August 9, 2012

Mr. Lonnie Wass
Supervising Engineer
California Regional Water Quality Control Board
Central Valley Region – Region 5 Fresno Office
1685 E Street
Fresno, California 93706-2007

**RE:** Hilmar Cheese Company ("HCC")
Hilmar, Merced County, California
Cleanup and Abatement Order ("Order") R5-2004-0722

Dear Mr. Wass:


*I certify under penalty of law that I have personally examined and am familiar with the information submitted in these documents and all attachments and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.*

Any questions on the above can be addressed to my attention at (209) 656-2271.

Sincerely,

Hilmar Cheese Company

[Signature]
Burton N. Fleischer
Environmental Director

cc: Jan Alfson, RWQCB, w/enclosure
Russell Walls, RWQCB
John Jeter, Hilmar Cheese Company
Groundwater Modeling for Remedial Alternatives Evaluation

9 August 2012

Prepared for

Hilmar Cheese Company
9001 North Lander Avenue
Hilmar, California 95324

K/J Project No. 0765018*11
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Executive Summary

This Groundwater Modeling for Remedial Alternatives Evaluation report was prepared by Kennedy/Jenks on behalf of the Hilmar Cheese Company (HCC), located near Hilmar, California. The groundwater modeling evaluation described in this report was performed in response to requirements set forth in a letter from the Regional Water Quality Control Board, Central Valley Region (RWQCB) to HCC dated 4 October 2011 and in accordance with the Work Plan for Groundwater Modeling (Kennedy/Jenks, 2012) as conditionally approved by the RWQCB in a letter dated 19 March 2012, with final authorization granted at a meeting at the RWQCB office in Fresno, California on 23 April 2012.

The past discharge of partially treated process wastewater at the HCC Site (the Site) contributed to a plume of total dissolved solids (TDS) in groundwater. A Remedial Investigation (RI) and Feasibility Study (FS) were completed by Jacobson James & Associates, Inc. (JJ&A, 2010a, b) in response to Cleanup and Abatement Order (CAO) No. R5-2004-0722, issued to HCC by the RWQCB. The FS identified, screened, and evaluated potentially applicable remedial alternatives for the Upper Aquifer based on the data and information available at that time. In a letter to HCC dated 4 October 2011, the RWQCB requested that groundwater modeling be conducted to estimate the time to reach or achieve the remedial action objectives (RAOs) for the proposed remedial alternatives (RWQCB, 2011).

To address the 4 October 2011 RWQCB request, a calibrated transient three-dimensional model of groundwater flow and solute transport (the HCC Model) was developed, evaluated, and used to compare estimated timeframes to achieve RAOs in the Upper Aquifer Shallow Zone and Upper Aquifer Supply Zone for the three proposed remedial alternatives, namely:

1. Monitored natural attenuation (MNA)
2. Groundwater extraction and treatment with onsite reinjection
3. Groundwater extraction and treatment with offsite discharge.

Each of the remedial alternatives considered in the FS also included institutional and engineering controls and irrigation-induced soil flushing. For purposes of this Report, the alternatives are distinguished and identified as noted above, without further reference to the other component activities.

Data for developing a hydrogeologic conceptual model (HCM) and for guiding selection of initial aquifer parameters, initial conditions, and boundary conditions for the HCC Model were based on previous investigation results submitted to the RWQCB (e.g., JJ&A, 2010a, b). Constituents of concern (COCs) for the purposes of the HCC Model are total dissolved solids (TDS), chloride, and sodium. These three solutes were defined to be the transport constituents (i.e., the solutes for which transport would be simulated).

The approach for developing the HCC Model was to use available data to characterize the subsurface, estimate average land application rates, and estimate average water quality of applied water. Subsurface heterogeneity is incorporated into the HCC Model at the scale of identified stratigraphic units. Heterogeneity within stratigraphic units was not considered. The
The purpose of modeling at this level of detail is to produce a robust, calibrated model that does not rely on over-parameterization. The objective of this approach is to minimize the number of adjustable parameters in the model, which in turn reduces uncertainty in the simulation results.

The groundwater flow component of the HCC Model was developed using MODFLOW-2000 (Harbaugh et al., 2000) and Groundwater Vistas 5 (ESI, 2007) to facilitate construction, execution, and processing results of the numerical model. The parameter estimation tool, Model-Independent Parameter Estimation (PEST) (Doherty, 2005), was used in conjunction with professional hydrogeological judgment to develop a calibrated model of groundwater flow that is consistent with the HCM. A sensitivity analysis was performed to evaluate the uncertainty associated with the simulation results.

MT3DMS (Zheng and Wang, 1999) and Groundwater Vistas 5 (ESI, 2007) were used to facilitate construction, execution, and processing results of the numerical solute transport component of the HCC Model. Professional hydrogeological judgment was used to develop a calibrated model of solute transport that is consistent with the HCM. A sensitivity analysis was performed to evaluate the uncertainty associated with the simulation results.

The remedial alternatives were simulated as future “what-if” scenarios, based on hydrological conditions developed from the recent past. A 10-year projected future climate cycle was developed from precipitation data, which contained average, wet, and dry years. This 10-year cycle was designed so that it could be repeated to assess the simulated time to achieve the RAOs, and thereby provide a basis for comparing the timeframes to achieve the RAOs for each of the three alternatives.

For MNA, the simulated time to achieve the RAOs is 1,642 days (year 2016) in the Shallow Zone and 4,018 days (year 2022) in the Supply Zone. For extraction and reinjection, the simulated time to achieve the RAOs is 1,642 days (year 2016) in the Shallow Zone and 3,834 days (year 2021) in the Supply Zone. For extraction only, the simulated time to achieve the RAOs is 1,642 days (year 2016) in the Shallow Zone and 3,653 days (year 2021) in the Supply Zone.

The HCC Model was calibrated with respect to groundwater flow. No changes to the model parameters were made based on the results of the solute transport simulations. Because the solute transport model demonstrated an appropriate degree of calibration with respect to measured concentrations, this indicates that the data-driven HCC Model is robust. This degree of calibration was achieved without adjustments to the rate, water quality, and spatial distribution of land applications as reported by HCC to the RWQCB in water quality monitoring reports.

The simulation results indicate that there is no discernible difference in the timeframes to meet the RAOs for each of the simulated remedial alternatives. Accordingly, the remedial alternative including MNA as an element, as recommended by HCC in the FS, is the appropriate remedial alternative for achieving the RAOs.
Section 1: Introduction

This Groundwater Modeling for Remedial Alternatives Evaluation report was prepared by Kennedy/Jenks on behalf of the Hilmar Cheese Company (HCC), located near Hilmar, California. The groundwater modeling evaluation described in this report was performed in response to requirements set forth in a letter from the Regional Water Quality Control Board, Central Valley Region (RWQCB) to HCC dated 4 October 2011 and in accordance with the Work Plan for Groundwater Modeling (Kennedy/Jenks, 2012) as conditionally approved by the RWQCB in a letter dated 19 March 2012, with final authorization granted at a meeting at the RWQCB office in Fresno, California on 23 April 2012. The groundwater modeling evaluation has been performed in support of the Upper Aquifer remediation evaluation and selection activities per Cleanup and Abatement Order No. R5-2004-0722 (CAO).

1.1 Background

Hilmar Cheese Company (HCC) operates a milk processing facility (the Site) near the town of Hilmar in Merced County, California, which is located within the Turlock Groundwater Basin (Figure 1-1). As shown on Figure 1-2, HCC process wastewater was initially discharged to an onsite holding/percolation pond (1985 to 1989) and then to an area identified as the Primary Lands (JJ&A, 2010a). The discharge of partially treated process wastewater to the Primary Lands occurred from 1997 through December 2010, with a maximum Primary Land area of 97 acres.

Since December 2010, the former Primary Lands have only been irrigated with HCC’s highly treated process wastewater (reclaimed water) or water from the Turlock Irrigation District (TID), although there is the option to irrigate these lands with dairy wastewater. Such usage is regulated by the Waste Discharge Requirements, Order No. R5-2010-0008, issued by the RWQCB in January 2010. As shown on Figure 1-3, portions of the former Primary Lands were designated as Reuse Areas S-63 and S-64 in March 2011 and as Reuse Area S-65 in April 2011.

A Remedial Investigation (RI) and Feasibility Study (FS) were completed by Jacobson James & Associates, Inc. (JJ&A, 2010a, b) for the Upper Aquifer in response to the CAO issued to HCC by the RWQCB. The past discharge of partially treated process wastewater contributed to a plume of total dissolved solids (TDS) in the Upper Aquifer groundwater. The FS identified, screened, and evaluated potentially applicable remedial alternatives for the Upper Aquifer based on the data and information available at the time.

The FS stated that estimates of time to achieve remedial action objectives (RAOs) could not be developed for inclusion in the FS, because discharges of partially treated process wastewater to the former Primary Lands were being terminated, which represented a change in land-use conditions, and no representative groundwater quality data were available to support development and calibration of a groundwater model. Therefore, the FS recommended that modeling be performed at a later date. In a letter to HCC dated 4 October 2011, the RWQCB requested that groundwater modeling be conducted to estimate the time to reach or achieve RAOs for the remedial alternatives (RWQCB, 2011).
HCC submitted a *Work Plan for Groundwater Modeling* (Kennedy/Jenks, 2102) to the RWQCB in January 2012. The RWQCB subsequently issued a conditional approval to HCC in a letter dated 19 March 2012 (RWQCB, 2012). Final authorization to proceed was granted at a meeting at the RWQCB office in Fresno, California on 23 April 2012. As requested by the RWQCB, three progress reports were subsequently prepared and submitted to inform the RWQCB of the groundwater modeling activities.

### 1.2 Purpose, Scope, and Modeling Objective

To address the 4 October 2011 RWQCB request, a calibrated transient three-dimensional model of groundwater flow and solute transport (the HCC Model) was developed, evaluated, and used to compare estimated timeframes to achieve the RAOs for three remedial alternatives for the Upper Aquifer Shallow and Supply Zones at the Site, namely:

1. Monitored natural attenuation
2. Groundwater extraction and treatment with onsite reinjection
3. Groundwater extraction and treatment with offsite discharge.

Each of the remedial alternatives considered in the FS also included components of institutional and engineering controls and irrigation-induced soil flushing. For purposes of this Report, the alternatives are distinguished and identified as noted above, without further reference to the other component activities.

The approach for developing the HCC Model was to use available data to characterize the subsurface, estimate average land application rates, and estimate average water quality of applied water. Subsurface heterogeneity was incorporated into the HCC Model at the scale of identified stratigraphic units. Heterogeneity within stratigraphic units was not considered. The purpose of modeling at this level of detail is to produce a robust, calibrated model that does not rely on over-parameterization. The objective of this approach is to minimize the number of adjustable parameters in the model, which in turn reduces uncertainty in the simulation results.

The model domain and key Site features are shown on Figure 1-4. The groundwater flow model is based on a detailed hydrogeologic conceptual model (HCM), which was developed from field and laboratory data previously collected and submitted to the RWQCB (e.g., JJ&A, 2010a, b). The numerical groundwater flow model was calibrated with respect to site-specific groundwater elevation data. The solute transport model is based on the HCM and is calibrated with respect to concentrations of TDS, chloride, and sodium measured in groundwater samples from monitoring wells.

The model domain includes the Upper Aquifer Shallow and Supply Zones, and does not include groundwater flow and solute transport processes below the Corcoran Clay. The model evaluation focuses on TDS, sodium and chloride. The modeling effort is consistent with relevant technical and regulatory guidance for groundwater modeling, including the *Draft Guidelines for Submittal of Information Developed from Models to the Central Valley Regional Board* (RWQCB, 2004). Table 1-1 identifies the sections in this report where the various *Draft Guidelines* are addressed.
Section 2: Hydrogeologic Conceptual Model

The HCM summarizes the key hydrogeological data and is the foundation for developing the numerical models of groundwater flow and solute transport. A robust conceptual model provides a description of the physical properties and processes that control groundwater flow and solute transport, which includes defining and describing the Site hydrostratigraphy, groundwater chemistry, and hydrogeologic water budget.

At least two previous modeling efforts have been conducted in the area that includes the Site. The U.S. Geological Survey (USGS) conducted regional-scale modeling in the Modesto area (Phillips et al., 2007). On behalf of HCC, Kennedy/Jenks conducted preliminary groundwater modeling of the Site and vicinity (Kennedy/Jenks, 2005). Both of these models were reviewed for the purpose of developing the HCM.

