectiveness of the program will be through long term monitoring of groundwater quality at continuously monitored sites throughout the basin, and at higher density sites within the high vulnerability areas.

Monitoring of groundwater quality will be intensified (more wells sampled) within/down gradient of the high vulnerability areas as compared to the basin as a whole to further identify the regions of highest concern, and to provide additional water quality data for the next GAR revision. Where the basin will be monitored at a minimum of one well per township, high vulnerability areas could be monitored at a rate of one well ever three or four sections, or at any such density deemed to be necessary.

Specialized studies in close proximity to DACs will look at the interaction between domestic wells and septic systems, the density of such system combinations, and potentially additional detailed hydrologic studies. Such studies may be included in the isotope studies planned (see below), or may be intensified surveys of the proximity of domestic wells to septic leach fields.

PRIORITIZATION OF COCs

For the KRWQC's CGMP, nitrate is the primary COC to be addressed. This is because of the suspected sources of nitrate within the groundwater basin, the low MCLs that exist for the constituent, and the general recognition that drinking water quality is in everybody's best interest. The other COC discussed in the KRWQC's GAR is TDS, a COC that is naturally occurring and not correctable through actions at the soil surface. TDS is an aesthetic objective (clarity, smell, and taste) and does not have health issues associated with it, unlike nitrates. Filtration at the source can bring this COC under control for domestic purposes, and soil or water treatment amendments (gypsum, acid injection) can resolve the issue for agricultural uses.

Regions identified as high vulnerable and near DACs will be targeted first through the MPEP studies and intensified groundwater monitoring. Growers in the affected regions will be given substantial outreach encouraging them to have their individual water sources tested for nitrate concentration, and how to adjust their fertilization practices accordingly. This could lead to a decrease in overall nitrogen fertilizer application within the region.

An Isotope Study is planned for the area within Alta Irrigation District. This is a region well within the high vulnerability area, with both nitrate exceedances and DACs in the study area. In cooperation with Lawrence Livermore National Laboratory, water samples from selected wells will be collected and the age of the water and nitrogen isotopes will be studied. This should indicate what the source of the nitrate is within the region. If successful, this testing can be expanded to include other regions identified as high vulnerable or other boundary regions where water is potentially entering the groundwater system.

ACTIONS TAKEN

COMPLIANCE WITH RECEIVING WATER LIMITATIONS

The MPEP will attempt to measure the amount of water applied to specific crops and monitor its movement through the rootzone and predict its entry into the local groundwater. While the specifics of how this would be done have not been established (the KRWQC will cooperate with the other Coalitions within Tulare Lake in conducting the necessary studies at the direction of an outside consultant), it is likely that soil moisture sensors, in combination with direct measurement of soil water at specific depths will be used to measure the movement of nutrients through the soil profile. Tagged nitrogen fertilizers (N_{15} or similar) may be used to track such movements. Use of such material may also be necessary to establish how much is retained within permanent plant structures (roots, trunk, and branches) versus how much ends up in the harvestable crop.

EDUCATION AND OUTREACH

Once the landowners have been identified within the defined high vulnerability areas, outreach materials can be prepared and grower meetings scheduled to discuss how to reduce inputs in the short term while the MPEP studies get set up. Once the consultant has identified the MPEP study criteria, suitable growers and other industry experts can be brought in to make the research practical. It is anticipated that Coalition staffing limitations will only allow for a couple of crops per year to be evaluated under the MPEP studies, so a crop prioritization schedule will need to be considered. It is anticipated that the practices identified may not be crop specific, so the results of this research will be communicated to all growers as they become available. Outreach will also be made to those growers outside of the high vulnerable areas in order to prevent an expansion of the high vulnerable region at the next GAR revision.

It is at this time that we would first approach landowners regarding well sampling for basin monitoring (with appropriate data sharing with the well owner/operator) and to discuss the necessary permissions to access the wells and the needed well construction data. Additional measures may be required should well construction data not be readily available. Given the current backlog for the well drilling industry, it is unlikely that constructed monitoring wells could be installed in a reasonable timeframe, thus making the use of existing wells necessary.

The potential exists that the nitrate issue is in fact a consequence of practices long since abandoned by growers, and that the problem will self-correct over a long period of time. This can create a certain amount of resistance to doing the research, as would be the dissemination of any potential “trade secrets” used by participating growers that they feel gives them an economic advantage. It will necessitate that the studies be general in nature, with specifics as needed should something prove to be highly protective to groundwater.

IDENTIFICATION AND VALIDATION OF PRACTICES THAT REDUCE LOADING

The MPEP process should identify a set of practices that reduces nutrient loading or improves the timing of applications such that the risks to groundwater are reduced. Measured results from monitored wells in the vicinity of the study area, will validate the practices in use. Reductions in the amount of available nitrate in the soil profile will also prove that the crop is using more of what is applied, leaving very little residual that would be subject to leaching risk.

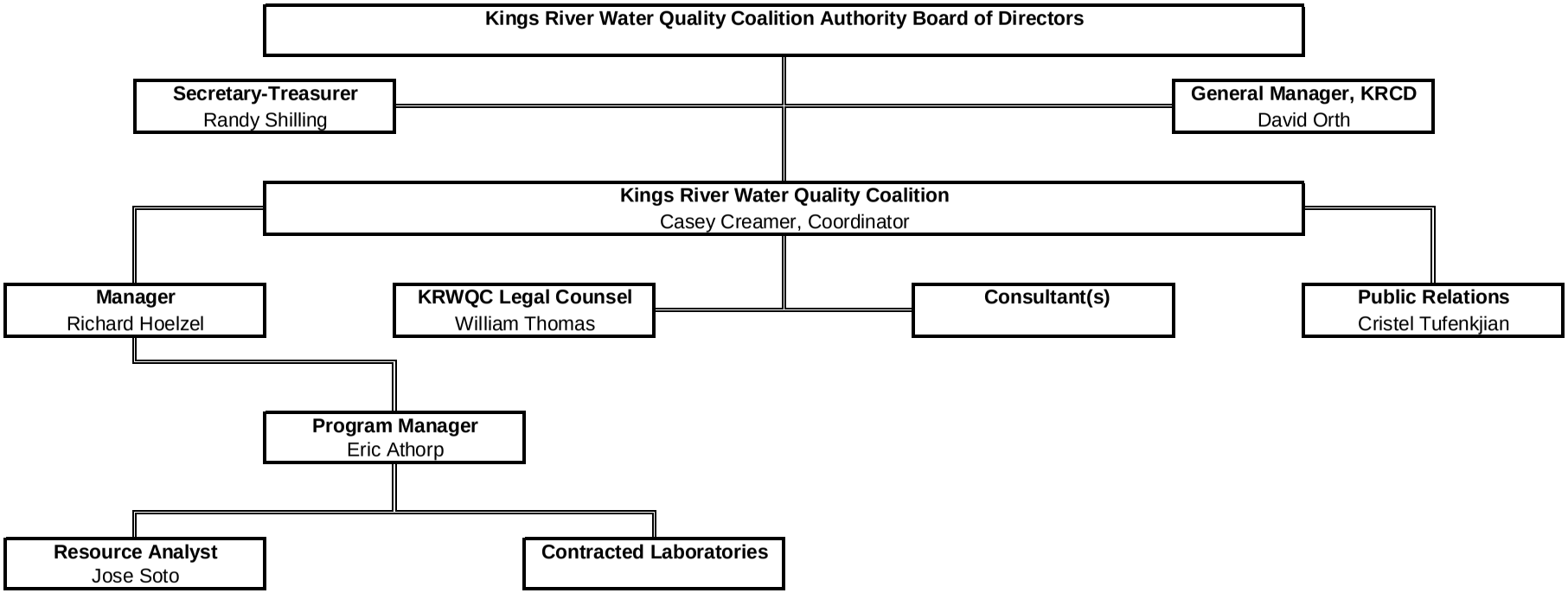
IDENTIFICATION OF INDIVIDUALS INVOLVED

The implementation of the CGMP by the KRWQC will involve a number of people in various capacities. Coordination of MPEP studies with other Coalition groups, hiring and supervision of the outside consultant(s), conducting the assorted studies with data collection and analysis, and reporting to the Regional Board. The complexity of the final task list will determine the total number of people involved.

On a conceptual level the following is a list of those involved plus the projected responsibilities:

Name	Position	Tasks	Reports To
KRWQC Board of Directors		Determine and Approve General Policies relating to KRWQC Activities Budget Approval (Expenditures and Fee Structures)	
David Orth	General Manager, KRCD	Policy State Board/Regional Board Interaction	KRWQC Board of Directors
Randy Shilling	Secretary-Treasurer	Finances and Budgeting Administrative Support	KRWQC Board of Directors
Casey Creamer	Coordinator, KRWQC	KRWQC Policy Implementation Budgeting Coalition Activity Coordination Hiring of Consultant for MPEP Supervision of Consultant Review and Approval of Reporting	KRWQC Board of Directors
Cristel Tufenkjian	Public Relations	Outreach Scheduling Newsletter Publication	Casey Creamer
William Thomas		Legal Counsel	Casey Creamer
Consultant(s)		Outside Consulting for Required Studies	Casey Creamer
Richard Hoelzel	Manager	Asset (staffing) Allocation Budget Preparation Outreach	Casey Creamer
Eric Athorp	Program Manager	Surface Water Monitoring Groundwater Monitoring CGMP Implementation MPEP Implementation KRWQC Studies under MPEP Laboratory Supervision Data Analysis and Reporting Outreach	Richard Hoelzel
Jose Soto	Resource Analyst	Membership Relations Field Study Assistant Outreach	Eric Athorp
Contracted Labs		Sample Analysis	Eric Athorp

Kings River Water Quality Coalition
Organization Chart



STRATEGIES TO IMPLEMENT MANAGEMENT PLAN TASKS

The GAR has already identified the high vulnerable areas on a section by section basis. A GIS overlay of the member parcels will identify those growers that have the elevated reporting requirements. This would include the high vulnerable areas that are intrinsically high vulnerable, plus those sections where a nitrate exceedance was reported.

The following steps would be taken once the member parcels are identified:

1. Information packets would be mailed to those parcel owners notifying them of their high vulnerability status, along with the necessary templates (if approved) and due dates for their submittal to the KRWQC.
2. Outreach meetings would be scheduled for these areas to discuss template completion and to discuss the need for intensified groundwater monitoring within these regions.
3. KRWQC would develop a workplan for the selection and sampling of groundwater wells within the high vulnerability regions. Protocols would be added to existing QAPP documents submitted for Surface Water Monitoring Program.
4. Farm Evaluation template information would be compiled and analyzed for use in developing the MPEP, and for setting the priorities for the MPEP studies.

The MPEP studies would be coordinated by a consultant hired by the Southern San Joaquin Valley Water Quality Coalition, as the member agencies of this Coalition plan to do cooperative research within the Tulare Lake Basin. The studies would include recognized experts for each crop type, plus experts in irrigation and nutrient management. These would likely be Crop Advisors from UC Cooperative Extension, with some of the field work potentially being done by UC students under Cooperative Extension supervision.

Specialized studies outside of the MPEP are to be conducted by the KRWQC staff in areas surrounding identified DACs. These studies would be done in cooperation with other efforts within the Kings Basin area.

MANAGEMENT PRACTICES USED

The first step of this process will be to compile a listing of practices currently in use, plus a general discussion of how these practices have changed over the years. The MPEP study will then look at what current practices are in use, compare them to what practices are potentially available, and evaluate whether the new practices improve crop management in a manner that is economical for the grower. Changes could be in irrigation scheduling, timing of fertilizer applications, expanded research in how irrigation and nutrient management influence yield and quality, plus impacts on overall plant health.

