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Hydrostratigraphy of the Shallow Aquifer in the Niles Cone Groundwater Basin

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HYDROSTRATIGRAPHY OF THE SHALLOW AQUIFER

IN THE NILES CONE GROUNDWATER BASIN

A Thesis

Presented to

The Faculty of the Department of Geology

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Ramon W. Cioco

August 2012

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HYDROSTRATIGRAPHY OF THE SHALLOW AQUIFER IN THE NILES CONE
GROUNDWATER BASIN

by

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APPROVED FOR THE DEPARTMENT OF GEOLOGY

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ABSTRACT

HYDROSTRATIGRAPHY OF THE SHALLOW AQUIFER IN THE NILES CONE GROUNDWATER BASIN

by Ramon W. Cioco

The Shallow Aquifer in the Niles Cone Groundwater Basin, southern Alameda County, California, can act as a migration pathway for surface contaminants into the underlying Newark Aquifer, a source of water supply. This study, we used 110 borehole logs from Alameda County Water District's database to classify the hydrostratigraphy of the uppermost geologic deposits, and utilized the Rockworks 2002[®] software package to define regions sensitive to surface contamination.

The Shallow Aquifer is a discontinuous and localized deposit covering approximately 40% of the study area. About 15% of the Shallow Aquifer is exposed to surface contamination, and roughly 15% is hydraulically connected to the Newark Aquifer. Combining both sensitive areas indicated that the Forebay and its vicinity are the sites most vulnerable to contamination. The spatial distribution of aquifer sediment indicated that two stream channels deposited the Shallow Aquifer, the larger being Alameda Creek and the smaller Dry Creek. Some deposition occurred when San Francisco Bay was at least 12 m below its present level sometime during the last glacial low stand and continued up to the present, at least in the Forebay area.

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INTRODUCTION

Purpose

The Alameda County Water District's (ACWD) service area generally sits on top of the Niles Cone Groundwater Basin. ACWD provides almost half of its water supply from groundwater wells. Figure 1 shows the map of the study area illustrating the boundaries of the ACWD and the Niles Cone Groundwater Basin. Due to uncontrolled groundwater pumping beginning in the early 20th century, the Niles Cone Basin experienced an overdraft of groundwater that ultimately led to saltwater encroachment from San Francisco Bay (ACWD, 2010a). A remnant of the saltwater intrusion still remains to date.

Although many hydrogeologic studies have been performed in the area, the Shallow Aquifer deposits in the upper 15 m of the Niles Cone Groundwater Basin have not been investigated, nor has the hydraulic connection of the Shallow Aquifer with the underlying main aquifers been established. As part of the program to conserve the Niles Cone Groundwater Basin, the ACWD expressed a concern about the Shallow Aquifer's potential as a migration pathway of possible contaminants from residential, commercial and industrial establishments in the area.



Figure 1. Map of the study area (modified from ACWD, 2010a).

The purpose of this hydrostratigraphic study of the uppermost sections of the Niles Cone Basin was to define the areal extent of the shallow, coarse-grained materials as well as their generalized hydraulic connection with the underlying regional aquifers. The results of this study also served to update and improve the Niles Cone Groundwater Basin model developed by ACWD. Additionally, it provided insight into the recent depositional history in the Niles Cone area.

Study Area

The study area encompassed the area west of the Hayward fault section of the Niles Cone Groundwater Basin, bounded on the north by the City of Hayward, on the south by the City of Milpitas, on the east by the Hayward fault and on the west by San Francisco Bay. ACWD's service area includes the cities of Fremont, Newark, and Union City. Excluded from this investigation were the portions of ACWD's service area located east of the Hayward fault, because of the absence of the Shallow Aquifer in that area. The study area comprised that portion of the basin for which borehole data were available and has an areal extent of about 130 km².

The study area gently slopes westward from the foot of the Diablo Range toward the shoreline of San Francisco Bay and Coyote Hills; the latter prominently rise above the sloping plain with a maximum elevation of 88 m above sea level.

The climate of the area is classified as dry-summer, subtropical, or Mediterranean under the Koppen climate classification system (FAO, 1999): hot and dry during the

summers and moderate temperatures and rainy weather during the winters. The mean annual rainfall in the area is 37.7 cm with the wettest period from November to March. The average annual temperature is 15.5°C; the warmest month of the year is August, with an average maximum temperature of 26°C, and the coldest month is December, with an average minimum temperature of 6°C (NOAA, 2004).

Cutting across the study area is Alameda Creek, the main drainage channel. It drains the Livermore Valley and exits Niles Canyon at the base of Diablo Range, flowing westward into San Francisco Bay. The Niles Cone Groundwater Basin is cut at the eastern boundary by the northwesterly trending Hayward fault, which skirts along the foot of the Diablo Range.

GEOLOGY AND HYDROGEOLOGY

Regional Geologic Setting

The landscape of San Francisco Bay region is shaped by the tectonic processes that generally control the area. The northwesterly oriented San Francisco Bay depression is a structural trough down-warped by the movement of the parallel northwesterly oriented active faults along its edges, the San Andreas fault on the west and the Hayward fault on the east. The inception of these two faults probably developed in the transition period during the shifting of the tectonic setting in the western edge of the North American continental plate from convergent margin to transform margin about 10 Ma (Graham et al., 1984). Flanking the depression are the northwesterly trending mountain ranges, the Santa Cruz Mountains on the west and the Diablo Range on the east. The evolution of the modern coastal ranges was likewise linked to the development of the transform boundary between the North American and Pacific plates (Graham et al., 1984).

The rock comprising the basement of the depression is the Franciscan Complex of Mesozoic age, which has igneous and metamorphic origins. Overlying the Franciscan rock complex are Mesozoic and several Cenozoic marine units and deposits of mostly coarse-grained alluvial sediments from the eroded mountainsides; these have been carried by various streams in the region (CRWQCB, 2003). Within the continental alluvial

deposits are beds of fine-grained clayey and silty sediments. The thickness of the sediments filling the San Francisco Bay depression varies along its axis, the thickest being in the south in Santa Clara Valley at more than 460 m to less than 150 m near the Coyote Hills (CDWR, 1967). A simplified geologic map of the study area is shown in Figure 2.

Brief Description of the Geologic History and Stratigraphic Deposition

The modern San Francisco Bay region was subjected to intense geological activity in the Quaternary period. The compressional forces from the northeast and southwest created intense folding, faulting, uplift and downwarped basins in the northwest-southeast oriented Coastal Ranges (Brown, 1990). The downwarped basin containing San Francisco Bay and Santa Clara Valley began to subside at that time, between 1 and 0.5 Ma (Rogers and Figuers, 1992). During the gradual subsiding of the San Francisco Bay region, estuarine, alluvial materials, and freshwater swamp sediments were deposited on the valley depression (Brown, 1990). These alluvial deposits that filled the valley floor emanated from the Santa Cruz Mountains and Diablo Range.

In contrast to the uplift of the coastal ranges during the Quaternary period, the valley depression gradually continued to subside between the San Andreas and Hayward faults. However, the valley floor did not subside uniformly. In the vicinity of the