2.1 Geological and Hydrogeological Setting

The Site is located within the Turlock Groundwater Basin in the San Joaquin Valley, a structural trough filled by a large thickness of complexly layered, mostly Cenozoic marine and continental sediments (Figure 1-1). These sediment layers comprise a series of aquitards and aquifers. The aquifers provide groundwater production, mainly for irrigation. Prior to agricultural development, regional groundwater flow was generally west to southwest from recharge areas within and along the Sierra Nevada, and groundwater discharge was generally to the San Joaquin River. For the past several decades, this general regional flow pattern has been locally influenced by large-scale groundwater pumping (Burow et al., 2004).

2.1.1 Geology

The basin beneath the San Joaquin Valley developed during the Cenozoic Era. The basin is situated between the Coast Ranges to the west and the Sierra Nevada to the east. The basement complex consists of Mesozoic Sierra Nevadan granitic rocks and Mesozoic and Paleozoic sedimentary rocks on the eastern side of the basin. On the western side of the basin, the basement complex is composed of Mesozoic rocks of the Franciscan Formation (sediments and ultramafic rocks) (Bartow, 1991). The basement rock is overlain by marine and continental sediments ranging in age from the Cretaceous to the Quaternary Periods as well as some Tertiary volcanic rocks (Page, 1977, 1986; Gronberg et al, 1998).

2.1.2 Hydrogeology

In general, the regional hydrogeological setting is comprised of a sequence of consolidated sedimentary rocks with a range of water-bearing characteristics including the Ione, Valley Springs, and Mehrten Formations (Burow et al., 2004 and references therein). These consolidated rocks are overlain by unconsolidated sediments of the Laguna, Turlock Lake, Riverbank, and Modesto Formations and a relatively thin veneer of Holocene deposits. The Corcoran Clay, a regionally extensive aquitard in the San Joaquin Valley subsurface, is part of the Turlock Lake Formation. At the Site, the Corcoran Clay ranges in thickness from 10 to 60 feet (JJ&A, 2010a).
At the Site, the shallow subsurface is generally divided into two aquifer systems. The Upper Aquifer extends from the ground surface to a depth of about 150 feet and overlies the Corcoran Clay. Most of the local groundwater is produced from the Lower Aquifer, which underlies the Corcoran Clay.

The Upper Aquifer has been subdivided into the Shallow Zone and Supply Zone (JJ&A, 2010a). The unconfined Shallow Zone extends from the ground surface to a depth of about 25 feet. The unconfined to semi-confined Supply Zone extends from the base of the shallow zone to the top of the Corcoran Clay.

### 2.1.3 Hydrostratigraphic Units

Figure 2-1 shows the locations of four hydrogeologic cross-sections that were constructed based upon available Site data (JJ&A, 2010a). Based upon subsurface investigations at the Site, the Upper Aquifer can be divided into four subunits: Shallow Zone, A-Zone, A-Aquitard, and B-Zone (Figures 2-2 through 2-5). The Supply Zone contains the A-Zone, A-Aquitard, and B-Zone. The Supply Zone is overlain by the Shallow Zone and is underlain by the Corcoran Clay, which is also referred to as the B-Aquitard. The B-Aquitard is underlain by the C-Zone, C-Aquitard, and D-Zone. The Shallow Zone and the three subunits of the Supply Zone are defined as hydrostratigraphic units (HSUs) for the purposes of the HCC Model.

The Shallow Zone, A-Zone, and A-Aquitard are considered to be part of the Modesto Formation. The B-Zone, B-Aquitard, as well as the C-Zone, C-Aquitard, and D-Zone, are considered to be part of the Turlock Lake Formation (JJ&A, 2010a). The three subunits below the B-Aquitard are part of the Lower Aquifer and were not included in the HCC Model.

### 2.1.4 Aquifer and Aquitard Properties

Table 2-1 summarizes the physical properties of the Upper Aquifer and Corcoran Clay. The lithologies of the units comprising the Upper Aquifer are described as follows:

- The Shallow Zone is partially saturated and generally consists of silts and sands. Depth to water at the Site is approximately 15 feet.
- The A-Zone is saturated and is characterized by interbedded sand, silty sands, silts, and clays (Figures 2-2 through 2-5).
- The A-Aquitard is a laterally discontinuous, fined-grained unit consisting of silts and clays and is present in the southwestern portion of the Site.
- The B-Zone is composed of coarse sands and gravels and is present in the southwestern portion of the Site.

The Corcoran Clay is continuous across the Site, with a thickness of 10 to 60 feet, and is comprised of dark greenish-gray clay (JJ&A, 2010a).
2.2 Hydrogeologic Budget

The hydrogeologic budget for the HCC Model represents the water balance for the local-area groundwater flow system and consists of groundwater storage, which is reflected in the groundwater elevations, and groundwater inflows and outflows. The elements of the hydrogeologic budget are described below and summarized on Figure 2-6 and in Table 2-2.

The local-area groundwater flow system for the HCC Model is a small part (approximately 4,600 acres) of the much larger, regional Turlock Groundwater Basin groundwater flow system (approximately 350,000 acres) (Figure 1-1). Thus, the upgradient and downgradient boundaries (i.e., boundaries across which regional, largely horizontal inflow and outflow occurs) established for the HCC Model do not coincide with the natural hydrologic boundaries of the Turlock Groundwater Basin, such as bodies of surface water or locations where aquifers truncate at natural no-flow boundaries (e.g., geological contacts with low-permeability rocks) at the distal edges of the groundwater basin.

As discussed in more detail in Section 3.2, these model boundaries were located far enough away from the Site to prevent artificial impacts to simulation results, but close enough to the Site to facilitate local-scale modeling. Consequently, groundwater flows across the upgradient and downgradient boundaries of the HCC Model are not determined a priori, but are calculated by the model. As used herein, the terms upgradient and downgradient refer to model boundaries that are located horizontally away from the Site, not at the ground surface or below the Site (Section 3.2).

2.2.1 Groundwater Elevations

Changes in groundwater elevations represent changes in groundwater storage, which are caused by transient differences between groundwater inflows and groundwater outflows. At times when inflows are greater than outflows, increased groundwater elevations indicate increases in groundwater storage. At times when outflows are greater than inflows, decreased groundwater elevations indicate decreases in groundwater storage.

Because groundwater stresses such as pumping and land application at the Site are variable through time, groundwater elevations are also variable through time, as shown on well-specific hydrographs and as observed by comparisons of groundwater potentiometric surface maps (e.g., see JJ&A, 2010a). Figure 2-7 shows representative maps of groundwater elevations in April 2010 for the Shallow Zone and the Supply Zone. Groundwater flow in both zones is to the west-southwest, and the hydraulic gradient in both zones is 0.001 feet/feet. This pattern of groundwater flow at the Site is generally consistent from 2005 through 2010, which is the simulation period for the numerical models described in Sections 3 and 4.

2.2.2 Groundwater Inflows

Inflows to the groundwater flow system include regional groundwater flow into the model domain across the upgradient boundary, precipitation falling directly on the area of the model domain, and applications of water to the former Primary Lands, Reuse Areas and other areas, which include irrigation. There are also two clay-lined storage ponds present on the Site that contain fully treated process wastewater. A stormwater retention pond, removed from service in
December 2011, was also located on the Site. For purposes of model development, these ponds were assumed to provide negligible recharge to the subsurface.

2.2.2.1 Precipitation

Precipitation data are available throughout California from the Western Regional Climate Center (WRCC), which reports monthly precipitation amounts for numerous stations. The closest station to the Site is Turlock #2 (Station #049073), about 4 miles to the north. It was assumed that data for this station are directly applicable to the Site and its surrounding area. Average annual rainfall is reported to be approximately 12 inches per year. Rainfall is higher in October through March than in April through September.

2.2.2.2 Former Primary Lands Applications

The simulation period for calibration of the HCC Model is January 2005 through December 2010, which is a period during which land applications to the former Primary Lands were relatively stable. Land application of partially treated wastewater to the former Primary Lands ceased in December 2010. Figure 1-2 shows the general usage patterns of the former Primary Lands and volumes of partially treated wastewater applied. To facilitate achieving the modeling objective, monthly time steps for partially treated wastewater discharge to formerly active Primary Lands were determined from monthly and quarterly water quality monitoring reports submitted by HCC to the RWQCB.

2.2.2.2.1 Water Volume

Each of the lettered former Primary Land areas shown on Figure 1-2 is comprised of a sequence of smaller “checks”. The amount of water applied to each of these checks was tabulated in the water quality monitoring reports submitted by HCC to the RWQCB. To estimate the spatial and temporal distribution of water applications to the former Primary Lands, data from these tables were compiled and analyzed. For each lettered area for each month of the 2005-2010 simulation period, the volume of water applied to the individual checks was summed, converted to a recharge flux (feet per day; ft/d), and applied uniformly in the model to the relevant lettered area.

2.2.2.2.2 Water Quality

The concentrations of TDS, chloride, and sodium for partially treated wastewater were taken from the same dataset used to estimate the volume of water applied to the former Primary Lands. For TID water, limited water quality data were available. Chloride was reported through March 2010 and TDS was reported after this time, but chloride and TDS were not reported for the same time periods and sodium was not reported. Because TID water is sourced from the Tuolumne River, water quality data collected at the Modesto stream-gauging station were used to estimate concentrations for the months that were missing data.

2.2.2.3 Secondary Lands and other Applications

As described in the water quality monitoring reports, the water applied to the Secondary Lands to irrigate crops came from several sources: TID water, fully treated HCC process wastewater, and dairy wastewater. The water quality monitoring reports provide data for water volumes and quality applied to the Secondary Lands.
2.2.2.3.1 Water Volume

For areas within the HCC Model domain but outside of the former Primary and Secondary Lands, irrigation data were not available. Irrigation with TID water and groundwater was assumed to have been used in these other areas. Estimated irrigation rates were crop-based, using the general land-use categories given in HCC’s Report of Waste Discharge (ROWD; Kennedy/Jenks 2008). The rates were estimated by assuming that two-thirds of the applied water plus precipitation is lost to evapotranspiration. That is, the crop-based evapotranspiration rate was estimated first (see Section 2.2.3.2) and the recharge rate was then estimated to satisfy the above criterion. Crop coefficients were also obtained from HCC’s ROWD (Kennedy/Jenks 2008).

2.2.2.3.2 Water Quality

Where possible, water quality data applied to Secondary Lands were taken from the water quality monitoring reports submitted by HCC to the RWQCB. For fully treated process wastewater, concentrations of TDS, chloride, and sodium were reported through March 2010. After March 2010, only TDS was reported and chloride and sodium concentrations were estimated based on concentration trends for TDS, chloride, and sodium from earlier periods.

For TID water applied to Secondary Lands, water quality was estimated using the same procedure described above for the former Primary Lands. The estimated TID water quality was used for irrigation within the HCC Model domain for areas outside of the former Primary and Secondary Lands.

2.2.3 Groundwater Outflows

In addition to groundwater flow across the downgradient boundary, groundwater discharges from the HCC Model domain include downward flow through the Corcoran Clay, evapotranspiration, agricultural tile drains, and groundwater pumping.

2.2.3.1 Corcoran Clay

The lower boundary of the HCC Model represents the uppermost part of the Corcoran Clay, which acts as an aquitard between the Upper and Lower Aquifers. This model boundary was defined based on its properties in the previous USGS and Kennedy/Jenks groundwater models (Phillips et al., 2007; Kennedy/Jenks, 2005). Both of these models included aquifers above and below the Corcoran Clay. The regional-scale USGS modeling results show a downward flow rate through the Corcoran Clay of about $8.4 \times 10^{-4}$ ft/d, while the local-scale Kennedy/Jenks model results indicate a range of flow rates from about $1.4 \times 10^{-3}$ to $2.5 \times 10^{-3}$ ft/d. The initial flow rate through the Corcoran Clay for the HCC Model was based on the Kennedy/Jenks (2005) model, because the spatial extents of the model domains more closely match and thus the Kennedy/Jenks (2005) model is more representative of local-scale flow processes. Flux through the Corcoran Clay was used as a calibration parameter during development of the numerical groundwater flow model (Section 3.6).

2.2.3.2 Evapotranspiration

Due to evapotranspiration, the amount of recharge to groundwater is generally less than the amount of water applied at the surface. For the HCC Model, evapotranspiration was estimated based on data from the California Irrigation Management Information System (CIMIS), which
reports reference evapotranspiration. The closest station to the Site is Patterson (Station #161), which is about 15 miles to the west. Site-specific estimates of actual evapotranspiration are calculated by multiplying the reference evapotranspiration by applicable crop coefficients. The specific crops at the facility are described in the water quality monitoring reports submitted by HCC to the RWQCB.