Those practices that have already been proven effective in protecting groundwater include:

1. Drip/microsprinkler irrigation. This is because of the low rates of application and the ability to match applied water to actual crop usage, thus limiting leaching of water below the rootzone. The downside is the high capital investment at the beginning (system installation, filtration, pumping plant upgrades), plus on-going maintenance and higher energy costs (systems run daily, rather than once every 2-3 weeks during peak irrigation demand).
2. Split applications of fertilizers. Growers no longer apply all of the plant's fertilizer needs in one application; rather they time the applications to when the plant needs it most (based on tissue sampling). Increased costs for labor to apply the material, increased risk of soil compaction for

tractor applied materials. Irrigation system applied materials require system improvements (backflow prevention, injection systems) as well.

3. Increased use of foliar fertilizers. Such fertilizers are applied directly to leaves as needed, using materials at very low concentrations. These materials are typically added to any pest control materials being applied (two benefits for a single application), but the timing of a pest control decision may not match the nutritional needs of the crop (early, late, or not needed).

OUTREACH STRATEGIES

The first outreach strategy to be used is direct contact of the impacted member/operators from the enrollment data collected. The KRWQC will provide notification of the findings of the GAR, and an offer to discuss with the landowner the characteristics that went into the classification of the lands as high vulnerable.

Grower meetings would follow once the initial contact phase is completed (notification of meeting location and time to be sent by mail, email, and posting on the KRWQC website, plus selected agricultural news outlets). These meetings would be held to discuss the specific requirements for growers within the high vulnerability zones, and the needs for increased groundwater monitoring and eventual plans for the MPEP studies. Sessions would be translated as needed. Once the MPEP study workplans are completed, growers would be selected for participation in the studies.

Results of the studies will be included in the KRWQC newsletters to all growers, plus posted on the KRWQC website (www.kingsriverwqc.org). It is anticipated that the results of the MPEP studies will also be published by UC Cooperative Extension, and potentially in peer reviewed professional journals. A discussion of the results will also be part of the annual outreach meetings conducted by the KRWQC.

The rate of implementation of the new practices found to be effective via the MPEP studies will be evaluated through the reported changes in the Farm Evaluation analysis. Conversion rates will depend upon the capital investments required, and the availability of financial resources (NRCS conservation programs or other) to help offset the costs for smaller growers. It is conceivable that no changes in practices may result from the MPEP studies, as the practices in use may already be deemed to be protective of groundwater.

SCHEDULE AND MILESTONES FOR IMPLEMENTATION

The MPEP workplan is to be developed within 2 years of the approval of the GAR (timing based upon the submission of the KRWQC GAR, other Tulare Lake Basin GARs to be submitted at later dates). During the development of the MPEP workplan, other tasks will be as follows:

1. 60 days after approval of the GAR/CGMP (whichever is later), the member/operators within the high vulnerability regions will be contacted and informed of the necessary requirements.
2. 90 to 120 days after notification of the affected member/operators, the first of the outreach meetings should be conducted to discuss the GAR results, the CGMP approaches to address the issues identified, and obtain the necessary authorizations for use of existing production wells for monitoring purposes.
3. Upon submittal of the CGMP to the Regional Board, conceptual development of a groundwater quality monitoring network will begin (both basin-wide trend monitoring and intensified high vulnerability monitoring).
4. Reporting of progress to be made with the KRWQC Annual Report due May 1 of each year.
5. Reporting of water quality results with each Annual Report
6. MPEP status reports to be submitted with each Annual Report

The timing for identification of new management practices is extremely variable. The MPEP may identify a practice that is beneficial, but it may take multiple years of research to determine if the practice is site specific or can be broadly applied. It is likely that for each crop studied, the MPEP will take between 3 and 5 years of research to confirm the results.

Once positive results have been demonstrated in the MPEP research (about 3 years of data would be required), the practices identified by the MPEP study can be disseminated to the other member/operators within the high vulnerability regions for each coalition group. Farm Evaluation data will show the pace of adoption of the identified practices within the high vulnerability areas. The rate of implementation will depend upon the cost of the previously mentioned capital expenditures required to change from current practices to those identified by the MPEP studies.

It is hoped that the MPEP identified practices can be fully adopted within the high vulnerability areas within a reasonable timeframe after they have been identified, but external conditions (drought, groundwater and surface water supply variability, crop pricing, other unknown factors) will affect the rate of implementation.

MONITORING METHODS

The MPEP workplan will outline the documentation of existing practices and how they will be evaluated as to how protective they are of groundwater quality. Basic information about field conditions and instrument placement would take place at this time.

Groundwater monitoring from a selected network of production wells will be conducted during the spring of each year (projected for May at present) is expected for the Trend monitoring program. The well owners would be notified of the sampling schedule at least 2 weeks in advance. The sampling protocol would be as follows:

Well Running at Arrival

1. Wait 5 minutes to insure that well casing has been evacuated and water from the surrounding aquifer is being pumped to the surface
2. Collect temperature readings of the discharged water. Attempt to measure Dissolved Oxygen (DO) within the discharge.
3. Once the water temperature or DO readings are stable, collect pH and electrical conductivity (EC) data and record values. Fill supplied sample bottle(s) for desired analysis. Constituents to be as outlined in General Order once every 5 years, nitrate and physical parameters at all others.
4. Collect a duplicate sample daily.

Well Off at Arrival

1. Measure depth to standing water and record (use acoustic sounder as much as possible to avoid cross-well contamination issues).
2. Start well (permission obtained when well was selected) and allow to run 5 minutes to insure well casing is pumped out, and water is reflective of current aquifer conditions.
3. Follow protocols listed above once the 5 minute waiting period is over.

In either case, samples are to be treated like any other analytical sample, stored in a cooler with “blue ice” for temperature control, eventually to be packed in “wet” ice (cubes) prior to delivery at lab. A Chain of Custody is to be maintained for all samples.

Within the high vulnerability areas, the frequency of water monitoring would be increased to at least twice per year, so as to measure changes that have occurred during the irrigation season.

DATA EVALUATION

The groundwater sampling points will remain fixed for an extended period of time, so a time series trend analysis of constituent values can be performed. The well locations/surface elevations are going to be known to the KRWQC (but not part of any published data due to privacy), so a GIS analysis of constituent concentrations can be created. This data would be added to any accumulated data analysis collected from the MPEP studies.

The MPEP studies can also provide the necessary supporting data for the nutrient removal calculations that may be required under the Nutrient Management Plan (NMP) requirements. This data is available for some crops, but not all. With the MPEP, the possibility exists to tie together the applied nutrients with the removed nutrients, making the NMP more valuable.

REPORTING

Data will be presented as required in the General Order by May 1 of each year.

APPENDIX

GEOLOGY OF THE TULARE FORMATION AND OTHER CONTINENTAL DEPOSITS, KETTLEMAN CITY AREA, SAN JOAQUIN VALLEY, CALIFORNIA, WITH A SECTION ON GROUND-WATER MANAGEMENT CONSIDERATIONS AND USE OF TEXTURE MAPS

By R. W. Page

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4000

6413-25

Sacramento, California
May 1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Federal Building, Room W-2235
2800 Cottage Way
Sacramento, CA 95825

Copies of this report
can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25424, Federal Center
Denver, CO 80225
Telephone: (303) 234-5888

CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	2
Location and general features	2
Previous reports	5
Well-numbering system	6
Geology of the Tulare Formation and other continental deposits	7
Depth, thickness, base, and structure	10
Fossils	11
Sedimentary material	12
Source and depositional environment	12
Alluvial-fan deposits	14
Deltaic deposits	14
Flood-plain, lake, and marsh deposits	15
Texture of the deposits	18
Ground-water-management considerations and use of texture maps	20
Summary and conclusions	21
Selected references	22

ILLUSTRATIONS

[Plates are in pocket]

Plate 1. Geologic map and sections, showing depth to base and thickness of the Tulare Formation and other continental deposits, Kettleman City area, San Joaquin Valley, California.

2. Texture maps of the Tulare Formation and other continental deposits, Kettleman City area, San Joaquin Valley, California.

	Page
Figure 1. Map of California showing study area	3
2. Map showing landforms in the Kettleman City area	4
3. Diagrammatic geologic section, west to east through study area	8
4. Diagram of an idealized alluvial fan	13
5. Diagram showing generalized geologic section and view of part of the Central Valley	13
6. Geophysical logs for part of well 23S/23E-25E	19

TABLE

Page

Table 1. Normal temperature and precipitation, Kettleman Station------- 5

CONVERSION FACTORS

For readers who may prefer to use the International System of Units rather than inch-pound units the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
acres	0.4047	ha (hectares)
ft (feet)	0.3048	m (meters)
inches	25.4	mm (millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)
µmho/cm at 25°C (micromhos per centimeter at 25° Celsius)	1.000	µS/cm at 25°C (microsiemens per centimeter at 25° Celsius)

Degrees Fahrenheit are converted to degrees Celsius by using the formula Temp °C = (temp °F - 32)/1.8.

National Geodetic Vertical Datum of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. The datum is shown as sea level in the geologic sections.

GEOLOGY OF THE TULARE FORMATION AND OTHER CONTINENTAL DEPOSITS, KETTLEMAN CITY AREA, SAN JOAQUIN VALLEY, CALIFORNIA, WITH A SECTION ON GROUND-WATER-MANAGEMENT CONSIDERATIONS AND USE OF TEXTURE MAPS

By R. W. Page

ABSTRACT

The Tulare Formation and other continental deposits of Pliocene to Holocene age crop out over most of the 1,040 square-mile area near Kettleman City in the San Joaquin Valley of California. These deposits range in thickness from 0 to more than 4,000 feet and overlie the upper Mya zone of the San Joaquin Formation of Pliocene age. Some features of the base, which ranges in depth from 0 to more than 4,000 feet, include a trough in the central part of the area, a steep, northeastward-sloping surface in and near the Kettleman Hills, and a deep, northwestward-trending trough just east of the hills. These features reflect structural deformation during Quaternary time.

Many freshwater fossils are found in the Tulare Formation itself, including the largest fossil assemblage of clams and snails known on the Pacific Coast.

Sediments in the Tulare Formation and other continental deposits consist mainly of unconsolidated deposits of clay, silt, sand, and gravel. In the study area, these sediments have been deposited as alluvial-fan, deltaic, flood-plain, lake, and marsh deposits.

Texture maps of the Tulare Formation and other continental deposits show that most of the sandy and gravelly coarse-grained sediment lies beneath the northern, eastern, and southern parts of the study area to depths greater than 1,800 feet. Most of the silty and clayey fine-grained sediment lies beneath the western and central parts of the area to depths of about 1,400 feet. Below 1,400 feet the fine-grained sediment becomes more widespread, and at depths of 2,400 to 2,800 feet it underlies most of the area.

Texture maps made during this study can be useful in making water-management decisions, such as where to drill wells in order to get large yields. The maps also can be used by ground-water modelers for determining relative values for hydraulic conductivity and storage coefficient.

Other factors involved in making water-management decisions in the area include the gas that occurs in the Tulare Formation and other continental deposits, and saline water that underlies the entire area.

INTRODUCTION

Purpose and Scope

The purpose of this report is to compile the available geologic information on the Kettleman City area of the Central Valley that would aid others in the proper management of the valley's ground-water resources.

The scope of the study included the collection, assembly, and evaluation of data (1) to determine the depth to the base and the thickness of the Tulare Formation of Pliocene and Pleistocene age and other continental deposits of Pliocene to Holocene age; (2) to describe the types of sediment in those deposits; (3) to show the relative proportions of coarse-grained to fine-grained sediment in the Tulare Formation and other continental deposits; and (4) to consider the geology as related to the management of ground water and the design of hydrologic models in the area. The investigation did not include any fieldwork.