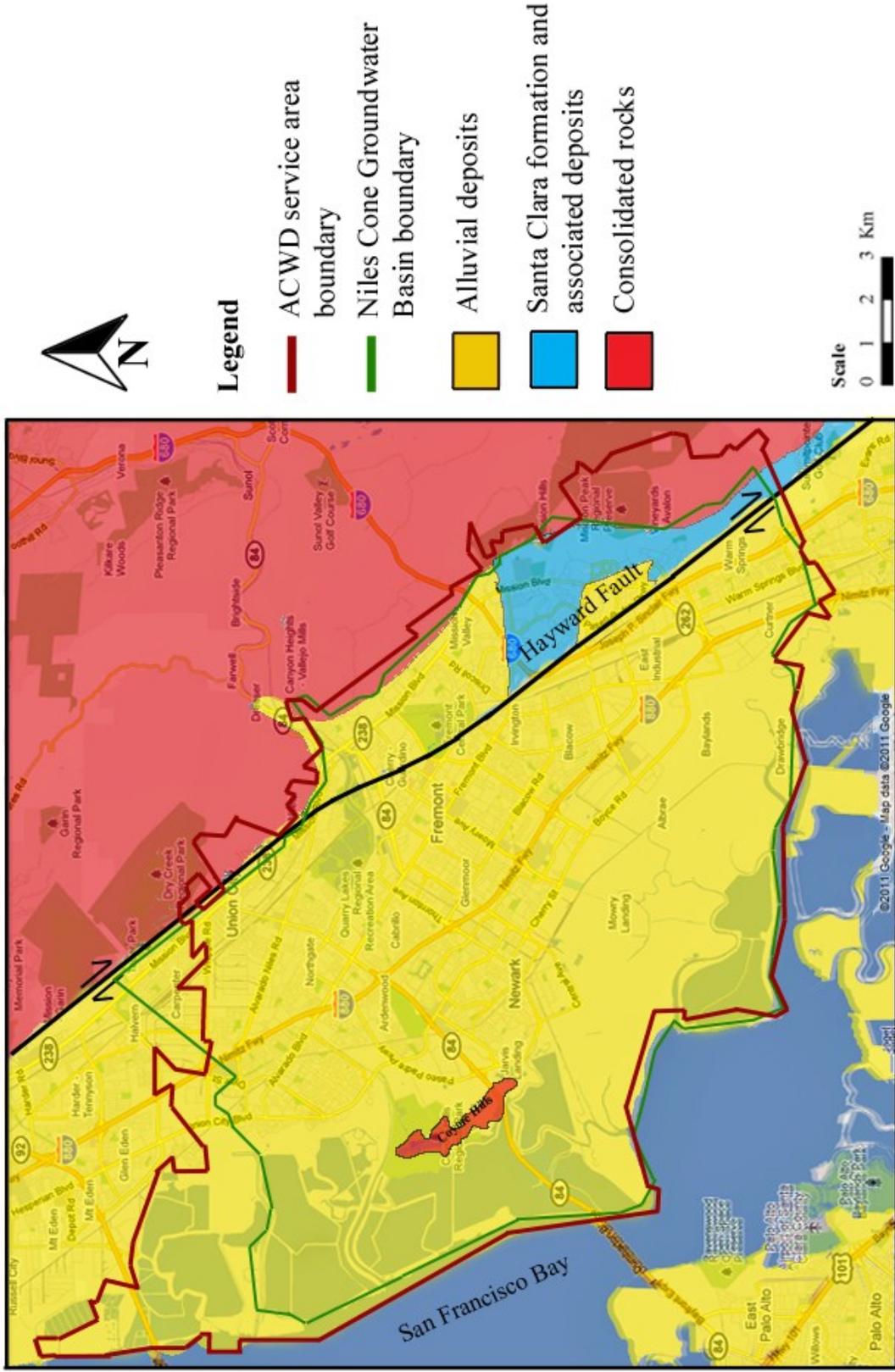


Figure 2. Simplified geologic map of the area (modified from Poland, 1984).

Oakland International Airport, the bedrock elevation is 305 m below sea level (Rogers, and Figuers, 1992), whereas the bedrock is exposed in the Coyote Hills.

Aside from uplift and erosion, sediment deposition in the Bay Area was also influenced by climate change during the Quaternary period. Koltermann and Gorelick (1992) suggested that coarse-grained layers indicate colder and wetter periods during glacial stages, whereas fine-grained layers indicate warmer and drier periods during interglacial stages. The widespread gravel and sand layers such as the Newark, Centerville, Fremont, and Deep Aquifers were probably deposited during glacial stages, and the fine-grained layers including the Newark, Irvington, and Mission aquitards were probably deposited during the interglacial stages. However, this theory was put into question with the USGS drill-hole data in Santa Clara Valley (Newhouse et al., 2004). Drilling there was conducted in 2000 to 2003.

The changes of global eustatic sea level correspond to the vast quantities of water that were accumulated in the continental ice sheets during glacial stages and the amount of water released when ice melted during interglacial stages. During glacial stages, sea level was lowered by as much as 120 m below present sea level, and the shorelines were about 75 km west of the present San Francisco coast. During interglacial stages, sea level rose and in the late Pleistocene probably reached the Coyote Hills area (Atwater et al., 1977).

Hydrogeologic Setting

The Niles Cone Groundwater Basin is composed of an alluvial fan formed by Alameda Creek as it issues out from the Diablo Range and flows towards San Francisco Bay. The alluvial fan, which began to form 600,000 years ago, consists of Quaternary gravels and sands derived from Mesozoic and Tertiary shale and sandstone from the Diablo Range (Koltermann and Gorelick, 1992). Aquifers in the Niles Cone basin are composed generally of sandy and gravelly deposits and have higher permeability whereas the aquitards, which consist mainly of clayey and silty sediments, have lower permeability (ACWD, 2010a).

The Hayward fault, which traverses the study area along the base of the Diablo Range, serves as a low-permeability barrier to the westward flow of groundwater. It creates sharp water-level differences between the wells to the east and west of the fault (ACWD, 2010a). ACWD's 2010 water-level measurements indicated a head difference of about 7 m across the fault (ACWD, 2010a), although the recorded maximum difference of 29 m was observed in October 21, 1958 (CWDR, 1967). For this reason, the Niles Cone Groundwater Basin was divided into two sub-basins: the Above Hayward Fault (AHF) and the Below Hayward Fault (BHF). The AHF sub-basin consists of highly permeable, coarse-grained deposits, whereas the BHF sub-basin is composed of alternating beds of aquifers and aquitards. Some of the thin clay layers within the aquifer beds were probably deposited as overbank deposits as stream channels shifted. Most of the aquifers in the BHF are confined (CDWR, 1967).

In the study area (BHF sub-basin), three main aquifers in the upper 120 m supply most of the water to wells for domestic, public, and industrial use. In descending order, they are known as the Newark, Centerville, and Fremont aquifers. Aquifers below 120 m are also known to exist, and they are referred to as the Deep Aquifers (ACWD, 2010a). Deposited between the main aquifers are fine-grained layers known as the Irvington Aquitard, separating the Newark and Centerville aquifers, and the Mission Aquitard, separating the Centerville and Fremont aquifers. Within the uppermost strata above the Newark Aquifer, referred to as the Newark Aquitard, exists a shallow and discontinuous coarse-grained deposit, known as the Shallow Aquifer. There are no historical records on the effect of saltwater intrusion within the Shallow aquifer in the study area. Table 1 lists the main hydrostratigraphic units, their thickness ranges and the depths at which they can be encountered.

Lying above the Newark Aquifer and covering almost the entire study area is the Newark Aquitard. Its thickness varies from location to location, but it is generally thicker near the bay shore and totally absent at the apex of the alluvial fan (CDWR, 1967). The thickness of the Newark aquitard plays a prominent role in the vertical movement of surface water to underlying aquifers. In areas where it is thick, downward movement of surface water is retarded and, conversely, where it is thin or absent the movement is unhindered.

The uppermost main aquifer in the study area is the Newark Aquifer, which underlies the Newark Aquitard. It is an extensive, permeable, gravel and sand layer, and its top can be encountered from depths of 12 to 42 m below the ground surface (bgs). In

TABLE 1. MAIN HYDROSTRATIGRAPHIC UNITS

Hydrostratigraphic Unit (top to bottom)	Encountered at depths (m bgs)	Thickness range (m)
Newark Aquitard	0 – 15	0 – 22
Newark Aquifer	12 – 42	6 – 42
Irvington Aquitard	18 – 55	10 – 35
Centerville Aquifer	55 – 61	3 – 30
Mission Aquitard	(top depth range) 58 – 90	7 – 27
Fremont Aquifer	90 – 120	5 – 23
Deep Aquifers	> 120	> 15

Note: Data from CWDR (1968) and ACWD (2010b).

some areas permeable sediment overlies the Newark Aquifer. The Newark aquifer is found in almost the entire study area except at the Coyote Hills and a few locations in the southeast. Its thickness ranges from 6 m near the shoreline of the bay to more than 42 m near the Hayward fault (ACWD, 2010a). Previous studies (CWDR, 1967 and Maslonkowi, 1988) in the area indicated that the Newark aquifer extends beneath the Bay and underneath the western side of the Bay in the San Mateo area. Thus, it serves as the primary pathway of saltwater migration from the Bay toward the interior of the basin to the east (CDWR, 1967). The aquifer is not a single continuous layer but rather sand and gravel layers separated by thin interbeds of clay and silt (Maslonkowski, 1988).