Cropping data were not included in all water quality monitoring reports. A general cropping pattern was estimated and applied to periods without crop data. For areas that seemed to have a steady rotation of oats and corn, this rotation was continued. Areas that appeared not to have crops were assumed to be fallow during the missing months.

For areas within the HCC Model domain but outside of the former Primary and Secondary Lands, general land-use categories given in the ROWD (Kennedy/Jenks, 2008) were assumed to be representative of the cropping. Areas listed as “Dairy Land” (including areas that are part of Secondary Lands) and “Other Agricultural Land” were assumed to be double-cropped with oats and corn. Areas listed as “Almond Land” were assumed to have almond trees present.

2.2.3.3 Tile Drains

Onsite and offsite agricultural tile drains have been used historically to lower the water table in cropped areas (Figure 1-4). The tile drains present within the Site were plugged in 2001 (the eastern end of the Site), in 2003 (the south-central part of the Site), and in 2008 (the western end of the Site) (JJ&A, 2010b). The state of the offsite tile drains is not known with certainty, but JJ&A (2010b) describe these drains as being active.

2.2.3.4 Pumping

Groundwater pumping within the HCC Model domain was estimated from the Kennedy/Jenks (2005) model and updated based on more recent information (e.g., JJ&A, 2011; 2012). Pumping at irrigation wells was assumed to occur May through September each year. Pumping rates at other wells were assumed to be steady-state. Active pumping wells and their respective estimated pumping rates are described more fully in Section 3.4.

2.3 Groundwater Quality

Groundwater quality beneath the Site is described in detail in the Remedial Investigation Report (JJ&A, 2010a) and the Remedial Action Feasibility Study and Proposed Remedial Actions for the Upper Aquifer (JJ&A, 2010b). For purposes of the HCC Model, the constituents of concern (COCs) are TDS, chloride, and sodium. Table 2-3 provides the mean background concentrations for these COCs in the Site vicinity. Also shown in Table 2-3 are the maximum concentrations in monitoring wells for the COCs in groundwater in the fourth quarter of 2010, which closely coincides with the end of the simulation period for model calibration. Figure 2-8 shows the footprints of the areas where COC concentrations exceed the ambient screening threshold concentrations, which were established based on the 95% upper tolerance limits presented in the RI (JJ&A, 2010a).

2.4 Geochemical Analysis

Iron and manganese are present as oxidized solid coatings on sediment surfaces derived from natural weathering of rocks and sediments. These oxidized solids can become chemically
reduced, dissolved, and mobilized if dissolved oxygen concentrations decrease below certain thresholds.

The purpose of the geochemical analysis described herein is to evaluate the relative contribution of naturally occurring redox-sensitive metals (i.e., iron and manganese) to the overall TDS concentration. The analysis was conducted to evaluate whether the concentrations of dissolved redox-sensitive metals are significant with regard to understanding changes in TDS concentrations in the remedial alternatives simulations presented in Section 5.

Table 2-4 shows average concentrations of the COCs and dissolved iron and manganese in groundwater monitoring wells from 2008 through 2011. Also shown is the percentage of TDS comprised of manganese plus iron. Figure 2-9 compares the concentrations of COCs and manganese plus iron. The data presented in Table 2-4 and Figure 2-9 show that in all cases the concentration of manganese plus iron is less than one percent of the TDS concentration. Therefore, concentrations of redox-sensitive metals are insignificant and not relevant to assessing the relative timeframes for the three remedial alternatives simulated.
Section 3: Groundwater Flow Model

A numerical groundwater flow model has been developed for the Site. The flow model is the foundation for the overall HCC Model, which also includes a numerical solute transport model (Section 4). The HCC Model includes the necessary detail and resolution to serve as a quantitative tool to evaluate the timeframes to achieve RAOs for the three remedial alternatives (Section 5).

The groundwater flow model is a numerical representation of the HCM. Ranges of values from the Site database and local area hydrogeologic reports were defined for aquifer properties and the hydrogeologic budget. These values represent the major physical features of the groundwater flow system, recharge and discharge components, definition of model layers, and the distribution of hydraulic conductivity and storage coefficients. During model calibration, these values were varied within the defined ranges to determine site-specific parameters for simulation of the three remedial alternatives.

3.1 Modeling Approach

A model is a representation of a real, natural system. Because natural groundwater flow systems are complex, assumptions regarding aquifer properties and boundary conditions must be made to create a practical model, while ensuring that these assumptions lead to a model that still represents the major processes influencing groundwater flow.

To support numerical model development, a range of values is defined for aquifer properties and the hydrologic budget based on measured field data and hydrogeological analysis. The general procedure for this process is to define values for a representative elementary volume as described by Bear and Verruijt (1987). These values represent the major physical features of the basin, including surface water-groundwater interactions, recharge and discharge components, definition of model layers, and the distribution of aquifer properties.

The approach for developing the HCC Model was to use available data to characterize the subsurface, estimate average land application rates, and estimate average water quality of applied water. Subsurface heterogeneity is incorporated into the HCC Model at the scale of identified stratigraphic units. Heterogeneity within stratigraphic units was not considered. The purpose of modeling at this level of detail is to produce a robust, calibrated model that does not rely on over-parameterization. The objective of this approach is to minimize the number of adjustable parameters in the model, which in turn reduces uncertainty in the simulation results.

The groundwater flow component of the HCC Model was developed using MODFLOW-2000, which solves the groundwater flow equation using the finite-difference method (Harbaugh et al., 2000). Groundwater Vistas 5 was used to facilitate construction, execution, and processing results of the numerical model (ESI, 2007).

MODFLOW-2000 is a process-based model that is founded on conservation of mass and conservation of energy principles, as described by groundwater flow equation and Darcy’s law. Two primary assumptions for groundwater flow models are that: (1) flow of water in the subsurface is laminar and (2) Darcy’s law is applicable at all scales (e.g., pore-scale
phenomena are assumed to be insignificant). These are standard assumptions and are appropriate for the scale and objectives of the HCC Model.

3.2 Model Domain

The spatial domain of the HCC Model is a rectangle aligned with the north-south and east-west cardinal directions of the State Plane coordinate system (Figure 1-4). The spatial domain is of sufficient extent such that model boundaries are far enough away from the area of interest that groundwater flow dynamics in the area of interest are not significantly influenced by the model boundaries. For calibration purposes, the temporal domain begins in 2005 and runs through the end of 2010.

The HCC Model simulates groundwater flow and solute transport in the Upper Aquifer. Therefore, the bottom boundary of the model domain is the upper part of the Corcoran Clay. Fluid flow is simulated to occur in saturated zone, below the water table. The vadose zone is not included within the spatial domain of the HCC Model.

3.2.1 Spatial Discretization

The groundwater flow equation is a partial differential equation that is continuous in space and time. To solve the spatial terms of the groundwater flow equation numerically, the spatial domain must be divided into discrete grid cells and model layers.

Horizontally, the HCC Model grid extends 14,700 feet east-west and 13,800 feet north-south. Grid cells within the spatial domain are uniformly defined at 100 feet by 100 feet. The grid contains 147 cells in the east-west direction and 138 cells in the north-south direction (Table 3-1). The spatial resolution is sufficiently fine that most grid cells do not contain more than one monitoring or production well.

Model layers in a finite-difference grid are required to be continuous across the spatial domain. Sixteen layers, each with uniform layer thickness of 10 feet, were defined to discretize the vertical dimension (Figure 3-1 for model layers and Figure 3-2 for the locations of east-west and north-south transect lines). Because the A-Aquitard and B-Zone are discontinuous and pinch out to the north-northeast, many of the model layers contain more than one HSU. The 10-foot thickness of the model layers was designed to provide sufficient numerical resolution for calculating groundwater elevations, which enables the model to simulate vertical hydraulic gradients observed at the Site.

3.2.2 Temporal Discretization

For transient simulations, the time term of the groundwater flow equation also needs to be discretized. In MODFLOW-2000, temporal discretization is achieved by defining a series of stress periods, during which stresses such as pumping and temporally variable boundary conditions can change from stress period to stress period.

Because partially and fully treated wastewater discharges and water quality data were reported on a monthly basis in HCC's water quality monitoring reports, stress periods of one month each were defined to simulate the input of water to the model at the former Primary and Secondary
Lands. The simulation period for model calibration is six years (2005 through 2010), which led to the definition of 72 stress periods.

### 3.3 Initial Aquifer Parameters

Section 2.1.4 describes the general characteristics of the subsurface at the Site. Ranges of values for representing the flow and storage properties for porous media at the Site are given in Table 2-1.

The parameters that represent the flow and storage properties of porous media are hydraulic conductivity \( K \), specific storage \( S_s \), and specific yield \( S_y \). In the model-calibration process, values of these parameters and boundary conditions are adjusted within appropriate ranges until the simulated groundwater elevations reasonably match the observed groundwater elevations in space and time. Initial parameter values for the HCC Model were based on prior subsurface investigations (JJ&A, 2010a, b) and are shown in Table 3-1.

### 3.4 Boundary Conditions

The hydrogeologic water balance is implemented in the groundwater flow model by defining boundary conditions (Figure 3-2). The flow of water into and out of the spatial domain is defined at the upper, lower, upgradient, and downgradient boundaries, and all sinks for water (e.g., wells).

#### 3.4.1 Upper Boundary

The upper model boundary corresponds with the water table, and water flow across it represents recharge to the HCC Model (natural and artificial). The water table occurs in model layer 1, except in the areas furthest downgradient, where the water table occurs in model layer 2.

For the HCC Model, flows across the upper boundary represent applications of partially and fully treated wastewater to the former Primary and Secondary Lands, irrigation, and precipitation, minus evapotranspiration. Estimation of the flux rates for the upper boundary was described in detail in Section 2.2.2. Evapotranspiration was estimated (Section 2.2.3.2) and subtracted from the flows prior to boundary condition implementation to provide a net recharge flux into the model domain.

The modeling approach for the upper boundary was to use the available data from HCC’s water quality monitoring reports, with no modifications other than consolidating into larger groups the individual checks at the former Primary Lands. These recharge fluxes were not changed during model calibration.

The net recharge fluxes were applied in the model with the recharge package of MODFLOW-2000. The average annual recharge flux rates for the former Primary and Secondary Lands are shown in Table 3-2. The annual total volumes for the simulation period (2005 through 2010) of partially and fully treated wastewater, irrigation, and precipitation applied at the upper boundary are shown on Figure 3-3.
3.4.2 Lower Boundary

The lower model boundary represents the upper part of the Corcoran Clay (Figure 3-1), which acts as an aquitard between the Upper and Lower aquifer systems. The lower boundary flux represents a net outflow of water from the model domain.

A flux boundary condition was specified along the lower boundary of the model to account for flow out of the Upper Aquifer through the Corcoran Clay. The hydraulic conductivity of the Corcoran Clay was adjusted during model calibration. The flux rate out of the model domain through the lower boundary was also adjusted during model calibration and is approximately $1.9 \times 10^{-3}$ ft/d, which is within the range of the values from the Kennedy/Jenks (2005) model (Section 2.2.3.1).

3.4.3 Upgradient Boundary

The upgradient boundary in the HCC Model was defined as a specified head boundary condition. The groundwater elevation was defined in every cell along the upgradient boundary for every time step of the simulation.

As described in Section 2.2, the HCC Model is a local-area sub-area within a regional groundwater flow system. Based on professional judgment, the upgradient boundary of the HCC Model was located at a sufficient distance from the area of interest (i.e., the Site) so as not to influence groundwater flow dynamics in the area of interest. The function of the upgradient boundary in the HCC Model is to approximate changes in groundwater elevations upgradient of the Site so that simulated groundwater elevations at the Site are in general agreement with observed groundwater elevations.

Groundwater elevations in unconfined aquifers generally rise and fall with trends in precipitation. To reproduce the effect of climatic trends on groundwater elevations in the area, groundwater elevations at the upgradient boundary were varied through time to match variations in annual precipitation and observed trends in Site monitoring wells (Figure 3-4).

3.4.4 Downgradient Boundary

The majority of groundwater flow out of the HCC Model domain occurs at the downgradient boundary. A general-head boundary condition was applied that used the same temporal pattern as the upgradient boundary of increases and decreases in groundwater elevations. The magnitude of the groundwater elevations at the downgradient boundary were set to simulate hydraulic gradients across the model domain that are in general agreement with observed hydraulic gradients.