Location and General Features

The study area comprises about 1,040 square miles in the Kettleman City area of the San Joaquin Valley (fig. 1). Boundaries of the area were determined by the extent of a fossil zone in the underlying San Joaquin Formation of Pliocene age (see p. 7). Lake bottoms, or beds, are the principal landforms in the area (fig. 2) and are characterized by very gentle slopes of the land surface (Davis and others, 1959, p. 29). At times the lake bottoms are flooded, but throughout most of the year they are farmed. Davis and others (1959, pl. 1) mapped overflow lands and lake bottoms as one unit, but their text (p. 28-29) indicates that Tulare Lake bed is the principal landform in the study area. Other landforms in the area are Goose Lake bed and overflow lands to the south, low alluvial plains and fans that bound the lakebeds on the north, east, and west, and dissected uplands that lie along the western and southern edges of the area (fig. 2). The Kettleman Hills, lying along the northwestern boundary of the area, have been mapped by Davis and others (1959, pl. 1) as part of the Coast Ranges. Summers in the area are hot and dry, and winters are cool and relatively moist (table 1).

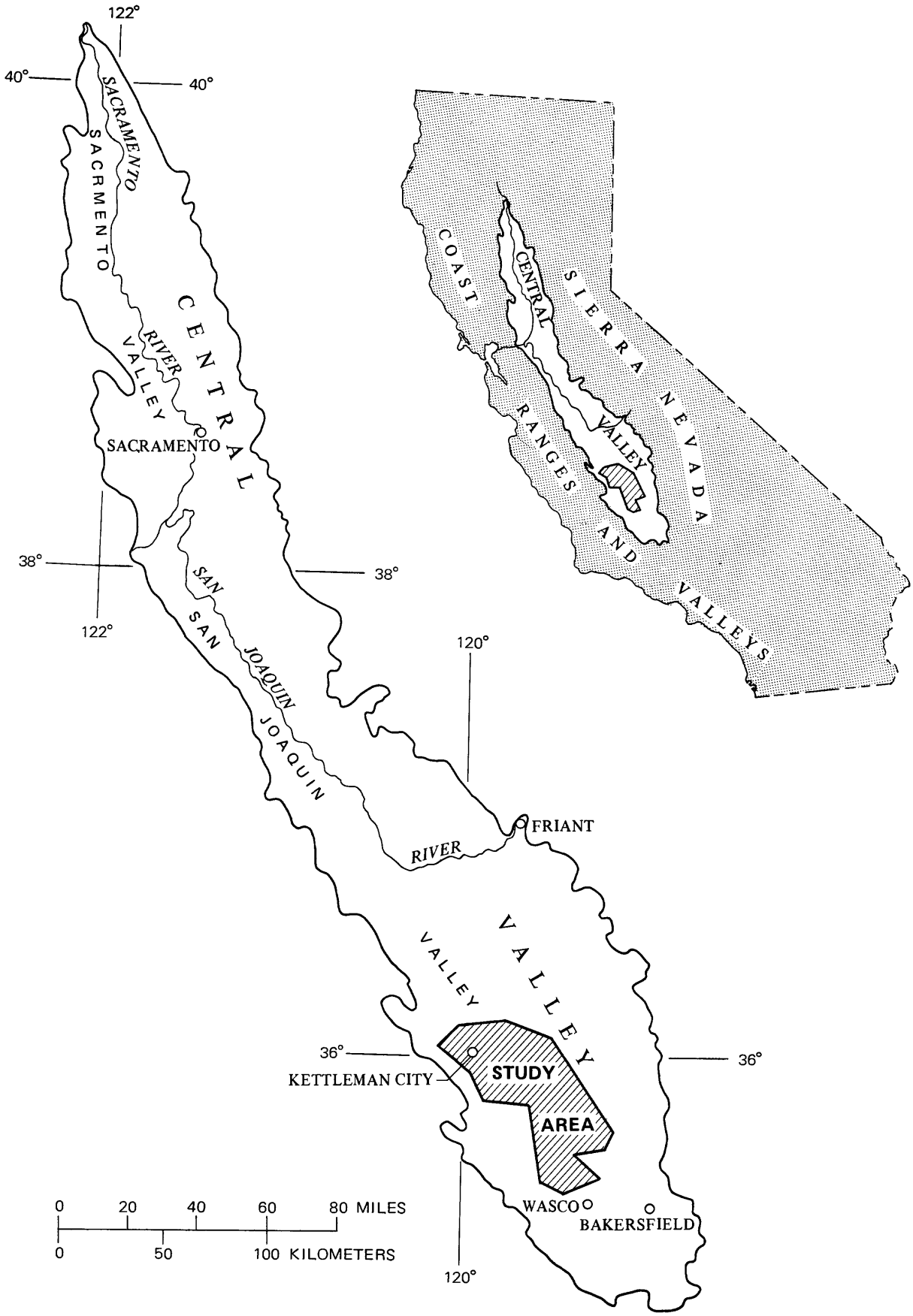
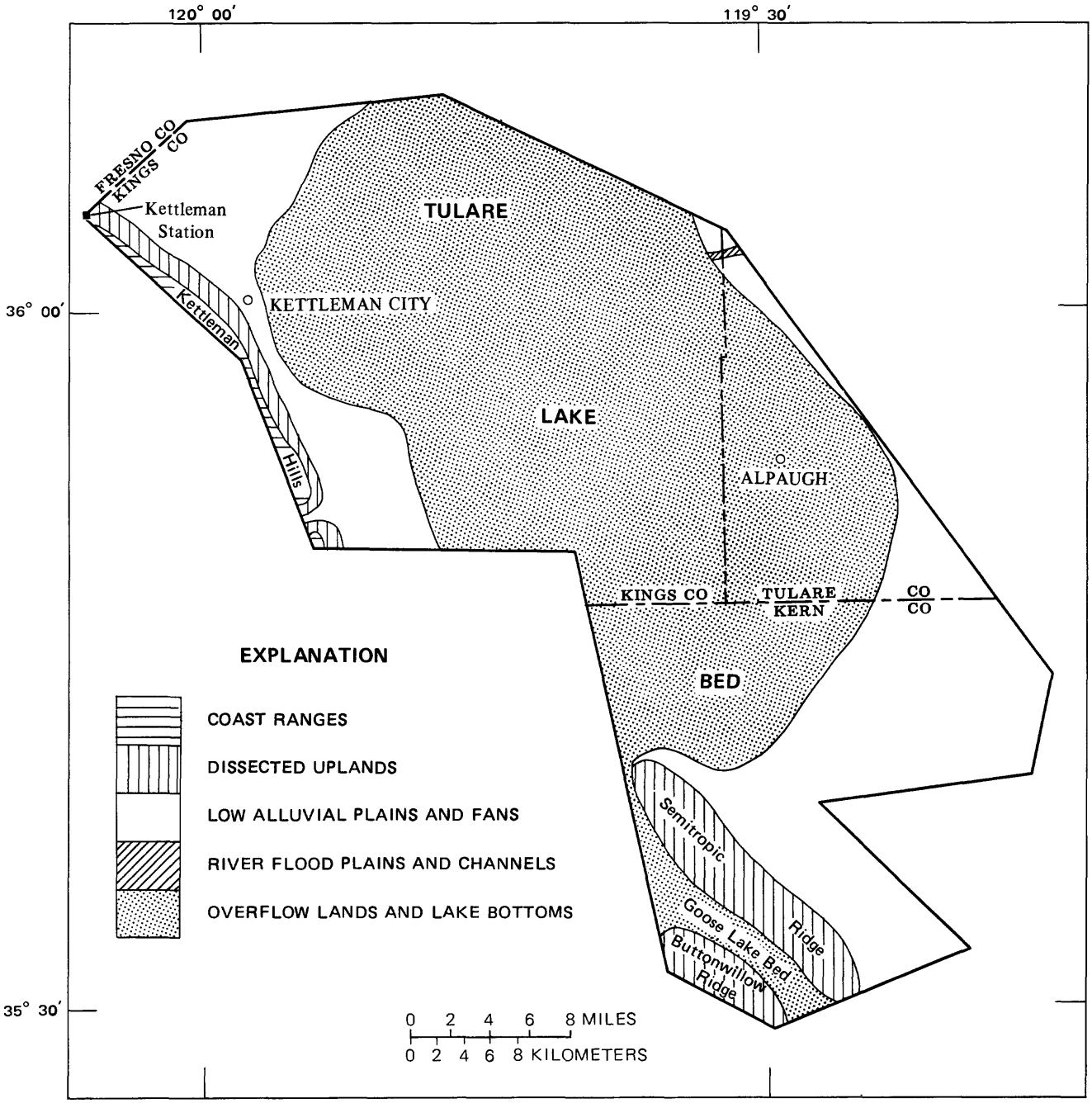


FIGURE 1. — Study area.



Landforms by Davis and others(1959, pl. 1) modified by R.W. Page, 1980

FIGURE 2. — Landforms in the Kettleman City area.

TABLE 1. - Normal[1] temperature and precipitation, Kettleman Station (from [U.S.] National Oceanic and Atmospheric Administration 1979, p. 4 and 18)

Month	Temperature (°F)	Precipitation (inches)	Month	Temperature (°F)	Precipitation (inches)
January	47.3	1.17	July	84.5	0.02
February	52.2	1.26	August	82.5	.04
March	56.3	.88	September	77.6	.05
April	62.5	.67	October	68.1	.21
May	69.6	.26	November	56.7	.68
June	77.0	.03	December	47.9	.85
Total					6.12

[1]Normals are climatological normals based on the period 1941-70 ([U.S.] National Oceanic and Atmospheric Administration, 1979, p. 27).

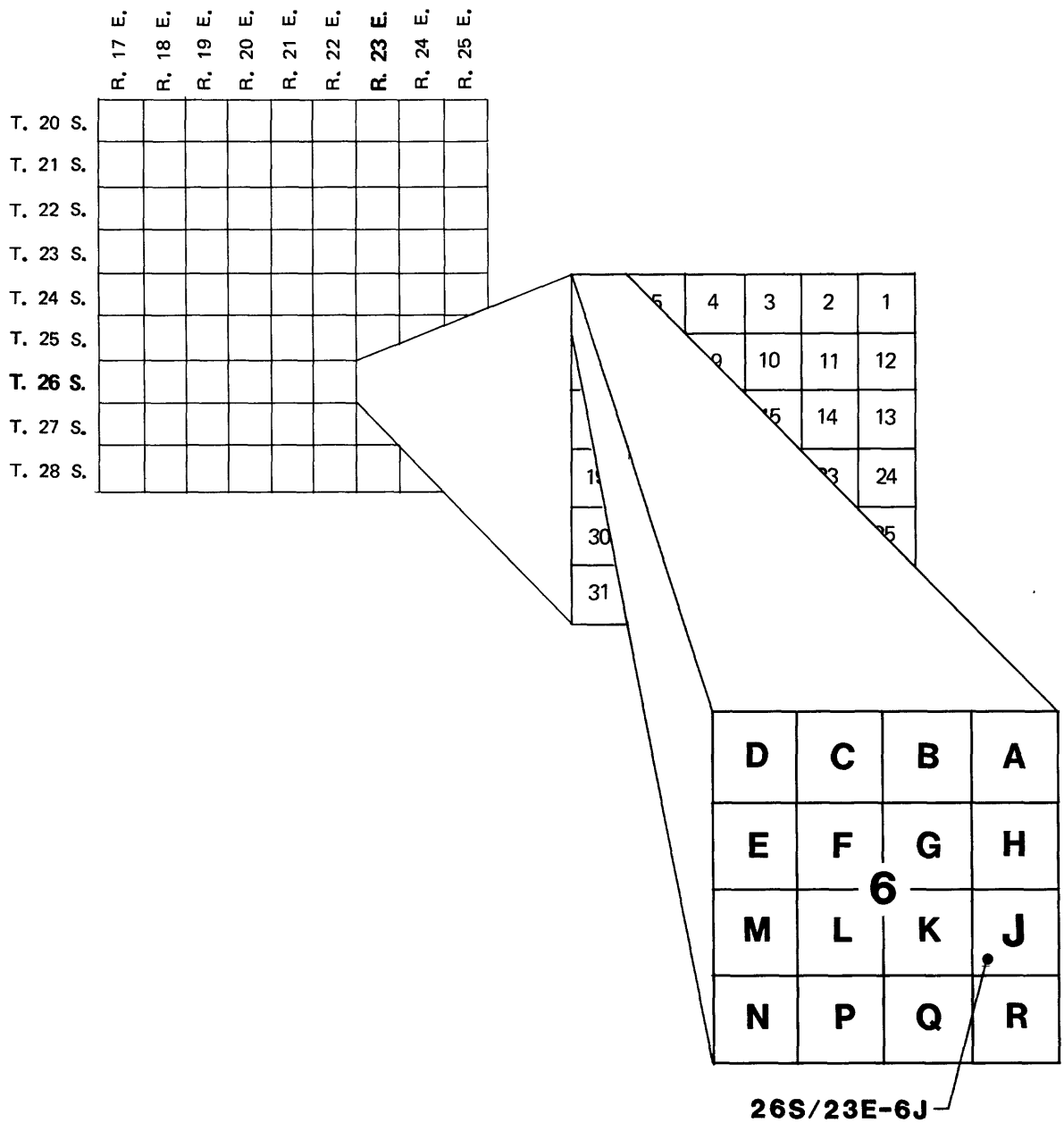
Previous Reports

In any study of an area, a knowledge of the works of others is essential for gaining an understanding of that area and for ensuring that work is not duplicated. Geologic reports pertinent to the study area include the following:

American Association of Petroleum Geologists, 1958, geologic section through the eastern part of the study area;
Croft, 1972, discussion of geology, maps showing the structure of three extensive clays;
Croft and Gordon, 1968, discussion of geology, geologic map, and geologic sections in northern part of area;
Davis and others, 1959, discussion and map of landforms, discussion of geology, map of an extensive lake clay, and geologic sections;
Frink and Kues, 1954, discussion of a lake clay of Pleistocene age;
Hill, 1964a and b, discussion of geology, structure map of the upper *Mya* zone--a fossil zone containing clams, and geologic sections in the central part of the area;
Hilton and others, 1963, discussion of geology, and geologic sections in southeastern part of area;
Hoots and others, 1954, structural contour map of the lower Pliocene;
Kaplow, 1940, discussion of geology, structure maps of the upper *Mya* zone, and geologic sections in the central and southern part of area;
Lofgren and Klausing, 1969, discussion of geology and geologic sections in eastern part of area;
Miller and others, 1971, discussion of geology, and geologic sections in northeastern part of area;
Page, 1981, basic-data report for the upper *Mya* zone in the study area; and Woodring and others, 1940, discussion of geology, geologic map, and geologic sections of the Kettleman Hills along the northwestern part of the study area.

Well-Numbering System

Wells are identified according to their location in the rectangular system for the subdivision of public lands. For example, in the number 26S/23E-6J, the part of the number preceding the slash indicates the township number (T. 26 S.); the number after the slash indicates the range (R. 23 E.); the number after the hyphen indicates the section (sec. 6); and the letter after the section number indicates the 40-acre subdivision of the section as indicated on the diagram below. Locations of most wells were taken from published maps and reports (Page, 1981a). Wells were not field located by the Geological Survey except for wells 23S/23E-33A1 and 27S/23E-1R1. The final digit in those well numbers indicates that the wells were the first to be field located in their particular 40-acre subdivision. The entire study area is south and east of the Mount Diablo base line and meridian.



GEOLOGY OF THE TULARE FORMATION AND OTHER CONTINENTAL DEPOSITS

Woodring and others (1940, p. 13) defined the Tulare Formation as the youngest folded strata exposed in the Kettleman Hills. They defined the base of the Tulare Formation as the layer just above the upper Mya zone of the San Joaquin Formation of Pliocene age (Woodring and others, 1940, p. 13-14). Upper Mya zone refers to the uppermost strata in which the burrowing pelecypod, or clam, Mya occurs in the San Joaquin Formation. This base marks a change from a dominantly marine environment to a continental environment of lakes, swamps, and streams. The upper Mya zone can be traced with a reasonable certainty over a considerable distance in the Kettleman Hills (Woodring and others, 1940, p. 13-14).

Kaplow (1940, pls. 3 and 5) mapped the base of the Tulare Formation as the top of the San Joaquin clay of Barbat and Galloway (1934) of Pliocene age. This clay lies about 500 feet above the Mya zone in the area of Buttonwillow and Semitropic Ridges (fig. 2). Kaplow (1940) did not mention an environmental change at the top of the upper Mya zone, but he did say that the upper Mya zone was by far the best subsurface marker in the area.

Later, Hill (1964a, p. 14), following the lead of Woodring and others (1940), defined the upper Mya zone in parts of T. 23 S., Rs. 21 and 22 E. as the top of the San Joaquin Formation, and the base of the Tulare Formation as the layer just above that zone. He indicated that the top of the upper Mya zone marked the greatest environmental change in the area and assumed that the contact between the San Joaquin Formation and the Tulare Formation was conformable (Hill, 1964a, p. 14), suggesting only slight erosional or structural changes over time between the two formations.

In this report, the base of the Tulare Formation is considered to be just above the upper Mya zone, except in the subsurface along the eastern side of the area where sediments from the Sierra Nevada have been deposited (fig. 3). The Tulare Formation is considered by most workers to include only that sediment derived from sources on the west side of the valley (Davis and others, 1959, p. 52); whereas, in the study area, sediments derived from the east side of the valley have, as yet, not been formally defined. The American Association of Petroleum Geologists (1958), however, showed that the eastern part of the study area is underlain by the Tulare Formation or the Kern River Formation, which is probably equivalent to the upper part of the Kern River Series of Diepenbrock (1933).

Nevertheless, without attempting to define the eastern extent of the Tulare Formation, the Tulare and sediments from the east side of the valley are here grouped as the Tulare Formation and other continental deposits. They crop out over most of the area (pl. 1). This grouping also includes the younger alluvium of Holocene age and the older alluvium of Pleistocene age that overlie the deformed Tulare Formation in the Kettleman Hills (Woodring and others, 1940, p. 13). Beneath Tulare Lake bed these two alluvial units cannot be easily distinguished from the Tulare Formation because of similarities in sedimentary material.

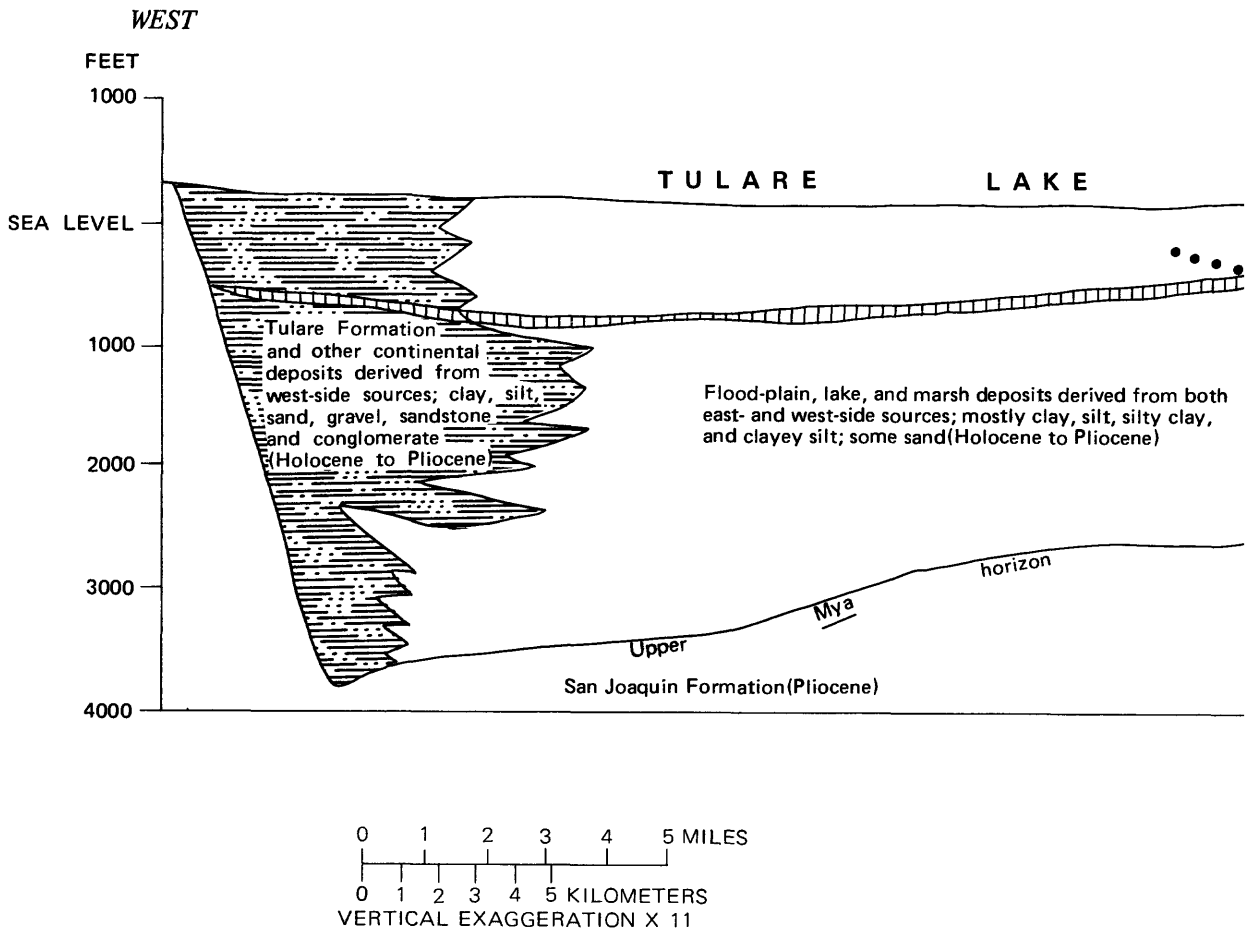
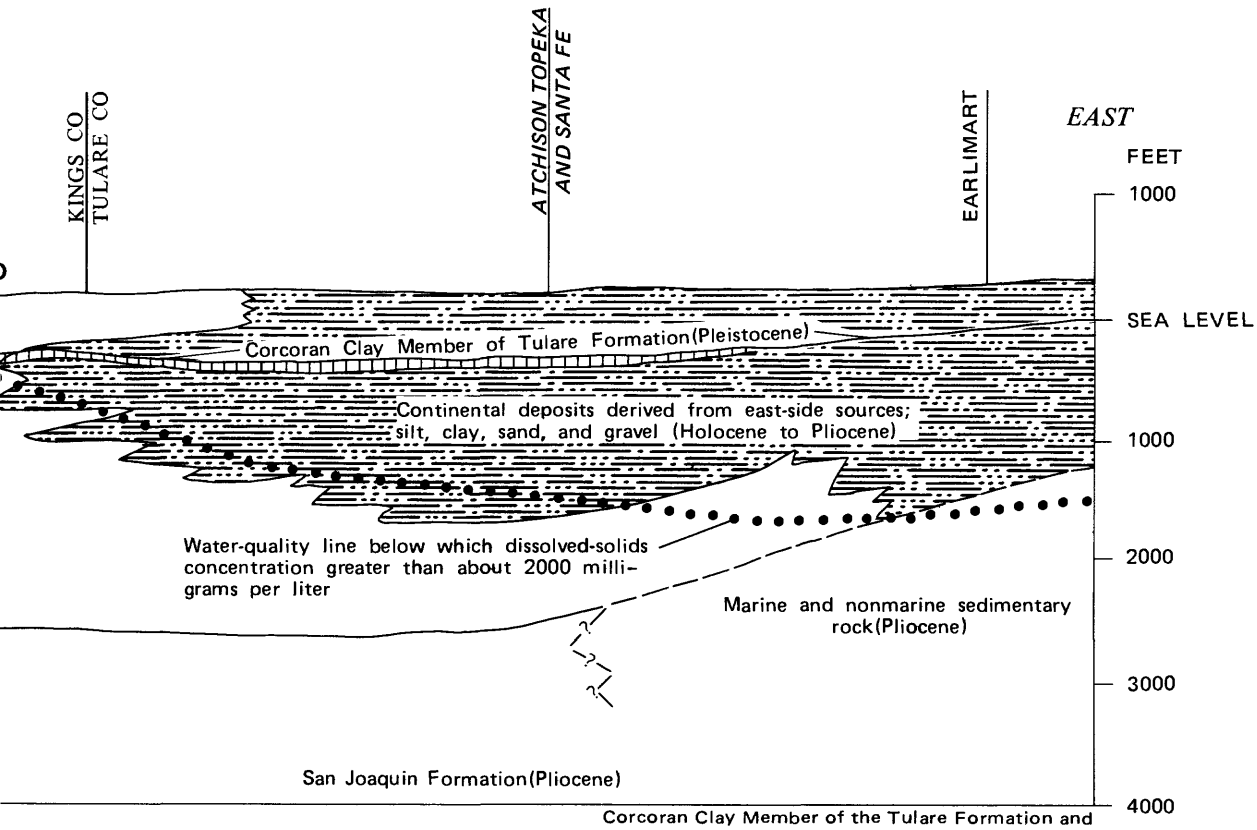