Below the Newark Aquifer is the fine-grained layer referred to as the Irvington Aquitard. The aquitard serves as a protective barrier to vertical saltwater migration from

the overlying Newark Aquifer. This was demonstrated by an exploratory well drilled into the underlying aquifer at the middle of the bay. The well yielded better quality water than did the overlying Newark aquifer. This indicates the impermeable nature of the Irvington Aquitard (CDWR, 1967). This condition has also been shown by the results of the investigation conducted by ACWD in their saltwater intrusion monitoring program in 2010 (ACWD, 2010b). That study yielded permeability results for the Irvington Aquitard ranging from 5.36×10^{-4} to 1.33×10^{-8} cm/sec.

Underlying the Irvington Aquitard is the Centerville Aquifer, the top of which can be encountered from depths of 55 to 61 m bgs. Its thickness ranges from 3 to 30 m, and the aquifer can be found over almost the entire study area except at the Coyote Hills. Like the Newark Aquifer, the Centerville Aquifer exists beneath the Bay and into its western margins. Wells drilled in Ravenswood, East Palo Alto, tapped this aquifer (CDWR, 1967).

The Mission Aquitard is a thick, extensive clay layer below the Centerville Aquifer. Permeability testing conducted by ACWD in 2009 yielded values ranging from 4.2×10^{-7} to 3.2×10^{-8} cm/sec. These values indicate that vertical flow is highly restricted (ACWD, 2010b).

The Fremont Aquifer can be found at depths between 90 and 120 m bgs. Although this aquifer is not well defined, it is generally regarded as more productive than the shallower aquifers (CDWR, 1967). ACWD's Inland Saltwater Intrusion Monitoring Wells Project indicated the thickness range of the Fremont aquifer to be from 5 to 23 m (ACWD, 2010b).

Previous studies (CWDR, 1967 and ACWD, 2010a) considered both the Centerville and Fremont aquifers as one water-bearing unit in the entire study area due to insignificant differences in groundwater levels, even with an aquitard separating the two aquifers. However, a recent investigation conducted by ACWD (2010b) indicated otherwise, and there are areas in the basin where hydraulic separation exists between the two aquifers. Monitoring of wells indicated differences in water levels and groundwater chemistry between the two aquifers. The chloride content of water samples from the Centerville Aquifer had maximum values of 660 parts per million (ppm), whereas the Fremont aquifer had maximum values of 1,300 ppm. During that study, water-level monitoring results likewise indicated water elevation differences ranging from 0.1 to 0.3 m between the two aquifers (ACWD, 2010b).

The main aquifers in the study area merge and act as a single aquifer that extends to the ground surface in the vicinity of the Hayward fault. The region of merged aquifers is referred to as the Forebay area (CDWR, 1967).

Groundwater Flow

Historical records in the study area from as early as the 1890s indicate that groundwater from the elevated portions of the basin in the east flows towards the west to San Francisco Bay. Groundwater levels started to decline in the early 1900s, when the Niles Cone Groundwater Basin was overpumped and the hydraulic gradient in the Newark aquifer reversed landward from the Bay (ACWD, 2010a). Due to the low

permeability of the Hayward fault, the groundwater levels in AHF aquifer remained above sea level throughout this time period.

In 1962, ACWD implemented programs to restore the groundwater of the Niles Cone to its original conditions, especially in the BHF aquifers. Subsequently, as the aquifers responded to these actions, groundwater levels started to recover. In 1972, water levels were measured to be above sea level, and the hydraulic gradient of the Newark aquifer returned to its original, westward direction (ACWD, 2010a). The latest water level measurements are presented in Figure 3, the groundwater elevation map of 2010.

Water Quality

Saltwater intrusion has greatly affected the water quality of the Niles Cone Groundwater Basin since the early 1900s. The reversal of the hydraulic gradient in the Newark aquifer allowed saltwater to migrate down into portions of the underlying aquifers. Because the Newark aquifer is the uppermost, main aquifer in the study area, it was the first to be impacted by saltwater intrusion. Subsequently, when the landward migration of the saltwater remained unabated, saltwater reached the Forebay area and resulted in the contamination of the underlying Centerville, Fremont, and Deep aquifers. A generalized diagram illustrating the saltwater intrusion is presented in Figure 4; it shows how the saltwater from the Bay intruded into the underlying aquifers. The AHF

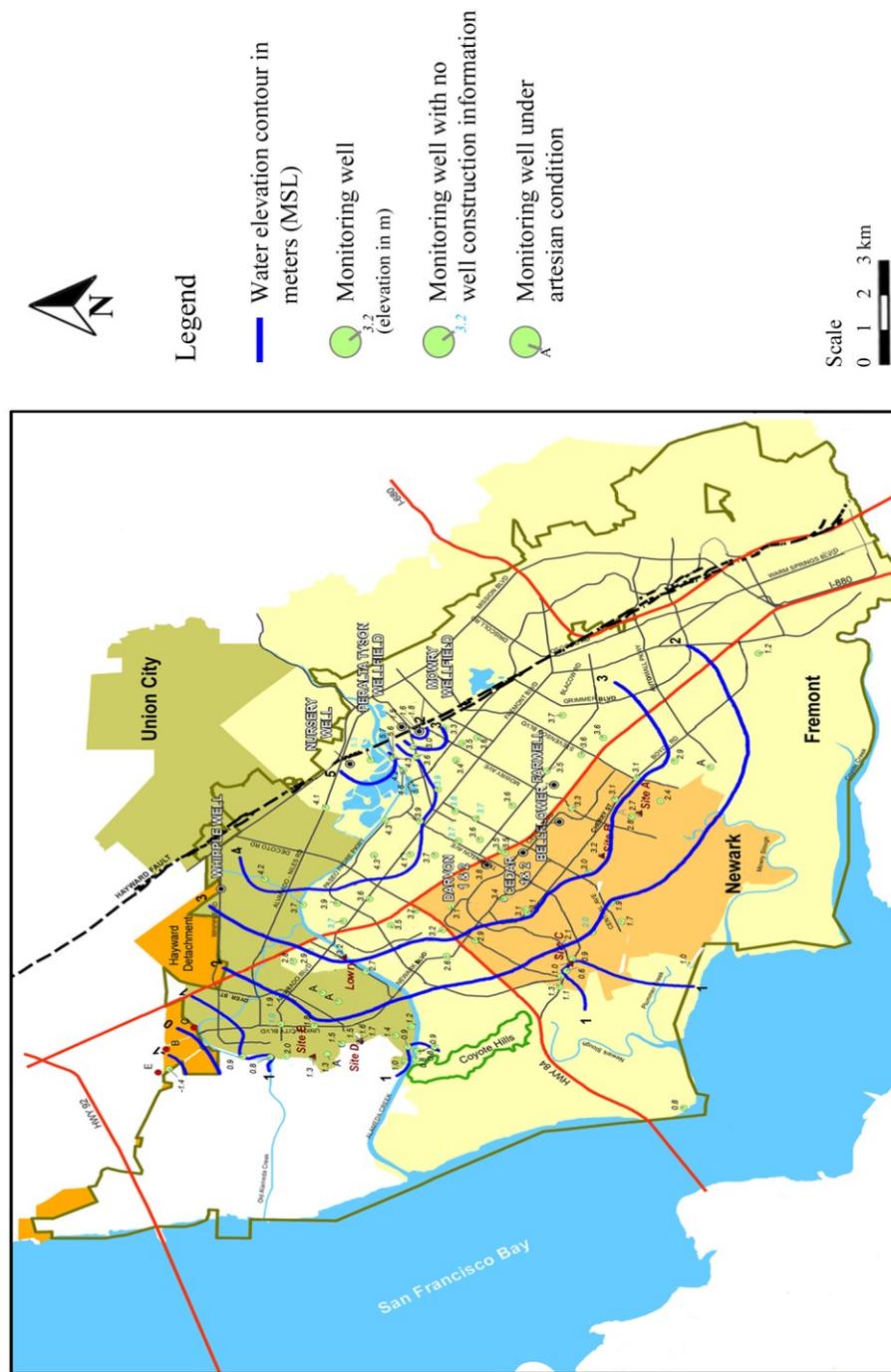


Figure 3. Groundwater elevation map of 2010 (modified from ACWD, 2011b).