3.4.5 Lateral Boundaries

The lateral boundaries of the model were defined to coincide with approximate groundwater flow lines. Flow lines represent a one-dimensional path along which particles of water flow; groundwater does not flow across a flow line at any angle. No-flow boundaries were set along the northern and southern boundaries of the HCC Model domain (Figure 3-2). Groundwater in the immediate vicinity of the no-flow boundaries flows perpendicularly to the boundary.
3.4.6  **Tile Drains**

Within the HCC Model domain, the MODFLOW-2000 drain package was used to simulate flow out of the model through agricultural tile drains. The drain package allows outflow from the model during the simulation when the water table rises to the elevation of the drains. Drains in the HCC Model function as a one-way valve; only flow out of the model occurs.

For the HCC Model, it was assumed that the walls of the tile drains are not an impediment to water flowing into the drains, and the conductance of the drains was set equal to the hydraulic conductivity of the shallow zone sediments. All known tile drains were included in the model. Inactive tile drains were assigned a conductance of zero, which prevents groundwater from flowing into the drain. The drains on the western end of the facility were assigned a conductance of zero starting at the beginning of 2008.

3.4.7  **Groundwater Production and Irrigation Wells**

Numerous wells produce groundwater from various depths of the groundwater system in the Site vicinity. Production wells in the HCC Model withdraw groundwater from the Upper Aquifer Supply Zone (JJ&A, 2010a, b). Pumping at irrigation wells was assumed to occur in May through September each year. Pumping rates at other wells were assumed to be steady-state. Well locations and pumping rates were taken from the Kennedy/Jenks (2005) model and updated based on more recent information (e.g., JJ&A, 2011; 2012; TID 2009). These wells and pumping rates are given in Table 3-3.

3.5  **Initial Conditions**

Initial conditions for the groundwater flow model are represented by estimated groundwater elevations at each cell in the finite difference grid on January 1, 2005. To generate this distribution of simulated groundwater elevations, a steady-state groundwater flow model for the same domain as the HCC Model was developed. The steady-state groundwater flow model was designed to represent the estimated spatial distribution of groundwater elevations at the end of 2004.

3.6  **Model Calibration**

The model calibration procedure for the HCC Model is consistent with ASTM D 5981-96. For groundwater flow, the model-performance objective is to minimize differences between observed and simulated heads at select observation points (i.e., monitoring wells). During model calibration, model parameters are systematically varied within a range consistent with the HCM, and the simulation results are compared to observed data. For the HCC Model, the sensitivity analysis and calibration for the groundwater flow model was accomplished with the use of zones, in which each HSU was a single zone. Parameters within zones were considered to be uniform.

A calibrated model represents the statistical best fit, evaluated by comparing simulated groundwater elevations with observed groundwater elevations. The “best fit” is often subjective, in the sense that it is possible for the statistical best-fit to be achieved using model parameters that are thought or known to be inconsistent with the conceptual understanding of the groundwater flow system. Such situations arise due to the inherent limited knowledge of the
subsurface, which can never be complete, or by exclusion in the numerical model of an important process controlling groundwater flow dynamics that was not adequately recognized in the conceptual model. Because of these limitations, model calibration is akin to hypothesis-testing. When a statistically demonstrated match between simulated and observed values is achieved using parameter values that are consistent with the conceptual model, the numerical model is said to be calibrated.

Once calibration is achieved, the model is considered capable of forecasting future conditions with a degree of accuracy that reflects the understanding and knowledge of the site subsurface and hydrogeologic budget. Input parameters can be set to simulate a wide range of potential future groundwater use, water quality, or hydrogeologic scenarios. The results can be evaluated for overall trends and more localized effects. The horizontal and vertical resolution used to construct the model dictate the range of scales that the model can evaluate.

### 3.6.1 Sensitivity Analysis

The first step in model calibration is a sensitivity analysis to determine which parameters, when changed, cause the largest changes in simulation results. For the groundwater flow model, values for hydraulic conductivity and specific yield in each hydrostratigraphic unit were varied systematically by up to plus/minus 50 percent of the initial value. Specific storage was not evaluated because its impact on groundwater flow in unconfined aquifers is significantly less than specific yield. The changes in model performance were evaluated by comparing a suite of model evaluation statistics for each sensitivity scenario (ESI, 2007).

Table 3-4 shows the results of the statistical comparisons. The global residual sum of squares for the full range of parameter variations are shown on Figure 3-5. Table 3-4 and Figure 3-5 indicate that the simulation results are most sensitive to hydraulic conductivity in the A-Zone, specific yield in the Shallow Zone, and the magnitude of water flux out of the model domain through the bottom boundary.

### 3.6.2 Calibration Results

First, a qualitative, manual calibration was performed based on the sensitivity analysis. The resulting initial values for key model parameters are shown in Table 3-1. Next, model parameters were adjusted systematically using PEST (Doherty, 2005), an automatic parameter estimation tool. Parameters were allowed to vary within a range of values consistent with the HCM.

Figure 3-6 shows the calibrated simulated groundwater elevations. Figure 3-7 shows a comparison of the calibrated simulated groundwater elevations and observed groundwater elevations. The scatterplot on Figure 3-7 shows two comparisons for two datasets. The first dataset, indicated on Figure 3-7 in gray, compares simulated and observed values for 20 groundwater monitoring wells used in the evaluation as calibration targets. The second dataset, shown in black, compares simulated and observed values for the ten best monitoring wells. The set of ten best wells consists of the wells with the best values of mean residual, absolute mean residual, and residual standard deviation.

Figure 3-8 shows the simulated groundwater elevations and observed groundwater elevations for the ten best monitoring wells for the duration of the simulation period. Figure 3-9 shows the
The final model parameters that gave the statistical and conceptual best fit, as measured by the residual sum of squares and are consistent with the HCM, are shown in Table 3-1. Comparing the final model parameters with the values given in Table 2-1 indicates that the set of parameters for the final HCC groundwater flow model is consistent with the HCM.
Section 4: Solute Transport Model

The groundwater flow model simulates the spatial and temporal distribution of groundwater elevations and the three-dimensional groundwater velocities within the model domain. To simulate subsurface solute transport, groundwater velocities from the output of the groundwater flow model are used as an input parameter for the solute transport model, which has the same spatial and temporal domains as the groundwater flow model. The complete HCC Model includes the necessary detail and resolution to serve as a quantitative tool to evaluate the timeframes to achieve RAOs for the remedial alternatives (Section 5).

The solute transport model is a numerical representation of the water quality aspects of the HCM. Ranges of values from the Site database and local-area hydrogeologic reports were defined for the relevant transport parameters. These parameters represent the major physical features of the groundwater flow system that influence the movement of dissolved solutes in groundwater: effective porosity and dispersivity. During model evaluation, these values were varied within defined ranges to determine site-specific parameters for simulation of the three remedial alternatives.

4.1 Modeling Approach

The modeling approach for the solute transport model uses process-based techniques founded on the physics of solute transport in saturated porous media. The governing equation for simulating solute transport is the advection-dispersion equation (i.e., the solute transport equation), which is based on conservation of mass principles.

MT3DMS (Zheng and Wang, 1999) was used to develop the numerical solute transport component of the HCC Model. The principle feature of MT3DMS that is relevant to the HCC Model is advective-dispersive transport of multiple chemical species. Groundwater Vistas 5 (ESI, 2007) was used to facilitate construction, execution, and processing results of the numerical solute transport model.

As requested by the RWQCB, the simulated transport constituents are TDS, chloride, and sodium (i.e., the COCs). Each transport constituent is represented by a separate solute transport equation.

4.1.1 Transport Parameters

Transport parameters reflect the physical properties of the porous media that influence the movement of solutes. These parameters are dispersivity, which is a scale-dependent parameter that describes the spreading of a solute as it is transported, and effective porosity, which affects the average linear velocity of a solute particle and thus has a direct impact on estimates of timeframes to achieve RAOs. It should be noted that the vertical transverse dispersivity was assumed to be smaller than the numerical dispersion that occurs with MT3DMS’s numerical method of solution. Hence, the value for vertical transverse dispersivity was set to zero. Other initial values for parameters were estimated based on Site data, and were adjusted within defined ranges during model evaluation and calibration (Section 4.2).
4.1.2 Boundary Conditions

Figure 4-1 shows the boundary conditions for the solute transport model at the lateral limits of the model grid. The inflow of solutes to the HCC Model domain across the upper boundary is simulated by defining specified flux boundary conditions, using the recharge package of MT3DMS. The concentrations of COCs that are transported by advection across the upper boundary of the HCC Model are shown on Figure 3-3. The concentrations of COCs for the former Primary and Secondary Lands and other areas were estimated using the analysis described in Sections 2.2.2.2.2 and 2.2.2.3.2.

For the upgradient boundary, the concentrations of TDS, chloride, and sodium were set to their respective background concentrations (Table 4-1). Background concentrations for the purposes of the model were represented by mean values for the Upper Aquifer Shallow Zone and Supply Zone datasets that were used to establish the 95% upper tolerance limits (ambient screening thresholds) presented in the RI (JJ&A, 2010a), Appendix G – Technical Memorandum: Ambient Screening Threshold Level Statistical Evaluation for the Upper Aquifer Shallow Zone and Upper Aquifer Supply Zone, Hilmar Cheese Company, June 18, 2010.

The modeling approach for the upper boundary was to use the available data from HCC’s water quality monitoring reports, with no modifications other than consolidating into larger groups the individual checks at the former Primary Lands. These recharge concentrations were not changed during model calibration.

Transport of the COCs out of the HCC Model domain is governed by advection. That is, a concentration gradient of zero is imposed on the outflow boundaries. A zero concentration gradient is also imposed on the lateral boundaries of the model domain. As discussed in Section 3.4.6, the lateral boundaries of the HCC Model spatial domain are defined as no-flow boundaries. Therefore, COCs are not transported across the lateral boundaries.

4.1.3 Initial Conditions

Initial concentrations within the spatial domain of the HCC Model were specified for each transport constituent. These initial concentrations were based on observed concentrations in monitoring wells at the beginning of 2005 as reported in HCC’s water quality monitoring reports.

4.1.4 Time Steps

Within each model stress period, it is possible for tens to thousands of transport time steps to be needed to ensure model stability and prevent excessive numerical dispersion. MT3DMS estimates the appropriate time step based on the Courant number, which relates time-step size to solute velocity.

4.2 Model Calibration

For solute transport, the model performance objective is to minimize the difference between observed and simulated concentrations at selected observation points. The same set of monitoring wells used for groundwater flow model calibration, and the same subset of ten monitoring wells, were also used to evaluate and calibrate the solute transport model (Section 3.6.2).
During model calibration, model parameters are systematically varied within a range consistent with the HCM, and the simulation results are compared to observed data. For the HCC Model, the sensitivity analysis and calibration for the solute transport model was accomplished by assuming the entire spatial domain was uniform with respect to dispersivity. Each HSU had variable values of effective porosity (Table 3-1).

Calibration of solute transport models is more difficult due to several factors. For example, the general physical behavior of solutes undergoing advection and dispersion is fundamentally different than the physics of groundwater flow. The dynamics of groundwater flow are governed by the spatial distribution of pressure (a mathematical field variable). Changes in pressure propagate relatively quickly throughout the pressure field. That is, pressure changes in one area of the pressure field influence pressures in other areas of the pressure field (in this case water pressure in an aquifer). Groundwater elevations represent the pressure field.

On the other hand, concentration is not a field variable; there is no concentration field. Changes in concentrations in one area of a spatial domain do not immediately influence concentrations in other areas of the spatial domain. Thus, aquifer characteristics such as heterogeneity and preferential flow paths have a muted impact on groundwater elevations, but can have a tremendous impact on local groundwater velocities and solute transport.

The modeling approach for a robust HCC Model does not account for small- to medium-scale heterogeneity or for preferential flow paths, due to data constraints. Therefore, small- to medium-scale features of the observed concentration distribution cannot be simulated by the HCC Model. The appropriateness of this approach is evaluated during model calibration.

### 4.2.1 Sensitivity Analysis

For the solute transport model, values for effective porosity, longitudinal dispersivity, and horizontal transverse dispersivity were varied by plus/minus 50 percent of the initial value. For vertical transverse dispersivity, the value was increased to 1.5 feet for the minus 50 percent analysis and increased to 4.5 feet for the plus 50 percent analysis. Changes in model performance were evaluated by comparing a suite of model evaluation statistics for each sensitivity scenario (ESI, 2007).

Table 4-2 shows the results of the statistical comparisons for sensitivity analysis for effective porosity and dispersivity. The normalized global residual sum of squares is shown on Figure 4-3. Table 4-2 and Figure 4-3 indicate that the simulation results are sensitive to effective porosity and dispersivity.