FIGURE 3. — Diagrammatic geologic



Corcoran Clay Member of the Tulare Formation and geology after Croft(1972, pl.1), modified by R.W. Page, 1980. Water-quality line after Page(1973). Upper Mya horizon by R.W. Page, 1980

section west to east through study area.

Depth, Thickness, Base, and Structure

The depth to the base of the Tulare Formation and other continental deposits (pl. 1) was mapped on the basis of 292 identifications of the upper Mya zone in the study area (Page, 1981), structure-contour maps and geologic sections showing the upper Mya zone by Hill (1964a, pl. 2; 1964b, pls. 3 and 4) and Kaplow (1940, pls. 2, 3, 5, and 7), as well as areas where the base of the Tulare Formation is exposed in the Kettleman Hills (Woodring and others, 1940, pl. 3). Because the depth to the base of these deposits is measured from land surface, their present thickness is also defined. Thus, the Tulare Formation and other continental deposits range in thickness, as well as depth to base, from zero where the Tulare Formation lies in contact with the San Joaquin Formation in the Kettleman Hills to more than 4,000 feet just east of the hills (pl. 1). In both of those areas, the Tulare Formation is the principal deposit.

It should be mentioned that, because the Tulare Formation was eroded as the Kettleman Hills were being uplifted, its present thickness in this area is not its original thickness, and that its thickness of 0 foot at its contact with the San Joaquin Formation does not indicate that the Tulare Formation pinched out in the area of the Kettleman Hills. On the contrary, Woodring and others (1940, p. 16-22) described thick sections of the Tulare on both the east and west flanks of the Kettleman Hills, indicating that the Tulare Formation was quite thick prior to uplift and erosion of the hills. For example, on the east flank of the Kettleman Hills the exposed Tulare is as much as 1,700 feet thick, and on the west flank it is as much as 3,500 feet thick (Woodring and others, 1940, p. 14).

Some of the features of the base of the Tulare Formation and other continental deposits are (1) a trough near Wilbur Ditch in the north-central part of the area, (2) two rather shallow areas at Buttonwillow and Semitropic Ridges, (3) a fairly shallow area between the Homeland Canal and the Liberty Farms East Canal, (4) a steep, northeastward-sloping surface in and near the Kettleman Hills, and (5) a deep, northwestward-trending trough just east of the Kettleman Hills (fig. 2; pl. 1). In addition, the base slopes southwestward near the southern part of the area and northwestward along the long axis of the area (pl. 1). Although a depth and thickness map cannot be used to properly interpret structure, the features shown on plate 1 reflect some of the structure in the area. Furthermore, it is assumed that the top of the upper Mya zone can be used as a structural datum because in the study area it

has been used to successfully define the structure of five gas fields (Hill, 1964a, 1964b, and Kaplow, 1940). Thus, the two shallow areas at Buttonwillow and Semitropic Ridges reflect the structure of two elliptical domes in that area (Kaplow, 1940, pl. 2); the shallow area between the Homeland Canal and the Liberty Farms East Canal partially reflects the structure of a dome and an anticlinal nose (Hill, 1964a, pl. 2); the rather steep, northeastward-sloping surface in and near the Kettleman Hills reflects the uplift that occurred at the close of the deposition of the Tulare Formation in Quaternary time (Hoots and others, 1954, p. 128); and the deep, northwestward-trending trough just east of the Kettleman Hills reflects a syncline, or downwarping, that also occurred as an effect of that uplift (Hoots and others, 1954, p. 129, pl. 5).

Furthermore, Davis and Green (1962, p. 90) postulated that the Tulare Lake area is an area of downwarping. Parts of the area have not only been sinking structurally, they also have been subsiding as fine-grained beds compacted because of ground-water overdraft (Poland and others, 1975, figs. 1, 5, and 12-17).

Fossils

Many freshwater fossils are found in the Tulare Formation itself. Woodring and others (1940, p. 104) said that the lower part of the Tulare Formation contains the largest fossil assemblages of freshwater mollusks, chiefly clams and snails, known on the Pacific Coast. Hill (1964a, table 1) showed that in parts of T. 23 S., Rs. 21 and 22 E. the freshwater clam Anodonta, the freshwater and brackish-water snail Amnicola, and the freshwater snails Fluminicola, Planorbis, and Pyrgulapsis occur in the Tulare Formation. And Croft (1972, p. 22) reported that the freshwater clam Sphaerium kettlemanense (Arnold), and the freshwater snails Valvata utahensis (Call), Lithoglyphus seminalis (Hinds), and Tryonia? occur about 50 feet above the E clay of Pleistocene age at a depth of 600-602 feet in sec. 31, T. 20 S., R. 19 E.

Lohman (1938, p. 88) identified 136 species and varieties of diatoms that were found in the Tulare Formation in the Kettleman Hills. Further, Davis and others (1959, p. 78, pl. 14) said that Lohman identified 113 species of diatoms that were found in their diatomaceous clay, which underlies a large part of the San Joaquin Valley. According to Lohman these species represent a dominantly freshwater to somewhat brackish-water flora (Davis and others, 1959, p. 78-79).

Sedimentary Material

Sedimentary material in the Tulare Formation and other continental deposits consists principally of unconsolidated clay, silt, sandy clay and silt, sand, clayey and silty sand, gravel, and clayey, silty, and sandy gravel (fig. 3). Locally, the deposits consist of more consolidated material such as conglomerate and sandstone. Hill (1964a, p. 14) mentioned the occurrence of conglomeratic deposits in parts of T. 23 S., Rs. 21 and 22 E., but most of the deposits in that area consist of clay, sand, and gravel (Hill, 1964a, table 1). In the Kettleman Hills, the Tulare Formation consists principally of sandstone, most of which is cross-bedded, silty, and pebbly, and conglomerate (Woodring and others, 1940, p. 13). There, most of the conglomerate and sandstone is poorly consolidated (Woodring and others, 1940, p. 13); thin-bedded, fine-grained sediments of silt, fine-grained sandstone, tuff, and limestone are also present. Miller and others (1971, p. 21) reported that in the northern part of the Kettleman Hills the Tulare Formation consists principally of sand, much of which is silty, pebbly, and crossbedded; it also contains some gravel, apparently laid down as stream deposits. Beneath Tulare Lake bed, the Tulare Formation and other continental deposits consist principally of silt and clay. Croft (1972, p. 13) considered the boundary between the upper Mya zone and the overlying deposits as probably representing a gradational change from mostly consolidated rocks, such as shale and sandstone, to mostly unconsolidated deposits, such as clay and sand.

Source and Depositional Environment

All the continental sedimentary material in the study area was derived chiefly from either the Sierra Nevada on the east or the Coast Ranges on the west (figs. 1 and 3). Some material probably was derived from those parts of the Sierra Nevada and Coast Ranges that form the southern border of the San Joaquin Valley. The type of material deposited is dependent on controls such as (1) type of rock in the source area, (2) competence of the streams that transported the sediments, and (3) environment of deposition.

The Sierra Nevada are composed of igneous and metamorphic rocks. Sediments derived from them have abundant feldspar, mica, and quartz. The Coast Ranges are composed of gypsiferous marine shale, sandstone, and volcanic rocks. Sediments derived from them are gypsiferous, and contain more rock fragments and are darker than those from the Sierra Nevada (Meade, 1967, p. 5). Sediments derived from the Sierra Nevada were transported mostly by major perennial streams; those derived from the Coast Ranges were transported mostly by ephemeral streams of intermediate to small size (Bull, 1964a). As a result of stream competence and source, sediments derived from the Sierra Nevada are, except for rock fragments, generally coarser than those derived from the Coast Ranges. Climatic change and uplift during the Quaternary have also influenced the competence and capacity of the streams (Croft, 1972, p. 15, and Mack, 1969).

In the study area, sediments have been deposited as alluvial-fan, flood-basin, lake, and marsh deposits (figs. 4 and 5), as well as deltaic deposits (not shown).