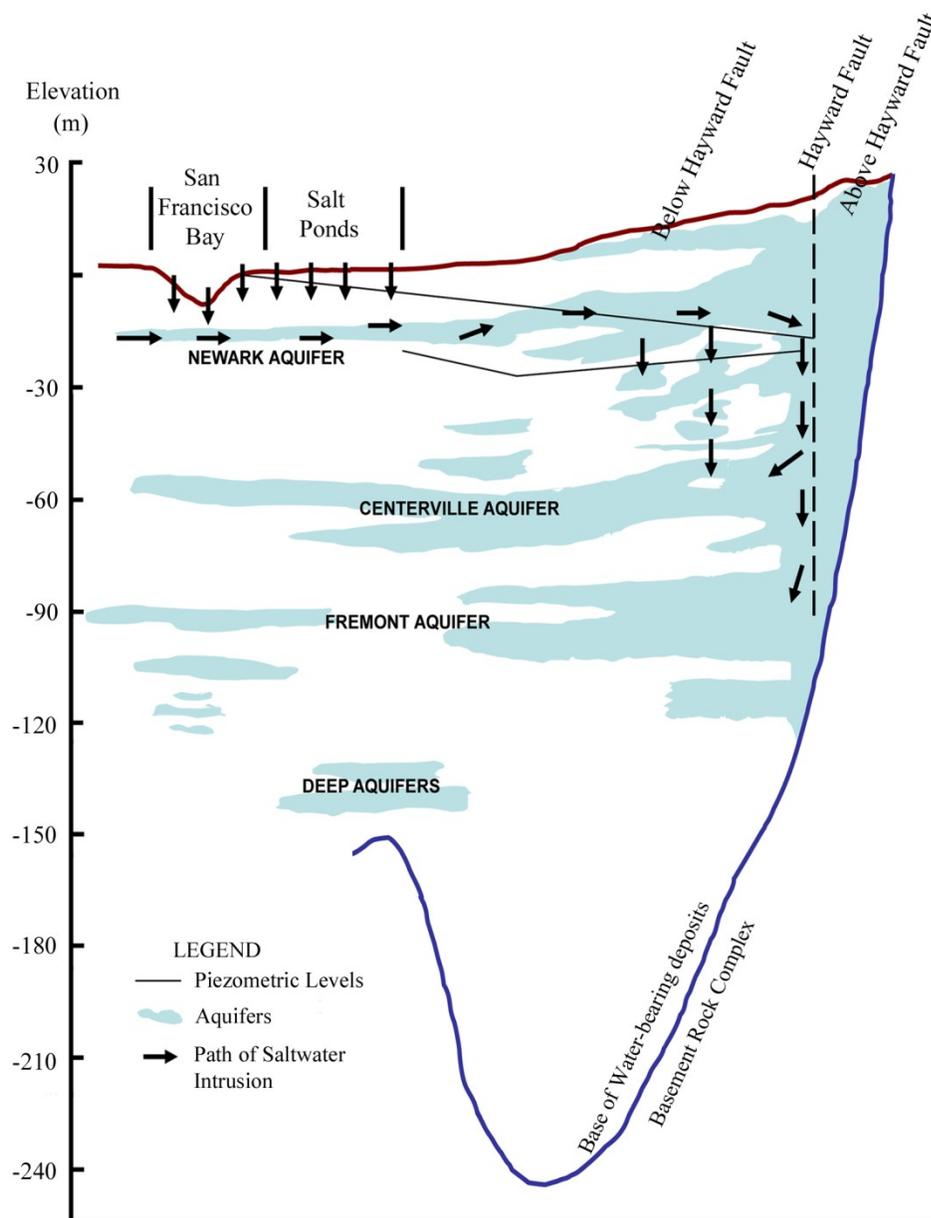


Figure 4. Diagram of saltwater intrusion (modified from ACWD, 2010a).

sub-basin was not affected by the saltwater contamination because of the barrier effect created by the Hayward fault, hence it maintained its quality.

In 1962, the combined water management programs of ACWD resulted in the improvement of groundwater quality, although a considerable amount of salt-contaminated groundwater still remains in the aquifers. The improved water quality was evidenced by the chloride content of the groundwater monitored by ACWD. In one monitoring well, 4S1W-30E4, the chloride content in the Newark aquifer decreased from a high of 2,200 ppm in 1985 to 200 ppm in 2010. Likewise, the chloride content of the Centerville-Fremont aquifers decreased from a high chloride content of 1,600 ppm in 1976 to 250 ppm in 2010, in monitoring well 4S1W-14N3 (ACWD, 2010a). The maximum allowable concentration recommended by the U.S. Environmental Protection Agency for chloride in drinking water is 250 mg/L (USEPA, 2009).

ACWD Groundwater Use

ACWD obtains its imported surface water from the State Water Project's South Bay Aqueduct, Hetch Hetchy Aqueduct, and Alameda Creek Watershed Runoff (Figure 5). The water from the State Water Project is mostly used to recharge the groundwater through percolation facilities, and a portion of the water received from the aqueduct is used to provide water directly to consumers after being purified in treatment plants. The water from the Hetch Hetchy Aqueduct is blended with water from other supply sources before being delivered to consumers. The runoff from Alameda Creek is used solely to

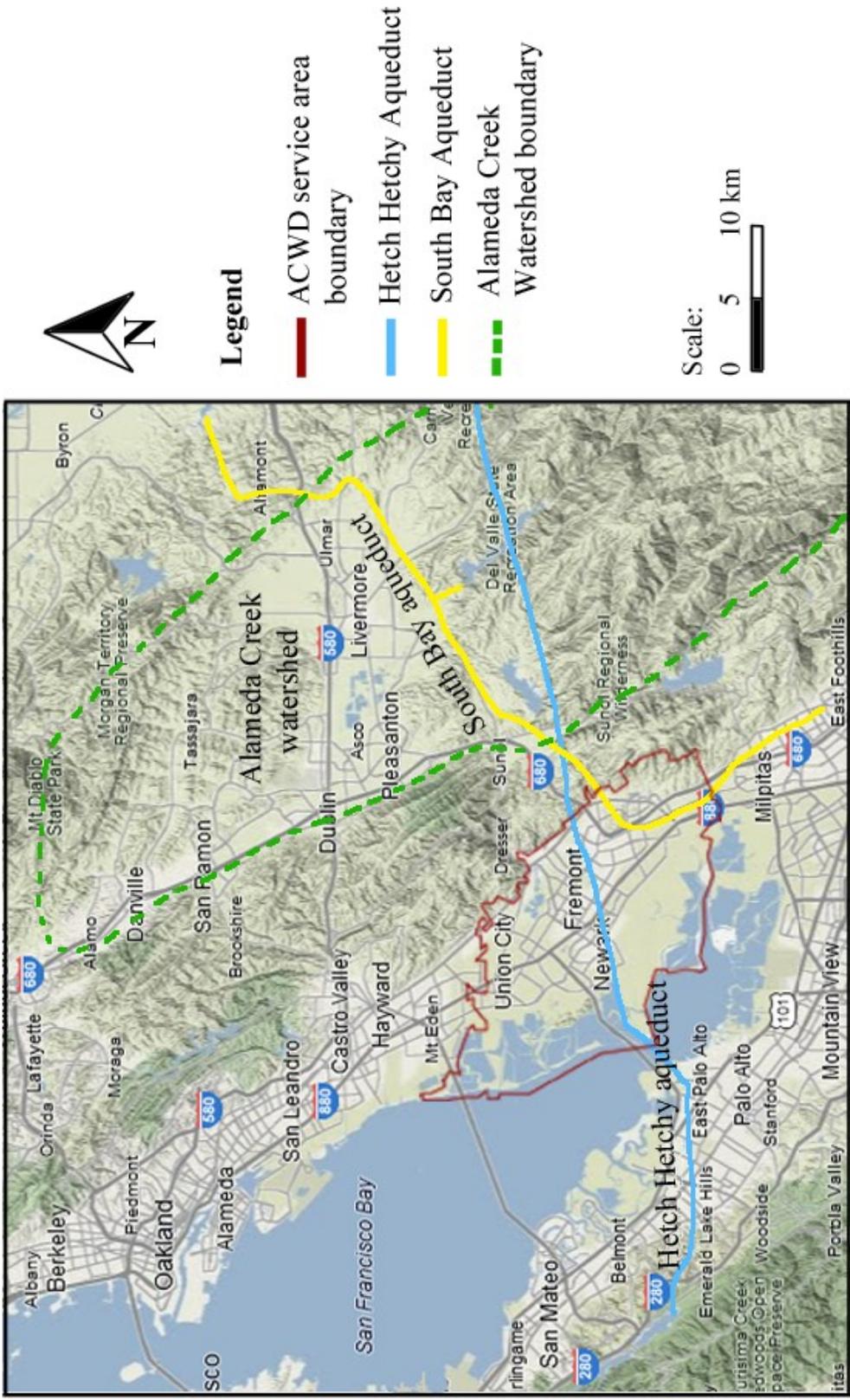


Figure 5. Map showing sources of water supply. (Approximate alignment of aqueducts and watershed boundaries based from ACWD, 2011a, Becker, 2011 and USGSGNIS, 1981).