### 4.2.2 Calibration Results

No changes were made to transport parameters during model calibration. Rather, the initial parameters were used and the resulting simulated spatial and temporal distributions of TDS, chloride, and sodium concentrations were evaluated with respect to observed concentrations. Figures 4-2a and 4-2b show the calibrated simulated concentrations of TDS, chloride, and sodium for the Shallow Zone and Supply Zone, respectively. Figure 4-4 shows a comparison of the calibrated simulated concentrations and the observed concentrations. The scatterplot on Figure 4-4 shows two comparisons for two datasets. The first dataset, indicated on Figure 4-4 in muted colors, compares simulated and observed values for all 20 groundwater monitoring wells...
used in the evaluation. The second dataset, shown in bright colors, compares simulated and observed values for the ten best monitoring wells. The set of ten best wells was determined by taking the wells with the best values of mean residual, absolute mean residual, and residual standard deviation (Section 3.6.2).

Figure 4-5 show the simulated concentrations and observed concentrations for the ten best monitoring wells for the duration of the simulation period. Figure 4-6 shows the global mean residual, absolute mean residual, and residual standard deviation for the simulation period. A slight increasing trend with time in the residuals indicates that the simulated concentrations are not significantly skewed systematically. Figure 4-7 is equivalent to Figure 4-5, but compares simulation results for 2011 only, which is the first-year dataset after discharge of partially treated process wastewater to the former Primary Lands was discontinued, and was used as a qualitative model evaluation period.

The HCC Model was calibrated with respect to groundwater flow. No changes to the model parameters were made based on the results of the solute transport simulations. Because the solute transport model was able to achieve calibration with respect to concentrations indicates that the data-driven HCC Model is robust. This degree of calibration was achieved with minimal adjustments to initial aquifer parameters and no adjustments to the rate, water quality, and spatial distribution of land applications.
Section 5: Remedial Alternatives Analysis

The calibrated groundwater flow and solute transport models were used to develop simulations for the following three remedial alternatives:

1. Monitored Natural Attenuation
2. Extraction and treatment with reinjection to the Upper Aquifer
3. Extraction and treatment with offsite disposal/discharge.

The results of this analysis provide a basis for evaluating the timeframes to achieve the RAOs. Timeframes associated with each alternative are compared to estimate the relative differences in time to achieve the RAOs. A sensitivity analysis was conducted with modified aquifer parameters to provide an assessment of uncertainty with regard to the estimated timeframes.

5.1 Remedial Alternatives

The remedial alternatives were simulated as future “what-if” scenarios, based on hydrological conditions developed from the recent past (i.e., climate, pumping, and irrigation). A ten-year projected future climate cycle was developed using the last ten years of data from Turlock #2 (Station #049073), located about four miles north of the Site (Section 2.2.2.1), which contained average, wet, and dry years. This ten-year cycle was designed so that it could be repeated sequentially to simulate different lengths of time for assessing the timeframes to achieve the RAOs.

As set forth in the FS (JJ&A, 2010b), two of the remedial alternatives evaluate the effect of a potential groundwater extraction well system, and one of the alternatives also includes a reinjection well system. The locations of these potential extraction and reinjection wells are shown on Figure 5-1.

For the simulation of remedial alternatives, the stress-period duration was increased to six months to facilitate execution of tens of years of simulated time.

5.1.1 Initial Conditions

Initial concentrations of the COCs for simulation of the remedial alternatives simulations were developed from the observed concentrations of TDS, chloride, and sodium in December 2010 to provide conservative estimates of timeframes to meet the RAOs.

5.1.2 Boundary Conditions

For the remedial alternatives, the upper boundary condition, the upgradient boundary condition, and the dowgradient boundary condition were modified from the historical model (i.e., calibrated) to accommodate the projected future climate cycle.

Figure 5-2 shows the annual total rainfall developed for the ten-year projected future climate. Also shown on Figure 5-2 are the corresponding simulated annual irrigation and
evapotranspiration. The sum of these three components equals the volume of water recharged to the model through the upper boundary for the future scenarios. Onsite and offsite irrigation and evapotranspiration were estimated from recent usage patterns, the bases for which are described in Sections 2.2.2 and 2.2.3.2.

Groundwater elevations at the upgradient and downgradient boundaries were modified from the historical model to reflect average, wet, and dry conditions in the projected future climate.

**5.2 Remedial Alternatives Simulation Results**

The results for the remedial alternatives analysis for the Shallow and Supply Zones are presented on Figure 5-3 and in Table 5-1, which are based on the depth-averaged simulated concentrations in the Shallow and Supply Zones.

The maximum simulated times to achieve the RAOs for concentrations at any point location at depth throughout the model domain are given in the sub-sections below. The relative differences in timeframes estimated by evaluating the depth-averaged concentration is comparable to the relative differences estimated by evaluating the maximum concentrations. For interpretation of simulation results, a point location at depth in the model domain is equal to the thickness of model layers (i.e., ten feet).

It should be noted that the TDS, sodium and chloride plumes shown in Figure 5-3a and 5-3b for 2014 for the different remedial alternatives are not identical. The differences in size and shape of the plumes are not very pronounced at concentrations above the RAOs. At lower concentrations, the differences in the spatial distributions of COC concentrations between the alternatives are more apparent.

**5.2.1 Monitored Natural Attenuation**

At the Site, MNA started after the discharge of partially treated process wastewater to the former Primary Lands ceased in December 2010. Year one of the MNA simulation is therefore 2011. Groundwater elevation and COC concentration data were used to evaluate the year-one simulation results (Figures 3-10 and 4-7).

The simulation was run forward to evaluate the effects of MNA for a sufficient duration to simulate achieving the RAOs. The simulated time to achieve the RAOs on a depth-averaged concentration basis for MNA is 1,642 days (year 2016) in the Shallow Zone and 4,018 days (year 2022) in the Supply Zone (Figure 5-3 and Table 5-1).

In the Shallow Zone, the RAOs for chloride and sodium are achieved within two years of the start of the simulation. The first year for which both chloride and sodium concentrations are below the respective RAOs in Shallow Zone is 2014 (Table 5-1). The RAO for TDS is achieved in the Shallow Zone in about 4.5 years. The first year for which TDS concentrations are below the RAO in the Shallow Zone is 2016 (Table 5-1). By 2014, the extent of the TDS plume in the Shallow Zone has decreased significantly and is limited to the north-central portion of the Site (Figure 5-3a).

In the Supply Zone, the TDS, chloride, and sodium plumes migrate slightly to the west by 2014 (Figure 5-3b). The portions of the TDS plume above the RAO evident at the beginning of the
simulation have merged into a single plume by 2014, and the chloride concentrations in the northeastern portion of the plume have decreased below the RAO. The RAOs for TDS, chloride, and sodium are achieved in the Supply Zone in about 11, 7, and 8 years, respectively. The first years for which chloride and sodium concentrations are below the RAOs are 2018 and 2019, respectively. The first year for which TDS concentrations are below the RAO in the Supply Zone is 2022 (Figure 5-3b and Table 5-1).

The maximum simulated time to achieve the RAOs for all concentrations at depth throughout the model domain is approximately 21 years.

### 5.2.2 Extraction and Treatment with Reinjection to the Upper Aquifer

In simulating this alternative, five potential extraction and three potential injection wells were assumed to start operation in January 2013. The extraction and injection wells were operated simultaneously in the simulation. Well locations, pumping, and injection rates for this remedial alternative were based on the capture zone simulations reported in JJ&A (2010b). The five potential extraction wells were assumed to operate at steady-state rates of 50 gallons per minute (gpm) each. The three potential injection wells were assumed to operate at steady-state rates of approximately 83 gpm each. The concentrations of TDS, chloride, and sodium in the injected water are 360 mg/L, 59 mg/L, and 124 mg/L, respectively, which are based on the concentrations of these constituents in HCC’s fully treated process wastewater since April 2010. It was assumed that extracted and treated groundwater is returned to the Upper Aquifer. The locations of the potential extraction and reinjection wells are shown on Figure 5-1.

The simulation was run forward to evaluate the effects of groundwater extraction and reinjection for sufficient duration to simulate achieving the RAOs. The simulated time to achieve the RAOs on a depth-averaged concentration basis is 1,642 days (year 2016) in the Shallow Zone and 3,834 days (year 2021) in the Supply Zone (Figure 5-3 and Table 5-1).

In the Shallow Zone, the RAOs for chloride and sodium are achieved within two years of the start of the extraction/reinjection simulation. The first year for which both chloride and sodium concentrations are below the respective RAOs in Shallow Zone is 2014 (Table 5-1). The RAO for TDS is achieved in the Shallow Zone in about 4.5 years. The first year for which TDS concentrations are below the RAO in the Shallow Zone is 2016 (Table 5-1). By 2014, the extent of the TDS plume in the Shallow Zone has decreased significantly and is limited to the north-central portion of the Site (Figure 5-3a).

In the Supply Zone, the TDS, chloride, and sodium plumes migrate slightly to the west by 2014 (Figure 5-3b). The portions of the TDS plume above the RAO evident at the beginning of the simulation have merged into a single plume by 2014, and the chloride concentrations in the northeastern portion of the plume have decreased below the RAO. The RAOs for TDS, chloride, and sodium are achieved in the Supply Zone in about 10, 6.5, and 7 years, respectively. The first year for which chloride and sodium concentrations are below the RAOs is 2018. The first year for which TDS concentrations are below the RAO in the Supply Zone is 2021 (Figure 5-3b and Table 5-1).
The maximum simulated time to achieve the RAOs for all COC concentrations at depth throughout the model domain is approximately 20 years.

The time differences for achieving the RAOs between MNA and extraction/reinjection are not significant, although the simulated TDS, chloride, and sodium plumes are spatially smaller in 2014 for extraction/injection than for MNA.

### 5.2.3 Extraction, Treatment and Offsite Discharge

In simulating this alternative, the five potential extraction wells were assumed to start operation in January 2013. Well locations and pumping rates were based on the capture zone simulations reported in the FS (JJ&A, 2010b). The five potential extraction wells were assumed to operate at steady-state rates of 50 gpm each. Extracted water is not returned to the subsurface, and is removed permanently from the model domain. The locations of the potential extraction wells are shown on Figure 5-1.

The simulation was run forward to evaluate the effects of groundwater extraction for sufficient duration to simulate achieving the RAOs. The simulated time to achieve the RAOs on a depth-averaged concentration basis is 1,642 days (year 2016) in the Shallow Zone and 3,653 days (year 2021) in the Supply Zone (Figure 5-3 and Table 5-1).

In the Shallow Zone, the RAOs for chloride and sodium are achieved within two years of the start of the extraction simulation. The first year for which both chloride and sodium concentrations are below the respective RAOs in Shallow Zone is 2014 (Figure 5-3a and Table 5-1). The RAO for TDS is achieved in the Shallow Zone in about 4.5 years. The first year for which TDS concentrations are below the RAO in the Shallow Zone is 2016. By 2014, the extent of the TDS plume in the Shallow Zone has decreased significantly and is limited to the north-central portion of the Site.

In the Supply Zone, the TDS, chloride, and sodium plumes have migrated slightly to the west by 2014 (Figure 5-3b). The portions of the TDS plume above the RAO evident at the beginning of the simulation have merged into a single plume by 2014, and the chloride concentrations in the northeastern portion of the plume have decreased below the RAO. The RAOs for TDS, chloride, and sodium are achieved in the Supply Zone in about 10.5, 6.5, and 7 years, respectively (Table 5-1). The first year for which chloride and sodium concentrations are below the RAOs is 2018. The first year for which TDS concentrations are below the RAO in the Supply Zone is 2021.

The maximum simulated time to achieve the RAOs for all COC concentrations at depth throughout the model domain is approximately 21 years (Figure 5-3b and Table 5-1).

The time differences for achieving the RAOs between the MNA, extraction/reinjection, and extraction only alternatives are not significant.

### 5.3 Sensitivity and Uncertainty Analysis

The sensitivity and uncertainty analysis was conducted by simulating the remedial alternatives with model parameters modified to use the high and low values from the sensitivity analyses.
The key parameters for the sensitivity and uncertainty analysis are hydraulic conductivity, specific yield, dispersivity, and effective porosity.

The results of the sensitivity and uncertainty analysis are presented in Table 5-2, which shows the maximum increases and decreases in simulated times to achieve the RAOs for each remedial alternative for the various permutations in the sensitivity analyses conducted during model calibration. For MNA, the estimated uncertainty for the time to achieve the RAOs is an increase in time to achieve RAOs of 6 years and a decrease in time to achieve RAOs of 4 years. The most sensitive parameters affecting the estimated time to achieve the RAOs are hydraulic conductivity and effective porosity.

For extraction and injection, the estimated uncertainty for the time to achieve the RAOs is an increase in time to achieve RAOs of 4.5 years and a decrease in time to achieve RAOs of 3.5 years. The most sensitive parameters affecting the estimated time to achieve the RAOs are hydraulic conductivity, effective porosity, and dispersivity.