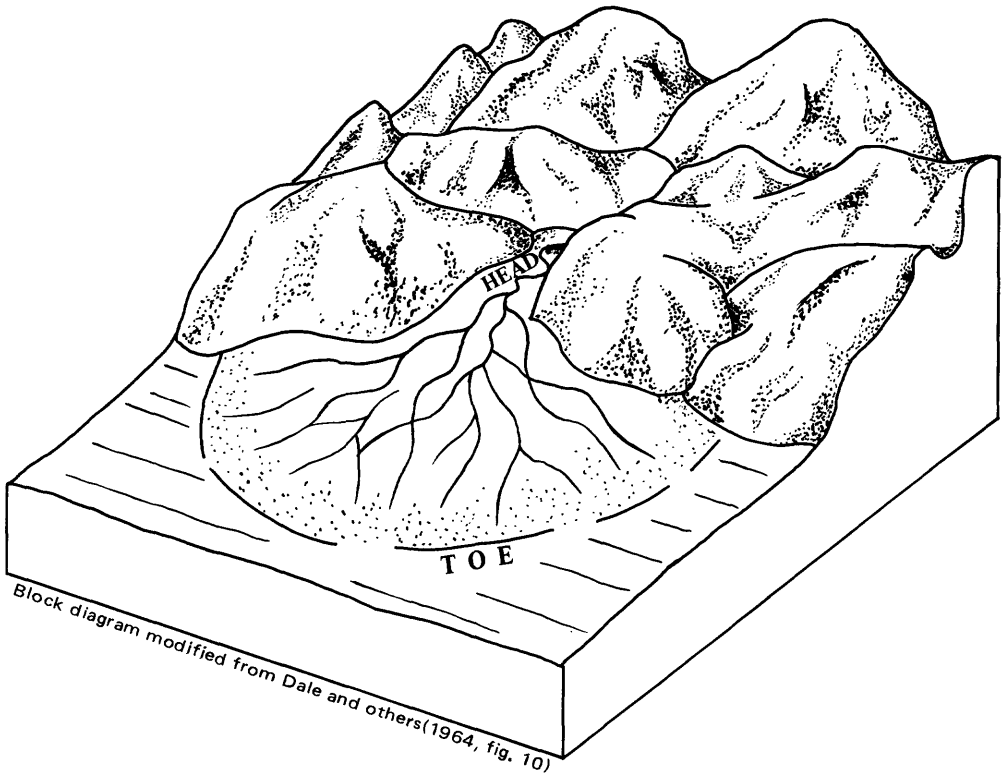
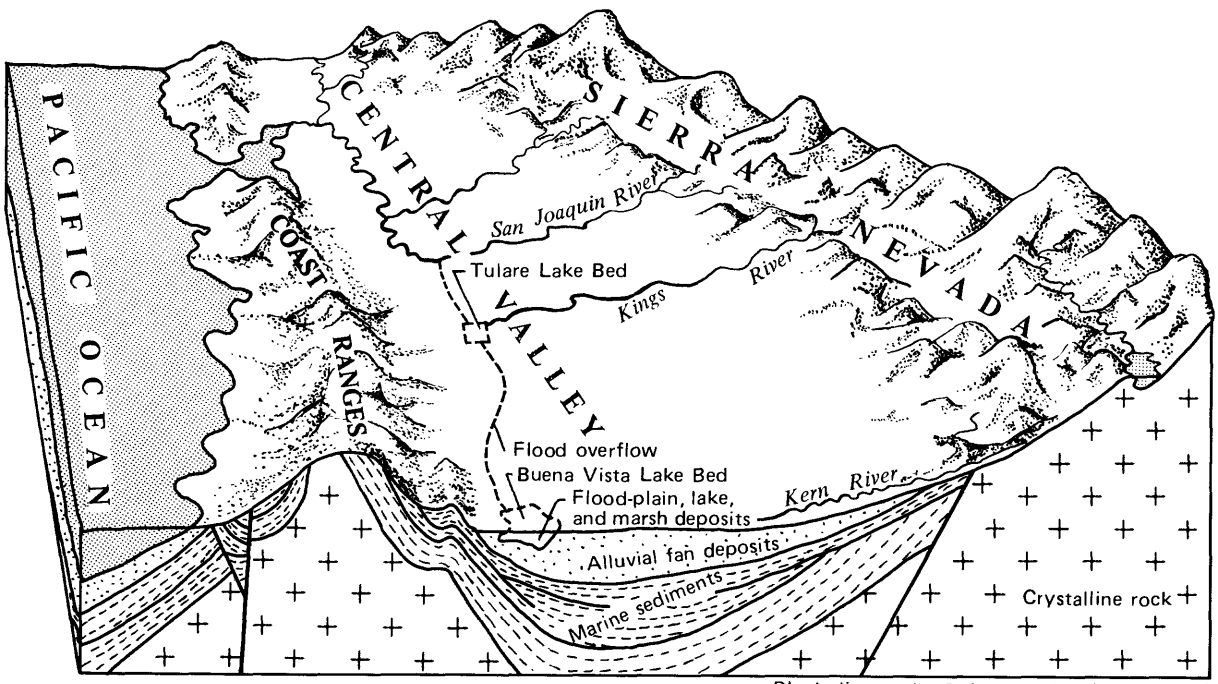


FIGURE 4. — Idealized alluvial fan.



Block diagram by Dale and others(1964, fig. 7)
Modified by R.W. Page, 1980

FIGURE 5. — Generalized geologic section and view of part of the Central Valley.

Alluvial-Fan Deposits

Alluvial-fan deposits generally grade from coarse-grained material near the head of the fan to finer-grained material near the toe. Depending on source areas, there are boulders, cobbles, gravel, and sand, mixed with some silt and clay, near the fan head. Near the middle of a fan may be found more sand and gravel with clay and silt; near the toe may be found sand, silt, and clay with some gravel. Within any segment of a fan can be found coarse-grained deposits, representing a bar or a main channel of a stream, and finer-grained deposits representing natural levees and overbank deposits. Furthermore, through time the main channel of a stream changes course and cuts and fills across previous deposits. Also, alluvial fans may join together out in the valley. Thus, deposits within alluvial fans comprise a heterogeneous mixture of coarse- and fine-grained material; these deposits tend toward hues of brown, red, and yellow because of oxidizing in subaerial environments.

Alluvial deposits in the study area were formed near the toes of alluvial fans. Miller and others (1971, pls. 3 and 4) showed that alluvial deposits near the northern part of the study area are as much as 1,950 feet deep and 1,650 feet thick. These deposits, as in other parts of the area, are interbedded with and overlie deltaic, flood-plain, lake, and marsh deposits. Woodring and others (1940) described beds of dark brown clay and silt, and beds of yellow and yellowish-brown sandstone as occurring in the Kettleman Hills; these beds probably were deposited as alluvial fans. Lofgren and Klausing (1969, fig. 5) showed that alluvial-fan deposits are as much as 1,050 feet deep and 1,000 feet thick in the eastern part of the area, and Croft (1972, pl. 1) showed that alluvial-fan deposits are as much as 1,050 feet deep and 980 feet thick in the southeastern part. Furthermore, alluvial-fan and some deltaic and lake deposits are indicated in the log of test hole 27S/23E-1R1 (depth 1,160 feet) from depths of 0 to about 890 feet (H. B. Goldman, U.S. Bureau of Reclamation, written commun., 1953).

Deltaic Deposits

Deltaic deposits were formed where the streams of alluvial fans dropped most of the remainder of their coarse-grained load as they entered lakes or marshes in the low-lying area, with the lakes and marshes, as well as the flood plains, receiving large quantities of fine-grained material. Miller and others (1971, p. 28) indicated that in the Tulare Formation near the northern part of the study area deltaic deposits consist primarily of bluish-green or greenish-gray, medium to well-sorted sand that is crossbedded and has depositional dips of 10°-40°.

Miller and others (1971, p. 28, pl. 4) mentioned that sandy deposits of presumably deltaic origin begin just north of the study area at a depth of about 350 feet and are about 2,000 feet thick. Woodring and others (1940, p. 13-26) did not mention deltaic deposits. Lofgren and Klausing (1969, pls. 4 and 5) also mapped reduced flood-plain and lacustrine deposits in the eastern part of the area; presumably, parts of these deposits are of deltaic origin. Croft (1972, p. 23) mentioned reduced deposits of alluvium that are bluish-green, fine to coarse sand, silt, and clay that interfinger with flood-basin, lake, and marsh deposits beneath Tulare Lake bed. Presumably, some of these reduced deposits of alluvium are of deltaic origin. Logs of test holes 23S/23E-33A1 (depth 1,200 feet) and 27S/23E-1R1 indicate beds of olive-gray, greenish-gray, and dark-greenish-gray well sorted sands, as well as some other material, from depths of 255 to 1,200 feet and 890 to 1,160 feet respectively (H. B. Goldman, U.S. Bureau of Reclamation, written commun., 1953). Although crossbedding is not mentioned, most of these beds probably are of deltaic origin as indicated by their color, sorting, and chiefly sandy nature.

Flood-Plain, Lake, and Marsh Deposits

Flood-plain, lake, and marsh deposits consist primarily of olive-brown, bluish-green, and greenish-blue beds of sand, silt, and clay. Miller and others (1971, p. 28) reported that flood-plain deposits in the Tulare Formation are coarser than those now being laid down on the central floor of the valley. Furthermore, lake and marsh deposits are more homogeneous than flood-plain deposits and generally are fine-grained except where mixed with deltaic sands from the Sierra Nevada (Miller and others, 1971, p. 28 and 30). The fine-grained deposits underlying the SW¼ T. 23 S., R. 20 E. are more than 3,600 feet thick, and their base lies at a depth greater than 3,600 feet (pl. 2).

If it were possible to open the Earth and look at the lake and marsh deposits, as well as some flood-plain deposits, in the study area they would appear as a thick plug of mostly clay and silt with discs of clay and silt emanating from the plug at irregular intervals (fig. 3). Croft (1972, pls. 1-6, p. 17-21) mapped six of these discs and designated them from youngest to oldest by the letters A-F. The A, C, and E clays of Quaternary age are the more extensive.

In the study area, the E clay is equivalent to the Corcoran Clay Member (Pleistocene) of the Tulare Formation and the diatomaceous clay of Davis and others (1959, pl. 14, p. 76-81); it lies below most of the area (Croft, 1972, pls. 1, 3, and 4) (pl. 1). In the northeastern part of the San Joaquin Valley, where virtually all deposits were derived from the Sierra Nevada, Marchand and Allwardt (1981, p. 34) considered that the Corcoran Clay Member of the Tulare Formation was also a member of the Turlock Lake Formation of Pleistocene age. The age of the Corcoran Clay Member or E clay (Croft, 1972, p. 18) is approximately bracketed by two dates determined from K-Ar (potassium-argon) dating techniques. Davis and others (1977, p. 388) reported that an ash found in the basal part of Croft's (1972, p. 18) E clay, in a test hole near Wasco, is about 725,000 years old. They considered this ash to be most probably the Bishop tuff (Davis and others, 1977, p. 388). In addition, they reported that a reversal in polarity occurred about 700,000 to 750,000 years ago represented by strata 12 feet below the ash at the base of the E clay (Davis and others, 1977, p. 388-389); this wide range in age is attributed to "a large margin of uncertainty" in the K-Ar dating of the ash and the sedimentation rate of the clay between the ash and the reversal (Davis and others, 1977, p. 388-389). Because of new decay constants for K-Ar dating techniques, the ash is now considered to be about 730,000 years old (Marchand and Allwardt, 1981, p. 33). The exact date of the reversal in polarity is still unknown. Janda and Croft (1967, p. 164) reported that a volcanic ash and pumice, the Friant Pumice Member of the Turlock Lake Formation (Marchand and Allwardt, 1981, p. 34), can be traced discontinuously from near Friant, where it is exposed, to beneath the axis of the San Joaquin Valley where it conformably overlies the Corcoran Clay Member. Using the new decay constants, G. B. Dalrymple (Marchand and Allwardt, 1981, p. 34) dated two separate collections of the Friant Pumice Member as 612,000±31,000 years and 618,000±31,000 years. Janda and Croft (1967) did not mention the Bishop tuff[1] as being in the area of the Friant Pumice Member, and Davis and others, (1977, p. 385) did not find the Friant Pumice Member in their test holes near Wasco. Therefore, the data concerning the bracketing of the age of the Corcoran Clay Member of the Tulare Formation and the Turlock Lake Formation is not conclusive. Nevertheless, because the Friant Pumice Member was found immediately above the Corcoran Clay Member near the axis of the San Joaquin Valley, and the reversal in polarity was found near the axis of the valley at the base of the Corcoran Clay Member, it can be inferred that the Corcoran Clay Member ranges in age from approximately 615,000 to 750,000 years before present time.

---

[1]Marchand and Allwardt (1981, p. 34) noted that "Considerable uncertainty exists as to whether the Friant Pumice Member is correlative with the Reds Meadows tuff of the upper San Joaquin drainage and with the Bishop tuff...," but if the Friant Pumice Member overlies the Corcoran Clay Member (Janda and Croft, 1967, p. 164) and if the probable Bishop tuff lies near the basal part of the Corcoran Member (Davis and others, 1977, p. 388) then the Friant Pumice Member and the probable Bishop tuff of Davis and others (1977, p. 388) are not correlative.

Janda and Croft (1967, p. 168) suggested that some of the clays older than the A clay (Croft, 1972, p. 18-20) may have been deposited in large lakes that were coeval with glaciation in the Sierra Nevada (U.S. Geological Survey, 1965, p. A100), but Davis and others (1977, p. 389) suggested that the E clay (Croft, 1972) may represent an interglacial stage.