recharge aquifers in the Niles Cone Groundwater Basin. The runoff water is stored behind inflatable rubber dams located along a stretch of Alameda Creek and then diverted to the infiltration ponds (Quarry Lakes Recreational Park). The water infiltrates from both the dammed stream bed and the lakes to recharge the underlying aquifers (ACWD, 2011a).

In addition, in 1973, ACWD implemented the Aquifer Reclamation Program (ARP) to assist in the removal of the trapped brackish water in the aquifers by pumping it from wells and discharging it to San Francisco Bay. Since 2003, when the Newark Desalination Facility (NDF) became operational, the water that is pumped out from the saltwater-affected portions of the aquifers has been treated and used for domestic water supply instead of being released into the Bay. The NDF uses reverse-osmosis technology to treat the brackish water before it is blended with water from other sources and released into the distribution system.

In 2009-2010, ACWD supplied water to about 330,000 people in its service area with an average consumption of 160,000 cubic meters per day (m^3/d). Total groundwater production contributed 55,400 m^3/d or 35% of the total daily water consumption with the balance coming from imported surface water. BHF aquifer production accounts for 32,100 m^3/d or 20% of the total water consumption (ACWD, 2011b). ACWD is expected to increase the total groundwater output (including AHF) to 41% of consumption in 2012 (ACWD, 2012).

METHODS OF INVESTIGATION

The ACWD's borehole database was utilized to achieve the objectives of this study. The inputs were mainly based on the geologic logs previously interpreted by ACWD, and no borehole geologic materials were examined in this study. The first step was to identify the boreholes that would be used in the study. Two hundred eighty geologic borehole logs stored in the database were reviewed and analyzed. After the logs were reviewed, it was found that not all wells could be integrated into the study. Some of the boreholes were drilled in cluster locations. Cluster-located wells are two or more wells drilled close to each other to obtain subsurface hydrogeologic data at various depths. To avoid repetition of data in this study, boreholes drilled in a cluster location were represented with only one well log. There are about 50 cluster well locations in the database. All of the wells in the database that were located in the AHF sub-basin were omitted, because the study covered only the BHF area. Boreholes with a discrepancy in geographic coordinates were likewise excluded, although some whose coordinates were subsequently corrected by ACWD were then included in the investigation. Although there are gaps in the southeast portion predominantly underlain by clay, the study area is adequately covered with borehole data. The study used data from 110 borehole logs, and the locations of the boreholes are shown in Figure 6.

The second step was to interpret the observed lithologic description of the selected boreholes as hydrostratigraphic units. The observed lithology is simply the

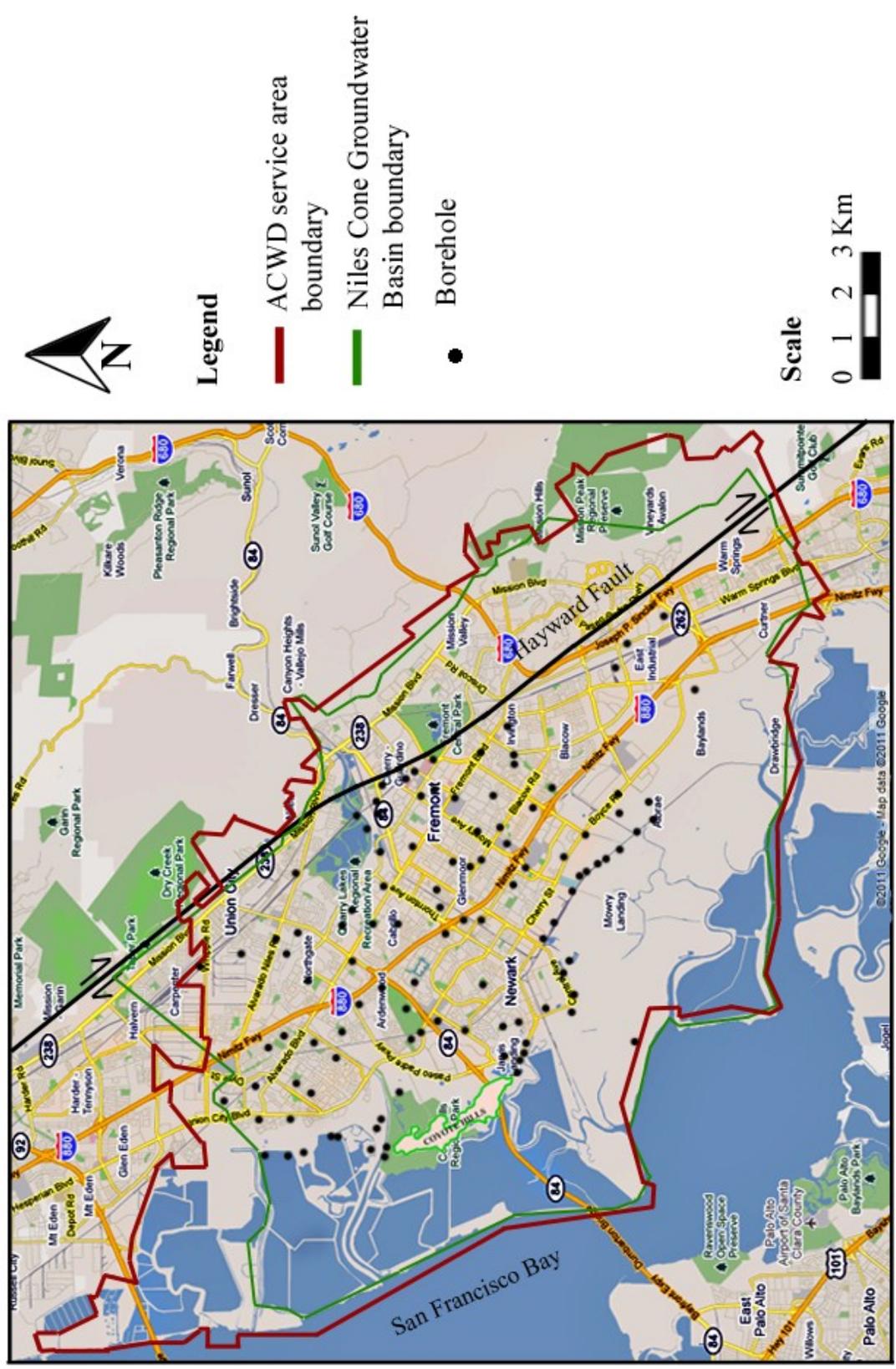


Figure 6. Borehole location map.

downhole sediment description such as sand, clay, or sand and clay, whereas the interpreted hydrostratigraphy is a group of lithologies with similar hydraulic characteristics. Based on similarity of hydraulic characteristics, the group of lithologies can be classified into aquifers and aquitards. A vertical sequence of coarse-grained lithologies (i.e., sand and gravel) can be classified as one stratigraphic unit, an aquifer, and, in the same manner, the clay and silt can be grouped together as one stratigraphic unit, an aquitard. The interlayered character of the aquifer (coarse-grained) and aquitard (fine-grained) units in the basin indicates glacial and interglacial stages of the recent past, which correspond to the fluctuation of the discharge and load capacity of Alameda Creek (Koltermann and Gorelick, 1992).