For extraction only, the estimated uncertainty for the time to achieve the RAOs is an increase in time to achieve RAOs of 5 years and a decrease in time to achieve RAOs of 4 years. The most sensitive parameters affecting the estimated time to achieve the RAOs are hydraulic conductivity, and effective porosity.
Section 6: Summary and Conclusions

6.1 Summary of the HCC Model

A calibrated transient three-dimensional model of groundwater flow and solute transport (the HCC Model) was developed, evaluated, and used to compare estimated timeframes to achieve RAOs for three remedial alternatives for the Upper Aquifer above the Corcoran Clay at the Site, namely:

1. Monitored natural attenuation
2. Groundwater extraction and treatment with onsite reinjection
3. Groundwater extraction and treatment with offsite discharge.

Data for developing a HCM and for guiding selection of initial aquifer parameters, initial conditions, and boundary conditions for the HCC Model were based on previous investigations (e.g., JJ&A, 2010a, b). COCs for the purposes of the HCC Model are TDS, chloride, and sodium. These three solutes were defined to be the transport constituents (i.e., the solutes for which transport would be simulated).

The approach for developing the HCC Model was to use available data to characterize the subsurface, estimate average land application rates, and estimate average water quality of applied water. Subsurface heterogeneity is incorporated into the HCC Model at the scale of identified stratigraphic units. Heterogeneity within stratigraphic units was not considered. The purpose of modeling at this level of detail is to produce a robust, calibrated model that does not rely on over-parameterization. The objective of this approach is to minimize the number of adjustable parameters in the model, which in turn reduces uncertainty in the simulation results.

The HCC Model was developed using MODFLOW-2000 (Harbaugh et al., 2000), MT3DMS (Zheng and Wang, 1999), Groundwater Vistas 5 (ESI, 2007) and PEST (Doherty, 2005). A sensitivity analysis was performed to evaluate the uncertainty associated with the simulation results.

The remedial alternatives were simulated as future “what-if” scenarios, based on hydrological conditions developed from the recent past. A ten-year projected future climate cycle was developed, which contained average, wet, and dry years. This ten-year cycle was designed so that it could be repeated to simulate specified lengths of time to assess the time to meet the RAOs. The results of this analysis provide a basis for evaluating and comparing the timeframes to meet the RAOs for the three remedial alternatives.

For MNA, the simulated time to achieve the RAOs on a depth-averaged concentration basis is 1,642 days (year 2016) in the Shallow Zone and 4,018 days (year 2022) in the Supply Zone. Based on a parameter sensitivity analysis, the estimated uncertainty for the time to achieve the RAOs is an increase in time to achieve RAOs of 6 years and a decrease in time to achieve RAOs of 4 years. The most sensitive parameters affecting the estimated time to achieve the RAOs are hydraulic conductivity and effective porosity.
For extraction and injection, the simulated time to achieve the RAOs on a depth-averaged concentration basis is 1,642 days (year 2016) in the Shallow Zone and 3,834 days (year 2021) in the Supply Zone. Based on a parameter sensitivity analysis, the estimated uncertainty for the time to achieve the RAOs is an increase in time to achieve RAOs of 4.5 years and a decrease in time to achieve RAOs of 3.5 years. The most sensitive parameters affecting the estimated time to achieve the RAOs are hydraulic conductivity, effective porosity, and dispersivity.

For extraction only, the simulated time to achieve the RAOs on a depth-averaged concentration basis is 1,642 days (year 2016) in the Shallow Zone and 3,653 days (year 2021) in the Supply Zone. Based on a parameter sensitivity analysis, the estimated uncertainty for the time to achieve the RAOs is an increase in time to achieve RAOs of 5 years and a decrease in time to achieve RAOs of 4 years. The most sensitive parameters affecting the estimated time to achieve the RAOs are hydraulic conductivity, and effective porosity.

6.2 Limitations of the Modeling Approach

Because models are simplifications of reality, model results must be interpreted in terms of the simplifying assumptions applied during model development. The general approach to testing the validity of modeling assumptions is to compare simulated results with observed data during the calibration period and to conduct sensitivity and uncertainty analyses. Overall, the amount of detail included in a model should reflect the purpose of the model, i.e., the modeling objective.

The application of boundary conditions to a groundwater flow model may be a source of uncertainty. For example, the groundwater flow directions at model boundaries are fixed in space and time. The closer these boundaries are to the area of interest, the greater the likelihood that the boundaries will cause a negative impact. On the other hand, if the boundaries in a local-scale are placed too far away from the area of interest, the model becomes impractical to build and execute, due to computer resource limitations.

Another source of uncertainty is caused by model parameterization. There are an infinite number of combinations of boundary conditions and model parameters that will give the same model results. No parameter estimation tool can circumvent this issue. The best way to avoid adding uncertainty to the model is by developing a robust HCM and ensuring that the HCM is represented correctly in the numerical model.

To avoid constructing a model with too many adjustable parameters, a situation which can lead to model results that are difficult to evaluate, standard modeling practice is that models should be made as simple as possible within the constraint of maintaining the ability to achieve the modeling objective. Some relevant simplifications for the HCC Model are:

- The use of steady-state pumping rates for domestic and industrial wells;
- Each HSU was considered to be internally homogeneous in terms of hydraulic conductivity and storage parameters; and
- Dispersivity was considered to be homogeneous throughout the model domain.
Overall, the limitations are considered not to negatively impact comparison of estimated timeframes to meet RAOs. Hydrogeologically reasonable assumptions were made that are consistent with the HCM.

6.3 Conclusions

The HCC Model was calibrated with respect to groundwater flow. No changes to the model parameters were made based on the results of the solute transport simulations. The calibrated model parameters were reviewed and determined to be reasonable for the HCM. Because the solute transport model demonstrated an appropriate degree of calibration with respect to measured COC concentrations in groundwater monitoring wells, this indicates that the data-driven HCC Model is robust. This degree of calibration was achieved without adjustments to the rate, water quality, and spatial distribution of land applications as reported by HCC to the RWQCB in water quality monitoring reports.

The simulation results indicate that there is no discernible difference in the timeframes to meet the RAOs for the simulated remedial alternatives. Accordingly, the remedial alternative including MNA as an element, as recommended by HCC in the FS, is the appropriate remedial alternative for achieving the RAOs.
References


in Response to California Regional Water Quality Control Board Central Valley Region ACL Complaint No. R5-2005-0501.


Tables
<table>
<thead>
<tr>
<th>RWQCB Guideline No.</th>
<th>Description</th>
<th>Report Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>What is the modeling objective? What is being modeled, why that information is needed, and how will the results be used?</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>What model has been chosen? (Name, author, version, etc.)</td>
<td>3.1, 4.1</td>
</tr>
<tr>
<td>3</td>
<td>Why is the chosen model applicable to this situation?</td>
<td>3.1, 4.1</td>
</tr>
<tr>
<td>4</td>
<td>Is the model open or proprietary? What level of peer review has been done on the model? Provide examples of previous use of the model.</td>
<td>3.1, 4.1</td>
</tr>
<tr>
<td>5</td>
<td>If the model is proprietary, explain why open models or EPA-approved models are not appropriate for the application.</td>
<td>N/A(b)</td>
</tr>
<tr>
<td>6</td>
<td>Describe the underlying fundamentals and assumptions of the model and why they are appropriate.</td>
<td>3.1, 4.1</td>
</tr>
<tr>
<td>7</td>
<td>What are the critical conditions that you are trying to model?</td>
<td>1.1, 1.2</td>
</tr>
<tr>
<td>8</td>
<td>What is the model’s performance objective or target?</td>
<td>3.6, 4.2</td>
</tr>
<tr>
<td>9</td>
<td>How will model performance be demonstrated, and what efforts will be taken to improve the model’s accuracy?</td>
<td>3.6, 4.2, 5.3</td>
</tr>
</tbody>
</table>

**Notes:**
(a) Draft Guidelines for Submittal of Information Developed from Models to the Central Valley Regional Board dated 16 August 2004.
(b) Not Applicable
### Table 2-1: Physical Properties of the Subsurface

<table>
<thead>
<tr>
<th>Zone</th>
<th>Hydraulic Conductivity (ft/d)</th>
<th>Effective Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>JJ&amp;A (b)</td>
<td>Freeze and Cherry (c)</td>
</tr>
<tr>
<td>Shallow Zone</td>
<td>--</td>
<td>3 x 10^{-2} - 300</td>
</tr>
<tr>
<td>A-Zone</td>
<td>0.2 - 20</td>
<td>3 x 10^{-2} - 300</td>
</tr>
<tr>
<td>A-Aquitard</td>
<td>2 x 10^{-3} - 1 x 10^{-2}</td>
<td>3 x 10^{-4} - 3</td>
</tr>
<tr>
<td>B-Zone</td>
<td>2 x 10^{-3} - 5</td>
<td>0.3 - 3000</td>
</tr>
<tr>
<td>B-Aquitard</td>
<td>1 x 10^{-3} - 2 x 10^{-2}</td>
<td>3 x 10^{-4} - 3</td>
</tr>
</tbody>
</table>

**Notes:**
- (a) ft/d = feet per day
- (c) *Groundwater* (Freeze and Cherry, 1979)
- (d) *Groundwater Hydrology and Hydraulics* (McWorter and Sunada, 1979)
### Table 2-2: Water Budget Components for 2005

<table>
<thead>
<tr>
<th></th>
<th>Inflows (acre-feet)</th>
<th>Outflows (acre-feet)</th>
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<tbody>
<tr>
<td>Precipitation</td>
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<tr>
<td>Primary Lands</td>
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<tr>
<td>A</td>
<td>308</td>
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<tr>
<td>C</td>
<td>138</td>
<td>--</td>
</tr>
<tr>
<td>D</td>
<td>64</td>
<td>--</td>
</tr>
<tr>
<td>E</td>
<td>20</td>
<td>--</td>
</tr>
<tr>
<td>F</td>
<td>166</td>
<td>--</td>
</tr>
<tr>
<td>G</td>
<td>139</td>
<td>--</td>
</tr>
<tr>
<td>H</td>
<td>334</td>
<td>--</td>
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<tr>
<td>Secondary Lands</td>
<td>455</td>
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<tr>
<td>Evapotranspiration</td>
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<td>13,937</td>
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<td>Corcoran Clay</td>
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<tr>
<td>Well Pumping</td>
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<td>Tile Drains</td>
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<td>1,164</td>
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<tr>
<td>Offsite Irrigation</td>
<td>17,197</td>
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</table>
### Table 2-3: Groundwater Quality

<table>
<thead>
<tr>
<th></th>
<th>TDS(^{(a)}) (mg/L)(^{(b)})</th>
<th>Chloride (mg/L)</th>
<th>Sodium (mg/L)</th>
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<tr>
<td><strong>Mean Background Concentrations(^{(c)})</strong></td>
<td></td>
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<tr>
<td>Shallow Zone(^{(d)})</td>
<td>535</td>
<td>28</td>
<td>40</td>
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<tr>
<td>Supply Zone(^{(e)})</td>
<td>487</td>
<td>26</td>
<td>69</td>
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<tr>
<td><strong>Maximum Observed Concentration, Fourth Quarter 2010(^{(f)})</strong></td>
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<tr>
<td>Shallow Zone</td>
<td>3400</td>
<td>510</td>
<td>790</td>
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<tr>
<td>Supply Zone</td>
<td>620</td>
<td>72</td>
<td>88</td>
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</table>

**Notes and Sources:**

(a) TDS = total dissolved solids  
(b) mg/L = milligrams per liter  
(c) Mean background concentrations for the purposes of the model were represented by mean values for the Upper Aquifer Shallow Zone and Supply Zone data sets used to establish the 95% Upper Tolerance Limits (ambient screening thresholds) presented in the Remedial Investigation Report (JJ&A 2010a), Appendix G - Technical Memorandum: Ambient Screening Threshold Level Statistical Evaluation for the Upper Aquifer Shallow Zone and Upper Aquifer Supply Zone, Hilmar Cheese Company; June 18, 2010.  
(d) Shallow Zone refers to the Upper Aquifer Shallow Zone  
(e) Supply Zone refers to the Upper Aquifer Supply Zone  
(f) Maximum concentrations for all Shallow Zone and Supply Zone monitoring wells
<table>
<thead>
<tr>
<th>Year</th>
<th>Average Wells</th>
<th>TDS</th>
<th>CL</th>
<th>Na</th>
<th>Mn</th>
<th>Fe</th>
<th>Average Mn+Fe Redox-Sensitive Metals</th>
<th>Redox % of TDS</th>
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<tbody>
<tr>
<td>2008</td>
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<td>700</td>
<td>8.18</td>
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<td>401</td>
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<td>7.91</td>
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<td>720</td>
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<td>MW-09</td>
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<td>MW-21</td>
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### Table 2-4: Geochemical Analysis of Redox-Sensitive Metals and Key Constituents