The C clay of Pleistocene age was mapped beneath the northern, eastern, and southern parts of the area but was not identified beneath Tulare Lake bed because of similarities in sedimentary material (Croft, 1972, pls. 1, 3, and 5) (pl. 1). As one of the older clays of Croft (1972), the C clay may have been deposited in a large lake during a glacial stage in the Sierra Nevada (Janda and Croft, 1967, p. 168, and U.S. Geological Survey, 1965, p. A100).

The A clay of Pleistocene and Holocene (?) age was mapped beneath the northern, northeastern, and southern edges of the study area (Croft, 1972, pls. 1, 3, and 6) (pl. 1). The A clay was not identified beneath Tulare Lake bed because of similarities in sedimentary material. Janda and Croft (1967, p. 168), said that the age of their youngest clay, the A clay of Croft (1972, p. 20-21), was bracketed by radiocarbon dating done by Meyer Rubin of the U.S. Geological Survey. These radiocarbon dates were from wood collected 3 feet beneath the A clay and for wood within the upper part of the clay and are 26,780 ± 600 years and 9,040 ± 300 years respectively (Croft, 1972, p. 21). Janda and Croft (1967, p. 168) considered the A clay to have been deposited in a large lake coeval with the Wisconsin Glaciation.

Croft (1972, p. 18) said that the flood-plain, lake, and marsh deposits range in age from late Pliocene to Holocene; therefore, deposition of these mostly fine-grained deposits has been going on for more than 2 million years. And, except for the expansion of the lake, as represented by the Corcoran Clay Member of the Tulare Formation (Croft, 1972, pl. 4), the ancient lakes and marshes of probable late Pliocene or early Pleistocene age occupied a much larger area for a longer period of time in the eastern and southeastern parts of the study area than later lakes and marshes, as evidenced by the thick deposits of fine-grained material at depths of 2,200 to 2,600 feet and below (pl. 2). Later, alluvial-fan and deltaic deposits from easterly sources encroached on the area formerly occupied by these lake and marsh deposits, as evidenced by the deposition of coarse-grained material above 2,200 feet (fig. 3; pl. 2).

Mack (1969, p. 2535) suggested a minimum rainfall of about 35 to 45 inches per year at the beginning of the deposition of the Tulare Formation in the late Pliocene. Thus, a more abundant rainfall than at present (table 1) and a lower lying area (Hoots and others, 1954, p. 128) probably contributed to the expansion of the ancient lake in the eastern and southeastern parts of the area. In any event, the fine-grained deposits in the central part of the area (pl. 2) were laid down seemingly without interuption throughout the late Pliocene, the entire Pleistocene, and the Holocene. Beneath Tulare Lake bed these deposits would probably yield excellent paleoclimatic data in the form of fossil diatoms, mollusks, and pollens. In turn, paleoclimatic data can help to explain more about the expansions and contractions of this ancient lake.

Texture of the Deposits

Texture as used in this report means the proportion of coarse-grained to fine-grained sedimentary material in the Tulare Formation and other continental deposits. In order to determine texture, geophysical logs, mostly from gas or gas-test wells, were used. These logs show properties of sedimentary material such as resistivity and spontaneous potential. Coarse-grained and fine-grained material, as well as their depth and thickness, can be determined from geophysical logs (Schlumberger Ltd., 1972). For example, in the study area high resistivities are interpreted as representing coarse-grained material, and lower resistivities as representing fine-grained material (fig. 6). The spontaneous potential also is a guide in determining coarse-grained and fine-grained material. Opposite a coarse-grained bed, the spontaneous-potential line, depending on water salinity in the bed and fluid salinity in the borehole, will move either to the right or left of a base line representing fine-grained material. Although the presence of coarse-grained and fine-grained material can be determined from geophysical logs, the logs cannot be used to determine if the coarse-grained material is gravel or sand, nor can they be used to determine if a fine-grained material is silt or clay.

Using geophysical logs and a computer program written by H. T. Mitten of the Geological Survey (written commun., 1980), texture maps of the sedimentary material beneath the study area were generated by computing and plotting the percentage of coarse-grained material in depth intervals of 200 feet (pl. 2). Most of the computations for texture were for depths below 400 feet because the California Division of Oil and Gas requires that before drilling an oil or gas well that a casing be set in the ground from the surface to a depth of 10 percent of the total depth of the well. This casing blocks the recording of resistivity and the spontaneous potential.

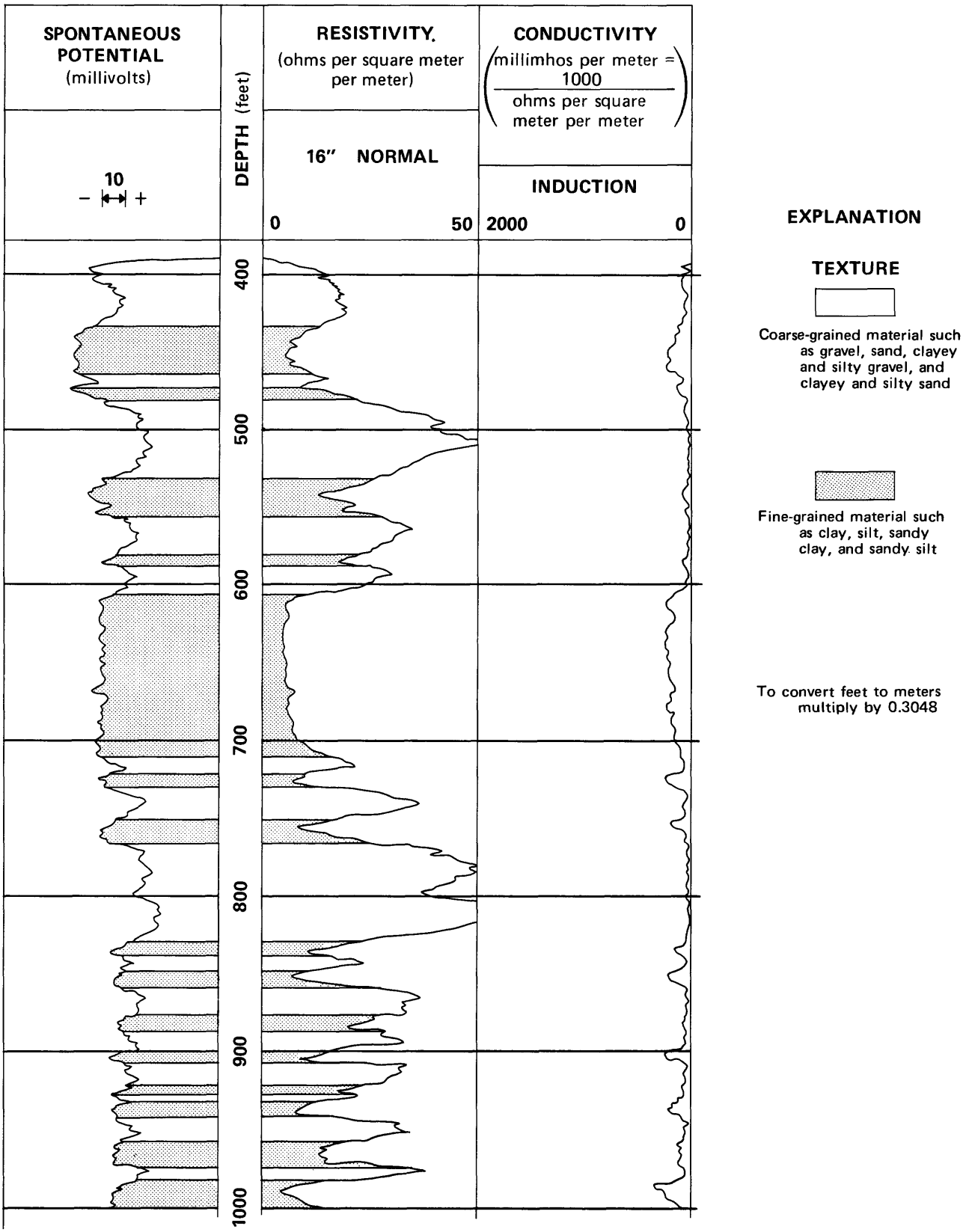


FIGURE 6. — Geophysical logs for part of well 23S/23E–25E.

GROUND-WATER-MANAGEMENT CONSIDERATIONS AND USE OF TEXTURE MAPS

Texture maps (pl. 2) can be useful in making water-management decisions in the study area. For example, coarse-grained material yields water to wells more rapidly and with less drawdown because in a given time it has a greater ability to take water into or release it from storage than fine-grained material and can transmit larger quantities of water. Using this fact, a water manager probably would not elect to drill wells in the central part of the Tulare Lake bed area because of the underlying thick section of fine-grained sediment (pl. 2). Instead, he or she would limit well drilling to the northern, southern, or eastern parts of the area, and in those areas probably would limit wells to depths above the fine-grained sediment, as indicated on plate 2. In the southeast corner of T. 21 S., R. 20 E. (pl. 2), he might elect to drill wells through the fine-grained sediment indicated at depths of 400 to 1,000 feet in order to test the coarse-grained sediment indicated at depths of 1,000 to 1,200 feet and below. On the other hand, if he were considering injecting wastes, following all State and local regulations, he might consider that the thick and extensive nature of the fine-grained sediment indicated beneath the lakebed would serve as an effective cap.

The texture maps (pl. 2) also can be used by ground-water modelers. Virtually any model of a ground-water system requires values for hydraulic conductivity, or transmissivity, and the coefficient of storage. These values must be placed in discrete units, or nodes, throughout an entire model. By knowing that coarse-grained sediment has a greater ability than fine-grained sediment to take water into or release it from storage and can transmit water more readily, a modeler can use the texture maps (pl. 2) to assign relative values of hydraulic conductivity and storage coefficient to the model nodes. Values for the storage coefficient, of course, would depend on whether conditions were confined or unconfined.

Through time, fine-grained sediment such as silt and clay can yield large quantities of water when the silt or clay is compacted because of an increase in effective stress (Lofgren, 1975, p. 35, pl. 5). Increased effective stress occurs when water levels in an aquifer are drawn down (Lofgren, 1968, p. 222). Compaction of fine-grained beds has resulted in land subsidence in parts of the Kettleman City area (Bull and Miller, 1975, fig. 4, and Lofgren and Klausing, 1969, fig. 50). Beds of silt and clay also can confine water under greater than atmospheric pressure and impede the vertical movement of water. In the study area, the A-F clays of Croft (1972, p. 17-21, pls. 1-6) function as confining beds. Anyone making decisions about recharge or discharge operations in the area should take these beds into account as well as the thick sections of fine-grained material (pls. 1 and 2). Most of the fine-grained material lies beneath the western and central parts of the study area to depths of over 1,400 feet (pl. 2). Below 1,400 feet the fine-grained material becomes more widespread, and at depths of 2,400 to 2,800 feet it underlies most of the area. Below 2,800 feet all the mapped deep areas are filled chiefly with fine-grained material (pls. 1 and 2).

Other factors involved in making water-management decisions in the study area include: (1) The gas that occurs in the Tulare Formation and other continental deposits, and (2) saline water that underlies the whole area. Corwin (1960, p. 7) reported the occurrence of gas in the Tulare Formation near the Kettleman Hills, and Hill (1964b, p. 18) reported that farmers in the Tulare Lake area used subcommercial volumes of gas produced from water wells for heating homes and running irrigation pumps. Because of the danger of drilling in gas zones, the California Division of Oil and Gas should be contacted before drilling wells in the area. Finally, water with a dissolved-solids concentration in excess of 2,000 milligrams per liter underlies the area (Page, 1973) (pl. 1). Wells with screens in or near this zone would yield water with a large dissolved-solids concentration.