For purposes of this study, only the Newark Aquifer and deposits overlying it were interpreted and grouped into correlatable hydrostratigraphic units with corresponding depth intervals. In this investigation, any uppermost deposits that were silty and clayey were referred to as the Upper Aquitard, and any sandy or gravelly deposits within the upper 15 m of the basin were called the Shallow Aquifer. The clayey and silty deposit separating the Shallow and Newark aquifers is the Newark Aquitard. In areas where the Shallow Aquifer is missing and only the Newark Aquitard overlies the Newark Aquifer, the uppermost 2-m layer was arbitrarily designated as Upper Aquitard. This value is the minimum thickness observed where the fine-grained material overlies the Shallow Aquifer deposits.

Below are examples of the different hydrostratigraphic interpretations that were adopted in this study based on the lithologic log descriptions in the database. Table 2 presents a typical interpretation where the sand and gravel formation, Shallow Aquifer, occurs between the uppermost clay layer, the Upper Aquitard, and an underlying clay bed, the Newark Aquitard

TABLE 2. HYDROSTRATIGRAPHIC INTERPRETATION FOR TYPICAL SHALLOW AQUIFER CASE

Lithology			Hydrostratigraphy		
Depth (m)		Description	Depth (m)		Description
From	To		From	To	
0.0	2.0	Overburden			
2.0	3.6	Clay			
3.6	6.4	Clay	0.0	6.4	Upper Aquitard
6.4	8.0	Sand			
8.0	10.0	Gravel	6.4	10.0	Shallow Aquifer
10.0	12.1	Clay	10.0	12.1	Newark Aquitard
12.1	12.8	Sand			
12.8	21.0	Gravel	12.1	21.0	Newark Aquifer

Note: Borehole 4S2W-24L3.

Table 3 illustrates the case where the gravelly layer, the Shallow Aquifer, is exposed on the surface while being underlain by a clay bed, the Newark Aquitard, and sand and gravel layers, the Newark Aquifer.

TABLE 3. HYDROSTRATIGRAPHIC INTERPRETATION FOR EXPOSED
SHALLOW AQUIFER CASE

Lithology		Hydrostratigraphy					
Depth (m)		Description		Depth (m)		Description	
From	To			From	To		
0.0	3.0	Gravel		0.0	3.0	Shallow Aquifer	
3.0	22.0	Clay		3.0	22.0	Newark Aquitard	
22.0	45.0	Sand		22.0	45.0		
45.0	52.0	Gravel		45.0	52.0	Newark Aquifer	

Note: Borehole 4S2W-12K8.

Table 4 illustrates an additional hydrostratigraphic interpretation where the Upper Aquitard is missing and the Shallow Aquifer overlies the Newark Aquifer. The thin layer (0.6 m) of silt was considered part of the Shallow Aquifer deposit in the uppermost 2 m. The borehole is located at the Forebay area.

TABLE 4. HYDROSTRATIGRAPHIC INTERPRETATION FOR ALL COARSE-
GRAINED MATERIAL CASE

Lithology			Hydrostratigraphy		
Depth (m)		Description	Depth (m)		Description
From	To		From	To	
0.0	0.6	Silt			
0.6	5.0	Gravel	0.0	2.0	Shallow Aquifer
5.0	5.5	Sand			
5.5	8.0	Gravel			
8.0	9.7	Sand			
9.7	17.7	Gravel			
17.7	24.3	Sand	2.0	23.4	Newark Aquifer

Note: Borehole 4S1W-20J5.

The third step in the project was to input the interpreted hydrostratigraphic classifications into the Rockworks 2002[®] software package along with the corresponding geographic coordinates. The software uses the borehole geologic data in subsurface visualizations such as contour maps and cross sections.

The outputs of Rockworks 2002[®] that were used in this study include the following:

1. Five stratigraphic cross-sections. The locations of the five lines of stratigraphic cross-section are shown in Figure 7. Two section lines are oriented in a northwesterly direction roughly parallel to the Hayward fault, one near the base

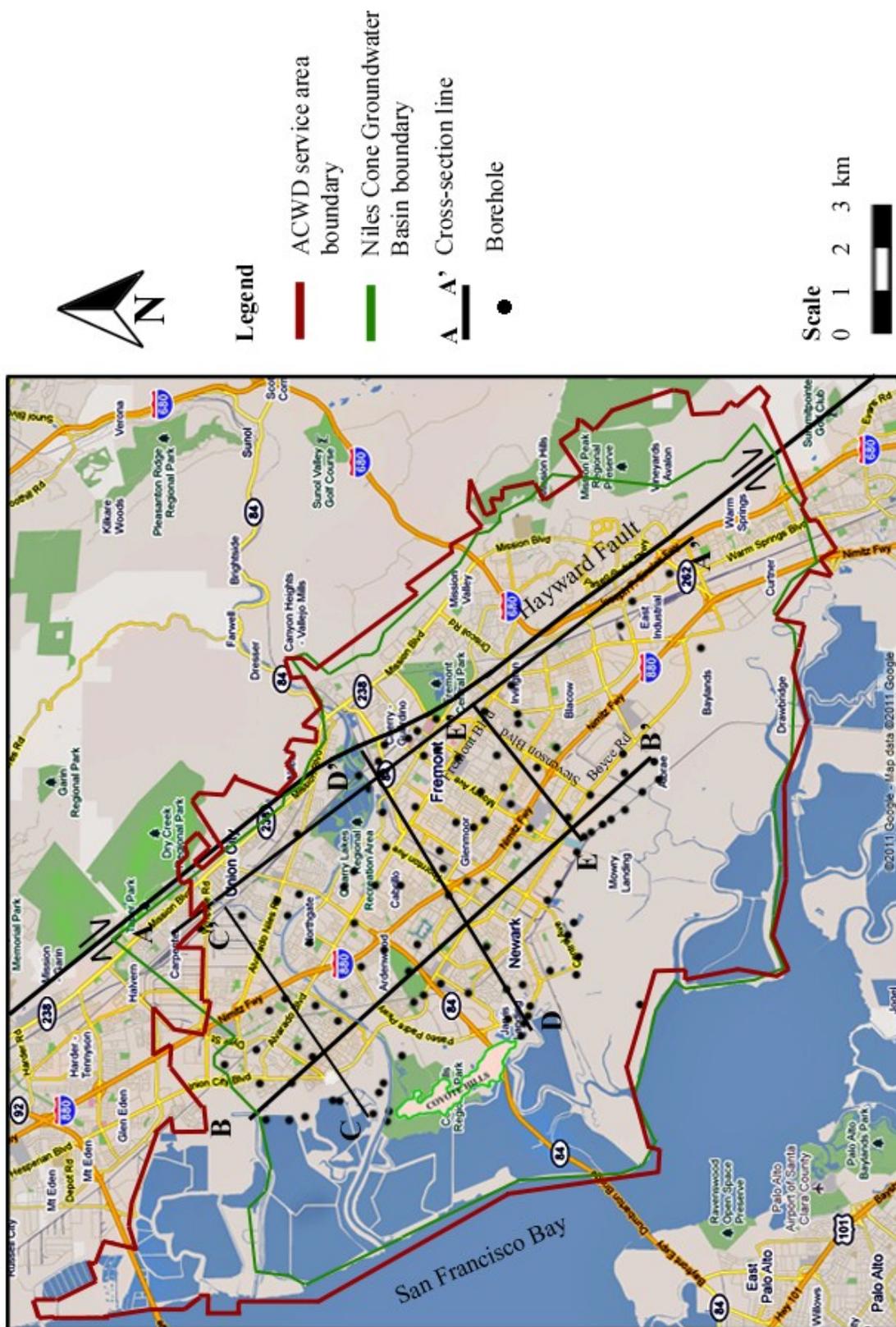


Figure 7. Location of stratigraphic cross-section lines.

- of the Diablo Range and one near the shoreline of San Francisco Bay. Three lines of section are oriented in a northeasterly direction.
2. Three thickness maps representing the Upper Aquitard, Shallow Aquifer, and Newark Aquitard. The thickness map is a 2-dimensional color flood showing the areal distribution of the varying thickness of the stratigraphic unit over the study area.
 3. Three stratigraphic surface maps of the Shallow Aquifer, Newark Aquitard, and Newark Aquifer. The stratigraphic surface map is a two-dimensional color flood showing the top surface elevations of a selected stratigraphic unit.
 4. A map showing where the Upper Aquitard overlying the Shallow Aquifer is absent or thin. Thin is defined as 2 m or less in thickness.
 5. A map showing where the Newark Aquitard is thin or absent. Thin is defined as a thickness of 2 m or less.
 6. A map showing which regions in ACWD's service area are most sensitive to contamination.
 7. A map tracing the inferred paleodrainage courses that flowed within the Niles Cone Groundwater Basin based on a Shallow Aquifer thickness of 1 m or more.