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| 2011         | MW-01    | 770    | 65    | 82    | NA   | 0.03  | 0.00                                |                |
|              | MW-02    | 370    | 19    | 33    | NA   | 0.04  | 0.00                                |                |
|              | MW-03    | 1400   | 558   | 340   | NA   | 0.18  | 0.01                                |                |
|              | MW-04    | 880    | 137   | 220   | NA   | 0.14  | 0.01                                |                |
|              | MW-05    | 1200   | 122   | 320   | NA   | 0.38  | 0.03                                |                |
|              | MW-06    | 2200   | 191   | 580   | NA   | 0.51  | 0.02                                |                |
|              | MW-07    | 940    | 619   | 200   | NA   | 0.63  | 0.07                                |                |
|              | MW-08    | 590    | 51    | 170   | NA   | 0.56  | 0.09                                |                |
|              | MW-09    | 1281   | 191   | 540   | NA   | 0.30  | 0.02                                |                |
|              | MW-10    | 569    | 46    | 85    | NA   | 0.15  | 0.03                                |                |
|              | MW-11    | 770    | 45    | 89    | NA   | 0.03  | 0.00                                |                |
|              | MW-12    | 780    | 78    | 77    | NA   | 0.03  | 0.00                                |                |
|              | MW-13    | 3500   | 590   | 900   | NA   | 0.03  | 0.00                                |                |
|              | MW-14    | 1200   | 210   | 150   | NA   | 0.03  | 0.00                                |                |
|              | MW-15    | 330    | 34    | 24    | NA   | 0.04  | 0.01                                |                |
|              | MW-16    | 960    | 75    | 110   | NA   | 0.09  | 0.01                                |                |
|              | MW-17    | 840    | 70    | 110   | NA   | 0.08  | 0.01                                |                |
|              | MW-18    | 560    | 23    | 40    | NA   | 0.03  | 0.00                                |                |
|              | MW-19    | 570    | 43    | 50    | NA   | 0.03  | 0.00                                |                |
|              | MW-20    | 170    | 3     | 9     | NA   | 0.03  | 0.01                                |                |
|              | MW-21    | 240    | 14    | 17    | NA   | 0.03  | 0.01                                |                |
|              | MW-22    | 500    | 72    | 89    | NA   | 0.03  | 0.01                                |                |
|              | MW-23    | 620    | 280   | 180   | NA   | 0.03  | 0.00                                |                |
|              | MW-24    | NA     | NA    | NA    | NA   | 0.03  | NA                                  |                |
|              | MW-25    | NA     | NA    | NA    | NA   | 0.00  | NA                                  |                |
|              | MW-29    | NA     | NA    | NA    | NA   | 0.00  | NA                                  |                |

**Note:**
NA = Not available
## Table 3-1: Model Parameters

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**Notes:**
(a) $K$ = horizontal hydraulic conductivity (feet per day)
(b) $S_y$ = specific yield (dimensionless)
(c) $S_s$ = storativity (inverse feet)
(d) $n$ = porosity (dimensionless)
(e) $\alpha_L$ = longitudinal dispersivity (feet)
(f) Shallow Zone refers to the Upper Aquifer Shallow Zone
Table 3-2: Simulated Annual Average Recharge Flux Rates for Former Primary and Secondary Lands

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<td>0.003</td>
<td>0.004</td>
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<td>--</td>
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<tr>
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<td>0.013</td>
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<td>0.016</td>
<td>0.005</td>
<td>--</td>
<td>0.011</td>
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<td>0.046</td>
<td>0.031</td>
<td>0.039</td>
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<td>0.005</td>
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<td>0.005</td>
<td>0.002</td>
<td>0.004</td>
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<td>TID(b) Water</td>
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<td>--</td>
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<td>Dairy Wastewater</td>
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<td>--</td>
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**Notes:**
(a) ft/d = feet per day
(b) TID = Turlock Irrigation District
Table 3-3: Calibration Targets & Extraction Wells Used in Groundwater Flow Model

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<tr>
<th>Pumping Well</th>
<th>Rate (gpm)(a)</th>
<th>Pumping Well</th>
<th>Rate (gpm)</th>
<th>Monitoring Well</th>
<th>Rate (gpm)</th>
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<td>DW-3</td>
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<td>DW-60</td>
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Note:
(a) gpm = gallons per minute
Table 3-4: Sensitivity Analysis and Calibration Results for Groundwater Flow Model

<table>
<thead>
<tr>
<th>Zone 1 (Shallow Zone)</th>
<th>Hydraulic Conductivity (K, ft/d)</th>
<th>Specific Yield (S_y, dimensionless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter Multiplier</td>
<td>0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2</td>
<td>1.3 1.4 1.5 0.5 0.6 0.7 0.8 0.9</td>
</tr>
<tr>
<td>Residual Sum of Squares</td>
<td>4,960 4,938 4,920 4,913 4,906 4,903</td>
<td>4,908 4,919 4,931 4,948 4,969</td>
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<tr>
<td>Residual Mean</td>
<td>1.61 1.61 1.61 1.61 1.61 1.61</td>
<td>1.61 1.61 1.61 1.61 1.61</td>
</tr>
<tr>
<td>Residual Standard Deviation</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Zone 2 (A-Zone)</th>
<th>Hydraulic Conductivity (K, ft/d)</th>
<th>Specific Yield (S_y, dimensionless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter Multiplier</td>
<td>0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2</td>
<td>1.3 1.4 1.5 0.5 0.6 0.7 0.8 0.9</td>
</tr>
<tr>
<td>Residual Sum of Squares</td>
<td>5,302 5,231 5,151 5,065 4,984 4,903</td>
<td>4,840 4,791 4,759 4,742 4,746</td>
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<tr>
<td>Residual Mean</td>
<td>1.65 1.65 1.64 1.63 1.62 1.61</td>
<td>1.61 1.61 1.61 1.61 1.61</td>
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<tr>
<td>Residual Standard Deviation</td>
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</table>

<table>
<thead>
<tr>
<th>Zone 3 (A-Aquitard)</th>
<th>Hydraulic Conductivity (K, ft/d)</th>
<th>Specific Yield (S_y, dimensionless)</th>
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<tr>
<td>Parameter Multiplier</td>
<td>0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2</td>
<td>1.3 1.4 1.5 0.5 0.6 0.7 0.8 0.9</td>
</tr>
<tr>
<td>Residual Sum of Squares</td>
<td>4,904 4,904 4,903 4,903 4,903 4,903</td>
<td>4,904 4,904 4,904 4,904 4,904</td>
</tr>
<tr>
<td>Residual Mean</td>
<td>1.61 1.61 1.61 1.61 1.61 1.61</td>
<td>1.61 1.61 1.61 1.61 1.61</td>
</tr>
<tr>
<td>Residual Standard Deviation</td>
<td>1.98 1.98 1.98 1.98 1.98 1.98</td>
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</table>

<table>
<thead>
<tr>
<th>Zone 4 (B-Zone)</th>
<th>Hydraulic Conductivity (K, ft/d)</th>
<th>Specific Yield (S_y, dimensionless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter Multiplier</td>
<td>0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2</td>
<td>1.3 1.4 1.5 0.5 0.6 0.7 0.8 0.9</td>
</tr>
<tr>
<td>Residual Sum of Squares</td>
<td>5,088 5,044 5,003 4,968 4,935 4,903</td>
<td>4,876 4,851 4,828 4,807 4,789</td>
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<tr>
<td>Residual Mean</td>
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<td>1.61 1.61 1.61 1.61 1.61</td>
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<tr>
<td>Residual Standard Deviation</td>
<td>2.00 2.00 1.99 1.99 1.98 1.98</td>
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</table>

<table>
<thead>
<tr>
<th>Zone 5 (B-Aquitard)</th>
<th>Hydraulic Conductivity (K, ft/d)</th>
<th>Specific Yield (S_y, dimensionless)</th>
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<td>Parameter Multiplier</td>
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<td>1.3 1.4 1.5 0.5 0.6 0.7 0.8 0.9</td>
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<tr>
<td>Residual Sum of Squares</td>
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<td>4,904 4,904 4,904 4,904</td>
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<tr>
<td>Residual Mean</td>
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<td>1.61 1.61 1.61 1.61 1.61</td>
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<tr>
<td>Residual Standard Deviation</td>
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<table>
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<tr>
<th>Bottom Boundary Flux</th>
<th>Vertical Flux (ft/d)</th>
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<td>Residual Sum of Squares</td>
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<tr>
<td>Residual Mean</td>
<td>1.78 1.72 1.68 1.64</td>
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<td>Residual Standard Deviation</td>
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Table 4-1: Average Annual Recharge and Boundary Concentrations

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<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>Overall Average</th>
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<tr>
<td></td>
<td>TDS(^{(a)})</td>
<td>Chloride (mg/L)</td>
<td>Sodium (mg/L)</td>
<td>TDS</td>
<td>Chloride (mg/L)</td>
<td>Sodium (mg/L)</td>
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<td>A</td>
<td>2072</td>
<td>396</td>
<td>506</td>
<td>2253</td>
<td>288</td>
<td>612</td>
<td>2113</td>
</tr>
<tr>
<td>B</td>
<td>1399</td>
<td>247</td>
<td>323</td>
<td>2253</td>
<td>288</td>
<td>612</td>
<td>2112</td>
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<tr>
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<td>207</td>
<td>323</td>
<td>2253</td>
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<td>352</td>
<td>2253</td>
<td>288</td>
<td>612</td>
<td>2115</td>
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<td>55</td>
<td>48</td>
<td>2253</td>
<td>288</td>
<td>612</td>
<td>2115</td>
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<td>488</td>
<td>2253</td>
<td>288</td>
<td>612</td>
<td>2107</td>
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<td>388</td>
<td>502</td>
<td>2253</td>
<td>288</td>
<td>612</td>
<td>2107</td>
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<td>491</td>
<td>2253</td>
<td>288</td>
<td>612</td>
<td>2070</td>
</tr>
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<td>Secondary Lands</td>
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<tr>
<td>HCC(^{(c)}) Irrigation Water</td>
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<td>142</td>
<td>207</td>
<td>492</td>
<td>82</td>
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<td>438</td>
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<tr>
<td>TID(^{(d)}) Water</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Dairy Wastewater</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Upgradient</td>
<td>Shallow Zone(^{(e)})</td>
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<td>28</td>
<td>40</td>
<td>535</td>
<td>28</td>
<td>40</td>
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<td>Supply Zone(^{(f)})</td>
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<td>26</td>
<td>69</td>
<td>487</td>
<td>26</td>
<td>69</td>
<td>487</td>
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</tbody>
</table>

Notes:
(a) TDS = total dissolved solids
(b) mg/L = milligrams per liter
(c) HCC = Hilmar Cheese Company
(d) TID = Turlock Irrigation District
(e) Shallow Zone refers to the Upper Aquifer Shallow Zone
(f) Supply Zone refers to the Upper Aquifer Supply Zone
Table 4-2:  Scaled Sensitivity Analysis and Calibration Results for Solute Transport Model

<table>
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<tr>
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<th>Porosity</th>
<th>Longitudinal Dispersivity (ft)(^{(a)})</th>
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<td>Parameter Multiplier</td>
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<td>Residual Mean (mg/L)(^{(b)})</td>
<td>105.4</td>
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<tr>
<td>Absolute Residual Mean (mg/L)</td>
<td>321.5</td>
<td>244.8</td>
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<td>Residual Standard Deviation (mg/L)</td>
<td>512.8</td>
<td>409.4</td>
</tr>
<tr>
<td>Residual Sum of Squares (\times 10^8) (mg(^2)/L(^2))(^{(c)})</td>
<td>8.7</td>
<td>5.5</td>
</tr>
<tr>
<td>Normalized RSS (dimensionless)</td>
<td>1.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Root Mean Squared (mg/L)</td>
<td>523.4</td>
<td>415.0</td>
</tr>
<tr>
<td>Scaled Residual Standard Deviation (dimensionless)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Scaled Absolute Mean (dimensionless)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Well Subset</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter Multiplier</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Residual Mean (mg/L)(^{(b)})</td>
<td>115.9</td>
<td>55.1</td>
</tr>
<tr>
<td>Absolute Residual Mean (mg/L)</td>
<td>209.7</td>
<td>148.3</td>
</tr>
<tr>
<td>Residual Standard Deviation (mg/L)</td>
<td>330.1</td>
<td>233.3</td>
</tr>
<tr>
<td>Residual Sum of Squares (\times 10^8) (mg(^2)/L(^2))(^{(c)})</td>
<td>1.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Normalized RSS (dimensionless)</td>
<td>2.1</td>
<td>--</td>
</tr>
<tr>
<td>Root Mean Squared (mg/L)</td>
<td>349.7</td>
<td>239.7</td>
</tr>
<tr>
<td>Scaled Residual Standard Deviation (dimensionless)</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Scaled Absolute Mean (dimensionless)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Scaled Root Mean Squared (dimensionless)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Notes:
(a) ft = feet
(b) mg/L = milligrams per liter
(c) mg\(^2\)/L\(^2\) = milligrams squared per liter squared
## Table 5-1: Remedial Alternatives Results