SUMMARY AND CONCLUSIONS

In the Kettleman City area the base of the Tulare Formation and other continental deposits marks a change from an underlying dominantly marine environment to a continental environment of lakes, swamps, and streams (Woodring and others, 1940, p. 13-14). The base is mapped as just above the upper Mya zone of the San Joaquin Formation. The eastern extent of the Tulare Formation is not defined. The Tulare has been grouped with continental deposits from the east side of the valley that interfinger with and overlie it; on the west side of the area the Tulare Formation has been grouped with younger deposits of similar material that overlie it.

The Tulare Formation and other continental deposits range in depth and thickness from zero in the Kettleman Hills to more than 4,000 feet just east of the hills. In both these areas, the Tulare Formation is the principal deposit. Prior to the uplift of the Kettleman Hills and erosion of all the exposed formations, the Tulare Formation in that area was quite thick, as indicated by measured sections of the Tulare on both the east and west flanks of the hills.

Some of the features of the base of the Tulare Formation and other continental deposits reflect geologic structures in the area. Two of the more prominent features are (1) the rather steep, northeastward-sloping surface in and near the Kettleman Hills that reflects the uplift that occurred at the close of the deposition of the Tulare Formation in Quaternary time, and (2) the deep, northwestward-trending trough that reflects a downwarping that occurred as an effect of that uplift.

Sedimentary material in the Tulare Formation and other continental deposits consists principally of unconsolidated deposits of clay, silt, sand, and gravel. These sediments have been derived chiefly from the Sierra Nevada on the east and the Coast Ranges on the west and have been deposited as alluvial-fan, deltaic, flood-plain, lake, and marsh deposits. Alluvial-fan and deltaic deposits, that contain most of the coarse-grained deposits in the area, underlie the northern, eastern, and southeastern parts. Flood-plain, lake, and marsh deposits of mostly fine-grained material underlie chiefly the central and western parts of the area to depths of 1,400 feet where they become more widespread. At depths of 2,400 to 2,800 feet they underlie most of the area.

For most recharge and discharge operations, water managers in the area would choose those areas underlain by coarse-grained material, as indicated by the texture maps. The texture maps also can be used by ground-water modelers for assigning relative values of hydraulic conductivity and storage coefficient to model nodes. Fine-grained material, when compacted, can yield large quantities of water, but compaction of fine-grained beds in the area has resulted in land subsidence. Water managers in the study area would also have to consider the subcommerical quantities of gas that occur in the Tulare Formation and other continental deposits and the saline water that underlies the area. Drilling in gas zones, of course, poses a danger, and wells completed near the saline water would yield water with a large dissolved-solids concentration.

SELECTED REFERENCES

Addicott, W. O., 1970, Tertiary paleoclimatic trends in the San Joaquin Basin, California: U.S. Geological Survey Professional Paper 644-D, 19 p.

American Association of Petroleum Geologists, 1958, Correlation sections, Riverdale through Tejon Ranch area (10 South), California: Pacific Section, American Association of Petroleum Geologists, Bakersfield, Calif., 1 sheet.

Arnow, Ted, Feth, J. H., and Mower, R. W., 1970, Ground water in deltas of the Bonneville Basin, the Great Basin, U.S.A., in Hydrology of deltas: Bucharest Symposium, Bucharest, Romania, 1969, Proceedings, IASH/AIHS-UNESCO, v. 2, p. 396-407.

Barbat, W. F., and Galloway, John, 1934, San Joaquin Clay, California: Bulletin of the American Association of Petroleum Geologists, v. 18, no. 4, p. 476-499.

Bull, W. B., 1964a, Alluvial fans and near-surface subsidence in western Fresno County, California: U.S. Geological Survey Professional Paper 437-A, 71 p.

_____1964b, Geomorphology of segmented alluvial fans in western Fresno County, California: U.S. Geological Survey Professional Paper 352-E, p. 89-129.

Bull, W. B., and Miller, R. E., 1975, Land subsidence due to ground-water withdrawal in the Los Banos-Kettleman City area, California, Part 1. Changes in the hydrologic environment conducive to subsidence: U.S. Geological Survey Professional Paper 437-E, 71 p.

Cehrs, David, Soenke, Stephen, and Bianchi, W. C., 1980, A geologic approach to artificial recharge site selection in the Fresno-Clovis area, California: U.S. Department of Agriculture, Technical Bulletin 1604, 73 p.

Corwin, C. H., 1960, Dudley Ridge gas field: California Department of Natural Resources, Division of Oil and Gas, Summary of Operations, California Oil Fields, v. 46, no. 1, p. 4-8.

Croft, M. G., 1968, Geology and radiocarbon ages of late Pleistocene lacustrine clay deposits, southern part of San Joaquin Valley, California, in U.S. Geological Survey Research 1968: U.S. Geological Survey Professional Paper 600-B, p. 151-155.

_____1972, Subsurface geology of the late Tertiary and Quaternary water-bearing deposits of the San Joaquin Valley, California: U.S. Geological Survey Water-Supply Paper 1999-H, 29 p.

Croft, M. G., and Gordon, G. V., 1968, Geology, hydrology, and quality of water in the Hanford-Visalia area, San Joquin Valley, California: U.S. Geological Survey open-file report, 63 p.

Dale, R. H., French, J. J., and Wilson, H. D., Jr., 1964, The story of ground water in the San Joaquin Valley, California: U.S. Geological Survey Circular 459, 11 p.

Davis, G. H., and Green, J. H., 1962, Structural control of interior drainage, southern San Joaquin Valley, California, in Geological Survey Research 1962: U.S. Geological Survey Professional Paper 450-D, p. 89-91.

Davis, G. H., Green, J. H., Olmsted, F. H., and Brown, D. W., 1959, Ground-water conditions and storage capacity in the San Joaquin Valley, California: U.S. Geological Survey Water-Supply Paper 1469, 187 p.

Davis, G. H., Lofgren, B. E., and Mack, Seymour, 1964, Use of ground-water reservoirs for storage of surface water in the San Joaquin Valley, California: U.S. Geological Survey Water-Supply Paper 1618, 125 p.

Davis, P., Smith, J., Kukla, G. J., and Opdyke, N. D., 1977, Paleomagnetic study at a nuclear power plant site near Bakersfield, California: Quaternary Research, v. 7, p. 380-397.

Diepenbrock, Alex, 1933, Mount Poso oil field: California Department of Natural Resources, Division of Oil and Gas, Summary of Operations, California Oil Fields, v. 19, no. 2, p. 4-35.

Egorov, V. V., 1970, Deltas of the zones characterized by sinking of the earth's crust, in Hydrology of deltas: Bucharest Symposium, Bucharest, Romania, 1969, Proceedings, IASH/AIHS-UNESCO, v. 1, p. 38-43.

Frink, J. W., and Kues, H. A., 1954, Corcoran Clay, a Pleistocene lacustrine deposit in San Joaquin Valley, California: Bulletin of the American Association of Petroluem Geologists, v. 38, no. 11, p. 2357-2371.

Hackel, Otto, 1966, Summary of the geology of the Great Valley, chapter 5 of Geology of northern California: California Division of Mines Bulletin 190, p. 217-238.

Hill, F. L., 1964a, Harvester gas field: California Department of Conservation, Division of Oil and Gas, Summary of Operations, California Oil Fields, v. 50, no. 1, p. 11-15.

_____1964b, Northwest Trico gas field: California Department of Conservation, Division of Oil and Gas, Summary of Operations, California Oil Fields, v. 50, no. 1, p. 17-20.

Hilton, G. S., McClelland, E. J., Klausing, R. L., and Kunkel, Fred, 1963, Geology, hydrology, and quality of water in the Terra Bella-Lost Hills area, San Joaquin Valley, California: U.S. Geological Survey open-file report, 158 p.

Hoots, H. W., Bear, T. L., and Kleinfell, W. D., 1954, Geological summary of the San Joaquin Valley, California, in Geology of the natural provinces, chapter 2 of Geology of southern California: California Division of Mines Bulletin 170, p. 113-131.

Hoyt, Carrie, ed., 1980, Layperson's guide to ground water: Sacramento, Calif., Western Water Education Foundation, 16 p.

Janda, R. J., and Croft, M. G., 1967, The stratigraphic significance of a sequence of noncalcic brown soils formed on the Quaternary alluvium of the northeastern San Joaquin Valley, California: Quaternary Soils, v. 9, VII Congress, p. 158-190.

Johnson, A. I., Moston, R. P., and Morris, D. A., 1968, Physical and hydrologic properties of water-bearing deposits in subsiding areas in central California: U.S. Geological Survey Professional Paper 497-A, 71 p.

Kaplow, E. J., 1940, Gas fields of southern San Joaquin Valley: California Department of Natural Resources, Division of Oil and Gas, Summary of Operations, California Oil Fields, v. 24, no. 1, in Reprint no. 1, 1955, p. 19-39.

Lofgren, B. E., 1968, Analysis of stresses causing land subsidence, in U.S. Geological Survey Research 1968: U.S. Geological Survey Professional Paper 600-B, p. 219-225.

_____1975, Land subsidence due to ground-water withdrawal, Arvin-Maricopa area, California: U.S. Geological Survey Professional Paper 437-D, 55 p.

Lofgren, B. E., and Klausing, R. L., 1969, Land subsidence due to ground-water withdrawal, Tulare-Wasco area, California: U.S. Geological Survey Professional Paper 437-B, 103 p.

Lohman, K. E., 1938, Pliocene diatoms from the Kettleman Hills, California: U.S. Geological Survey Professional Paper 189-C, p. 81-102.

Mack, Seymour, 1969, Climatic and tectonic factors affecting water quality in the San Joaquin Valley near Fresno, California: Bulletin of the Geological Society of America, v. 80, no. 12, p. 2527-2537.

Marchand, D. E., and Allwardt, Alan, 1981, Late Cenozoic stratigraphic units, northeastern San Joaquin Valley, California: U.S. Geological Survey Bulletin 1470, 70 p.

Meade, R. H., 1967, Petrology of sediments underlying areas of land subsidence in central California: U.S. Geological Survey Professional Paper 497-C, 83 p.

Miller, R. E., Green, J. H., and Davis, G. H., 1971, Geology of the compacting deposits in the Los Banos-Kettleman City subsidence area, California: U.S. Geological Survey Professional Paper 497-E, 46 p.

Newman, W. L., 1977, Geologic time: U.S. Geological Survey, 20 p.

Page, B. M., 1966, Geology of the Coast Range of California, chapter 6 in Geology of Northern California: California Division of Mines Bulletin 190, p. 255-276.

Page, R. W., 1973, Base of fresh ground water (approximately 3,000 micromhos) in the San Joaquin Valley, California: U.S. Geological Survey Hydrologic Investigations Atlas HA-489.

_____1981, Data on depths to the upper Mya zone of the San Joaquin Formation in the Kettleman City area, San Joaquin Valley, California: U.S. Geological Survey Open-File Report 81-699, 8 p.

Poland, J. F., and Evenson, R. E., 1966, Hydrogeology and land subsidence, Great Central Valley, California, chapter 5 of Geology of northern California: California Division of Mines Bulletin 190, p. 239-247.

Poland, J. F., Lofgren, B. E., Ireland, R. L., and Pugh, R. G., 1975, Land subsidence in the San Joaquin Valley, California, as of 1972: U.S. Geological Survey Professional Paper 437-H, 78 p.

Schlumberger, Ltd., 1972, Log interpretation, volume 1--Principles: New York, Schlumberger Limited, 113 p.

U.S. Geological Survey, 1965, Geological Survey Research 1965: U.S. Geological Survey Professional Paper 525-A, 376 p.

[U.S.] National Oceanic and Atmospheric Administration, 1979, Climatological data, annual summary, California, 1979: U.S. Department of Commerce, National Climatic Center, v. 83, no. 13, 29 p.

Woodring, W. P., Steward, Ralph, and Richards, R. W., 1940, Geology of the Kettleman Hills oil field, California: U.S. Geological Survey Professional Paper 195, 170 p.