The fourth step was to review the visualization results. After the initial plots were generated, they were analyzed for validity and reasonableness based on knowledge of geologic conditions in the area. Analysis tools in Rockworks 2002[®] were used in the adjustments and refining of the generated visualizations. Some gridding methods in Rockworks 2002[®] were likewise tried in interpolating the data. The inverse-distance

gridding method was deemed to reflect most accurately the general geologic conditions in the study area.

The fifth step was the geologic interpretation of the lateral extent of the Shallow Aquifer, based on the visualizations described above.

RESULTS

With all of the visualizations presented in this section, two things must be kept in mind. First, the data density of the boreholes is in some places on the order of kilometers, whereas some features, such as stream channels, have dimensions on the order of meters or tens of meters. Thus the data density may not be high enough to identify all smaller features. Secondly, Rockworks 2002[®] uses consistent interpolation algorithms between data points that may create features, such as “bull’s eyes” on contour maps, that are contouring artifacts rather than reflections of a geologic reality. Another software artifact results in an inaccurate thickness in some of the stratigraphic units in cross sections. A contour interval of 0.5 m was used in the maps to clearly display the thickness variability and elevation of the stratigraphic unit.

Thickness Maps

Except at the Forebay and the northern portion of the study area, the Upper Aquitard covers almost the entire Niles Cone Groundwater Basin. Figure 8 presents the thickness map of the Upper Aquitard. The absence of the Upper Aquitard in the Forebay indicates that the fine grained aquitard materials were washed away by the continuous flow of the Alameda Creek as it drained westward. Left behind were the heavier and coarser materials near the fan apex. The missing Upper Aquitard in the Forebay stretches 3 km westward from the Hayward fault. Likewise, its absence in the northern part of the

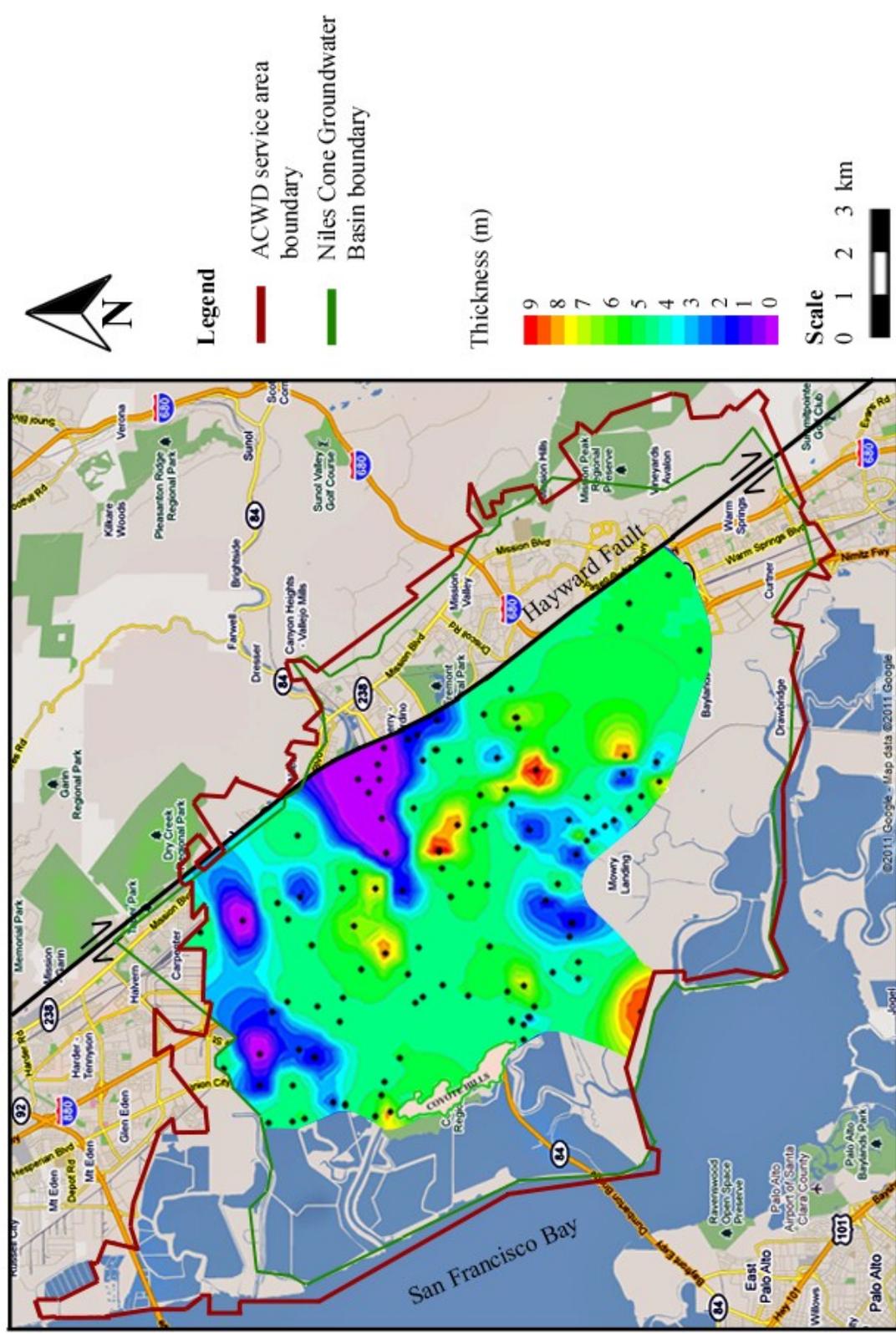


Figure 8. Thickness map of the Upper Aquitard.

study area suggests the presence of another paleodrainage channel, probably from the smaller Dry Creek alluvial fan.

The thickness map of the Shallow Aquifer in Figure 9 indicates that it was not deposited throughout the Niles Cone Groundwater Basin. It is mostly found in the Forebay and in some localized areas, in total covering approximately 40% of the study area. Apparently, its abundance around the Forebay area may indicate continuous deposition of coarse-grained materials by the creek. The presence of isolated shallow coarse-grained materials in other areas may also suggest that they are remnants of the paleochannel course of Alameda Creek as it flowed westward towards the Bay. The greater absence of the Shallow Aquifer east of the Coyote Hills implies that, during the Holocene Epoch, Alameda Creek did not flow near the hills but mainly flowed southwest of the hills and, perhaps at times, northwest towards San Francisco Bay.

In Figure 10, the Newark Aquitard is missing in the Forebay area where the aquifers are predominantly present from surface to considerable depth. The figure likewise shows isolated areas of thin (2 m thick or less) Newark Aquitard deposits, and a predominance of thick clay deposits in the southern and northeastern part of the study area. The thickness of the Newark Aquitard is important because thicker deposits hinder downward movement of shallow pollutants to the underlying, groundwater-producing Newark Aquifer. In areas where the aquitard is thinner (2 m or less), pollutants could migrate downward more easily.