<table>
<thead>
<tr>
<th></th>
<th>Shallow Zone(^{(b)})</th>
<th></th>
<th>Supply Zone(^{(c)})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TDS(^{(d)})</td>
<td>Chloride</td>
<td>Sodium</td>
</tr>
<tr>
<td>MNA(^{(e)})</td>
<td>1,642 2016</td>
<td>547 2013</td>
<td>731 2014</td>
</tr>
<tr>
<td>Extraction and Injection</td>
<td>1,642 2016</td>
<td>547 2013</td>
<td>731 2014</td>
</tr>
<tr>
<td>Extraction</td>
<td>1,642 2016</td>
<td>547 2013</td>
<td>731 2014</td>
</tr>
</tbody>
</table>

**Notes:**
(a) The average simulated concentrations were used to compare the timeframes for achieving the RAOs.
(b) Shallow Zone refers to the Upper Aquifer Shallow Zone. Remedial Action Objectives are: TDS = 912 mg/L; Cl = 239 mg/L; Na = 346 mg/L.
(c) Supply Zone refers to the Upper Aquifer Supply Zone. Remedial Action Objectives are: TDS = 713 mg/L; Cl = 60 mg/L; Na = 133 mg/L.
(d) TDS = Total Dissolved Solids
(e) MNA = monitored natural attenuation
(f) Year refers to the first calendar year in which simulated concentrations do not exceed the Remedial Action Objectives.
<table>
<thead>
<tr>
<th>Table 5-2: Sensitivity and Uncertainty Analysis for Remedial Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Increased Time in Years to Achieve Remedial Objectives Due to Parameter Change</td>
</tr>
</tbody>
</table>

**Monitored Natural Attenuation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum Increased</th>
<th>Maximum Decreased</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic Conductivity (ft/d)</td>
<td>6.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Specific Yield (-)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Effective Porosity (-)</td>
<td>5.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Dispersivity (ft)</td>
<td>NA (c)</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Extraction and Treatment with Reinjection to the Upper Aquifer**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum Increased</th>
<th>Maximum Decreased</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic Conductivity (ft/d)</td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Specific Yield (-)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Effective Porosity (-)</td>
<td>4.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Dispersivity (ft)</td>
<td>NA</td>
<td>3.5</td>
</tr>
</tbody>
</table>

**Extraction and Treatment with Offsite Disposal/Discharge**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum Increased</th>
<th>Maximum Decreased</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic Conductivity (ft/d)</td>
<td>4.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Specific Yield (-)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Effective Porosity (-)</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Dispersivity (ft)</td>
<td>NA</td>
<td>3.5</td>
</tr>
</tbody>
</table>

**Notes:**
(a) ft/d = feet per day (units of hydraulic conductivity)
(b) ft = feet (units of dispersivity)
(c) NA: Sensitivity analysis for decreased dispersivity could not be conducted due to numerical dispersion. See text for details.
Site Location

TURLOCK GROUNDWATER BASIN

Source: ESRI

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Hilmar Cheese Company
Merced County, California

K/J 0765018*11
August 2012

Figure 1-1
**Figure 1-2**

**Path:** Z:\Projects\HilmarGroundwaterModeling\Events\20120706_ModelingReport\Figure01_02_Timeline.mxd

**From:** Remedial Investigation Report, Hilmar Cheese Co., Hilmar, CA (JJ&A, 2010a)

**Primary Land Use Timeline**

- **1977-1985:** Treatment operations began.
- **1986-1989:** Application began in 2B area, followed by 1A area.
- **1990:** Application in 1B area began.
- **1991:** Application in 1B area ended gradually.
- **1995:** Application in 1A area ended.
- **1996:** Application in 1B area ended.
- **1997:** Application in 2B area ended.
- **1998-2000:** Application in 1A area ended.
- **2001:** Application in 1B area ended.
- **2002:** Application in 2B area ended.
- **2003:** Application in 1A area ended.
- **2004:** Application in 1B area ended.
- **2005-2006:** Application in 2B area ended.
- **2007:** Application in 1A area ended.
- **2008:** Application in 1B area ended.
- **2009:** Application in 2B area ended.
- **2010:** Application in 1A area ended.

**Wastewater and Primary Land Use Timeline**

- **1977-1985:** Treatment operations began.
- **1986-1989:** Application began in 2B area, followed by 1B area.
- **1990:** Application in 1A area began.
- **1991:** Application in 2B area ended.
- **1992:** Application in 1B area ended.
- **1993:** Application in 1A area ended.
- **1994:** Application in 2B area ended.
- **1995:** Application in 1B area ended.
- **1996:** Application in 1A area ended.
- **1997:** Application in 2B area ended.
- **1998:** Application in 1B area ended.
- **1999:** Application in 1A area ended.
- **2000:** Application in 2B area ended.
- **2001:** Application in 1B area ended.
- **2002:** Application in 1A area ended.
- **2003:** Application in 2B area ended.
- **2004:** Application in 1B area ended.
- **2005-2006:** Application in 1A area ended.
- **2007:** Application in 1B area ended.
- **2008:** Application in 2B area ended.
- **2009:** Application in 1A area ended.
- **2010:** Application in 1B area ended.

**Notes:**

**Abbreviations:**
- EGSB = extended granular sludge bed
- HCC = Hilmar Cheese Co.
- mgd = million gallons per day
- NF = nanofiltration
- RO = reverse osmosis
- SBR = sequencing batch reactor
- UF = ultrafiltration
- VSEP = vibratory shear enhancement process
- WDR = Waste Discharge Requirement
- WPCF = Wastewater and Primary Land Use Timeline

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Merced County, California
Wastewater and Primary Land Use Timeline

**KU 0765018111**
August 2012

**Figure 1-2**
Figure 2-2

From: Remedial Investigation Report, Hilmar Cheese Co., Hilmar, CA (J&A, 2010a)
Observed Concentrations of Key Constituents

Shallow Zone Legend:
- Total Dissolved Solids Concentrations in Groundwater Monitoring Wells in 2010 Exceeding the Ambient Screening Threshold of 912 mg/L
- Chloride Concentrations in Groundwater Monitoring Wells in 2010 Exceeding the Ambient Screening Threshold of 239 mg/L
- Sodium Concentrations in Groundwater Monitoring Wells in 2010 Exceeding the Ambient Screening Threshold of 346 mg/L

Supply Zone Legend:
- Total Dissolved Solids Concentrations in Groundwater Monitoring Wells in 2010 Exceeding the Ambient Screening Threshold of 713 mg/L
- Chloride Concentrations in Groundwater Monitoring Wells in 2010 Exceeding the Ambient Screening Threshold of 60 mg/L
- Sodium Concentrations in Groundwater Monitoring Wells in 2010 Exceeding the Ambient Screening Threshold of 133 mg/L
Boundary Conditions for Groundwater Flow Model

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Boundary Conditions for
Groundwater Flow Model

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Figure 3-2
Figure 3-3

Legend

- Green: Precipitation
- Yellow: TID Freshwater
- Blue: Treated Process Wastewater
- Purple: TDS
- Green: Cl
- Red: Na
Figure 3-4

Legend
- Rainfall
- Boundary Head

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Precipitation and Upgradient Boundary Head versus Time
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Groundwater Head Elevation at Upgradient Boundary (ft msl)

Annual Rainfall (in)

Year
2005 2006 2007 2008 2009 2010 2011 2012

95 96 97 98 99 100 101

0 5 10 15 20 25 30
Legend

- Shallow Zone
- A-Zone
- A-Aquitard
- B-Zone
- B-Aquitard
- Bottom Boundary Flux (ft/d)

Hydraulic Conductivity (ft/d)

Specific Yield & Bottom Boundary Flux

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Sensitivity Analysis for Groundwater Flow Model
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Figure 3-5
Groundwater Flow Direction

Legend
- Site Boundary
- Model Boundary
- Simulated Groundwater Flow Direction
- Simulated Groundwater Elevation (ft)

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Calibrated Simulated Groundwater Elevations

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Figure 3-6
Legend

+ All Calibration Targets

+ 10 Best Calibration Targets

$R^2 = 0.7$
Shallow Zone:
- TDS = 535 mg/L
- Cl = 28 mg/L
- Na = 40 mg/L

Supply Zone:
- TDS = 487 mg/L
- Cl = 26 mg/L
- Na = 69 mg/L
Simulated Total Dissolved Solids Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 912 mg/L

Simulated Chloride Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 239 mg/L

Simulated Sodium Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 346 mg/L

Legend

TDS Concentration (mg/L)  Monitoring Well
Chloride Concentration (mg/L)  Site Boundary
Sodium Concentration (mg/L)
Simulated Total Dissolved Solids Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 713 mg/L

Simulated Chloride Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 106 mg/L

Simulated Sodium Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 133 mg/L

Legend:
- **TDS Concentration (mg/L)**
- **Chloride Concentration (mg/L)**
- **Sodium Concentration (mg/L)**
- Monitoring Well
- Site Boundary
Figure 4-3

Porosity

Normalized RSS vs. Parameter Multiplier

Longitudinal Dispersivity (ft)

Normalized RSS vs. Parameter Multiplier
Legend

- Dark symbols represent data from the 10 best calibration targets; light symbols represent data from all calibration targets.

**Note:**

- \( R^2 = 0.8 \)
- \( R^2 = 0.6 \)
- \( R^2 = 0.7 \)

Simulated vs. Observed Concentrations

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Merced County, California

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Figure 4-4
Legend
- TDS
- Na
- Cl

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Solute Transport Model Calibration
Residual versus Time
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Figure 4-6
Simulated and Observed Concentration Histories for 2011 Model Evaluation Period

Legend
- Monitoring Well
- Site Boundary
- Model Boundary

Concentration Histories:
- △ Observed Na
- ● Calculated Na
- ◇ Observed Cl
- ■ Calculated Cl
- ○ Observed TDS
- — Calculated TDS

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Merced County, California

Simulated and Observed Concentration Histories for 2011 Model Evaluation Period

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Figure 4-7
Hilmar Cheese Company
Merced County, California

Potential Well Locations for Remedial Alternatives

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Potential Extraction Well as Proposed in Feasibility Study (JJ&A, 2010b)
Potential Injection Well as Proposed in Feasibility Study (JJ&A, 2010b)

Legend

Site Boundary
Model Boundary

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Figure 5-1
Figure 5-2

Legend
- Evapotranspiration
- Irrigation
- Precipitation

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Recharge Components for Remedial Alternative Simulations
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August 2012
Legend

- Simulated Total Dissolved Solids Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 912 mg/L
- Simulated Chloride Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 239 mg/L
- Simulated Sodium Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 346 mg/L
- Potential Extraction Well as Proposed in Feasibility Study (J&A, 2010b)
- Potential Injection Well as Proposed in Feasibility Study (J&A, 2010b)
- Site Boundary

Monitored Natural Attenuation

Beginning of Simulation 2011

2014

All Concentrations Less Than Remedial Action Objective 2016

Extraction Plus Injection

Beginning of Simulation 2011

2014

All Concentrations Less Than Remedial Action Objective 2016

Extraction Only

Beginning of Simulation 2011

2014

All Concentrations Less Than Remedial Action Objective 2016

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Average Simulated Shallow-Zone Concentrations for Remedial Alternatives

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Figure 5-3a
Figure 5-3b

Average Simulated Supply-Zone Concentrations for Remedial Alternatives

Legend

- Simulated Total Dissolved Solids Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 713 mg/L
- Simulated Chloride Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 106 mg/L
- Simulated Sodium Concentrations in Groundwater Monitoring Wells Exceeding Remedial Action Objective of 133 mg/L
- Potential Extraction Well as Proposed in Feasibility Study (J&A, 2010b)
- Potential Injection Well as Proposed in Feasibility Study (J&A, 2010b)
- Site Boundary