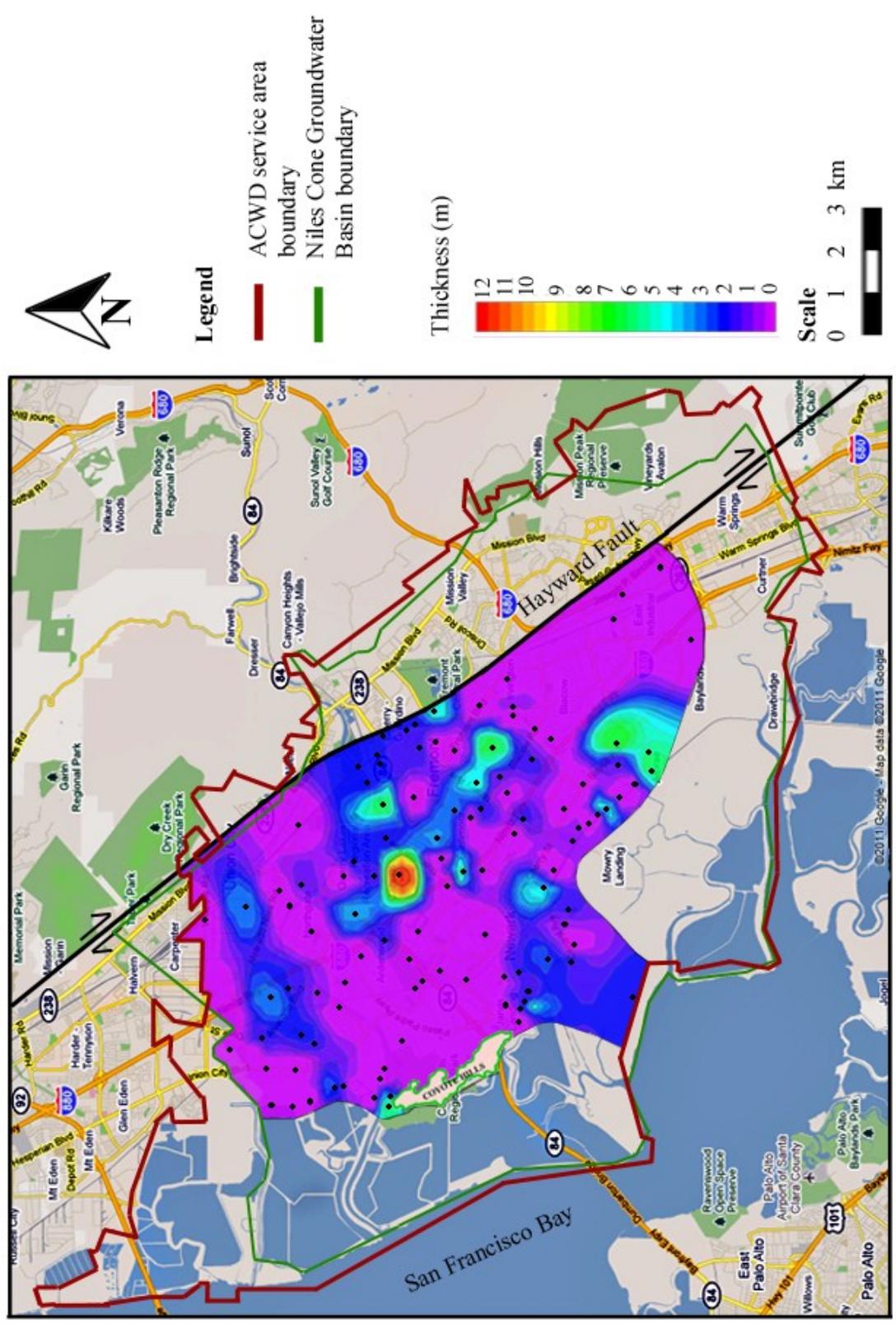


Figure 9. Thickness map of the Shallow Aquifer.

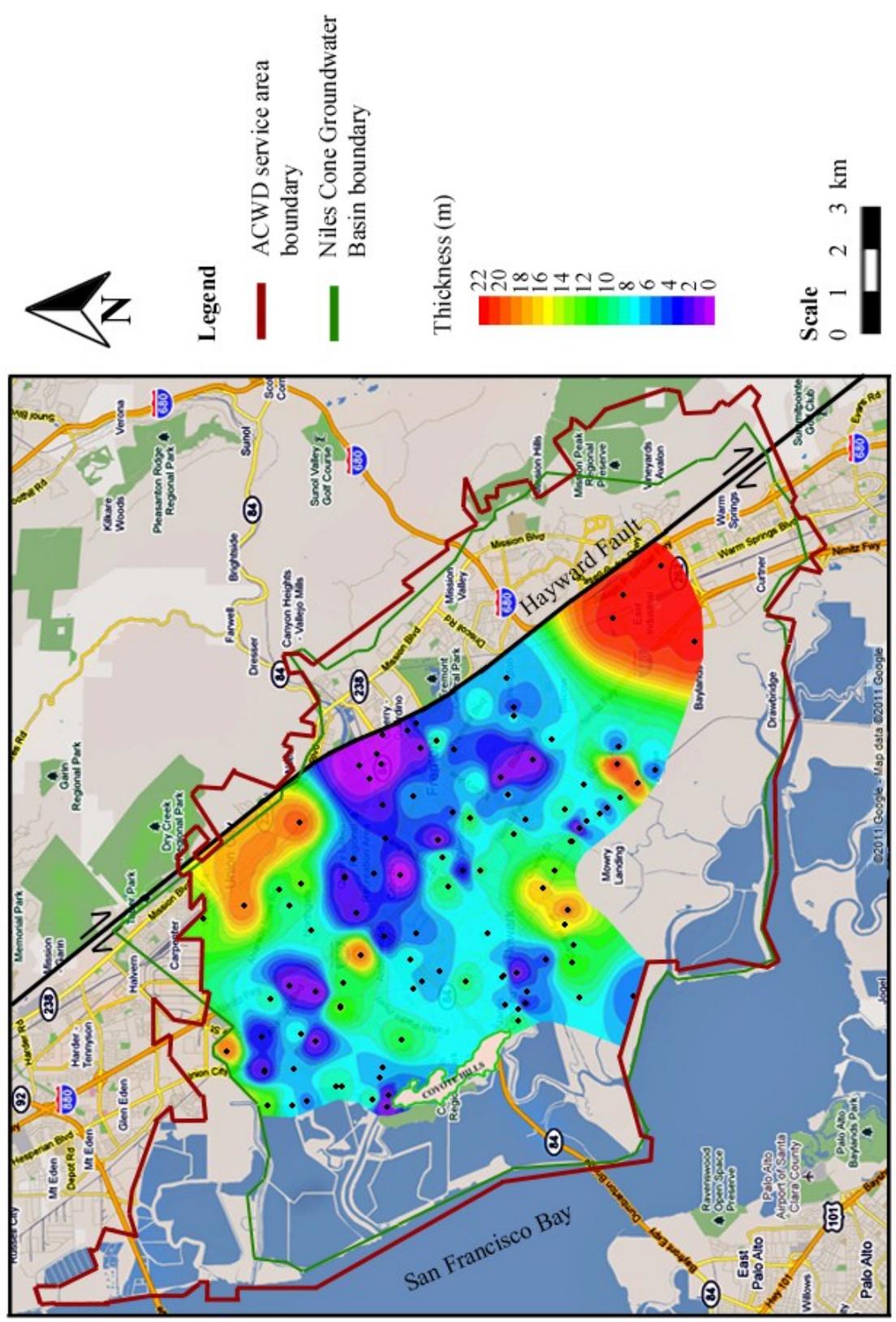


Figure 10. Thickness map of the Newark Aquitard.

Stratigraphic Surface Maps

The Shallow Aquifer deposits in the Niles Cone basin primarily slope southwest toward the Bay, with the highest elevation of about 20 m above mean sea level (amsl) at the Forebay area and the lowest at 8 m below mean sea level (bmsl) in the west, as shown in Figure 11. An elevated Shallow Aquifer also exists in the north of the study area where it is inferred to be part of the apex of the smaller Dry Creek alluvial fan. If the aquifer is entirely alluvial, the elevation of the lowest Shallow Aquifer bottom, which was encountered at 12 m bmsl, indicates that part of the aquifer was deposited when San Francisco Bay was still at least 12 m below the present sea level. Several investigators conducted studies on eustatic sea-level rise. The study of Atwater et al. (1977) on Holocene sea level changes in southern San Francisco Bay showed that the Shallow Aquifer began to be deposited at the latest around 7,000 years before present (Figure 12) following the last glacial low stand. The deposition continued up to the present at least in the Forebay area.

Figure 13 shows that the Newark Aquitard also slopes southwesterly, with the highest elevation of its top at 20 m amsl in the south, where there are predominantly clayey deposits, and the lowest elevation of its upper surface at 12 m bmsl. The Newark Aquifer likewise dips southwesterly, with the highest elevation of its upper surface at 8 m amsl in the Forebay and the lowest point of its upper surface elevation at 30 m bmsl, in the south, as shown in Figure 14.

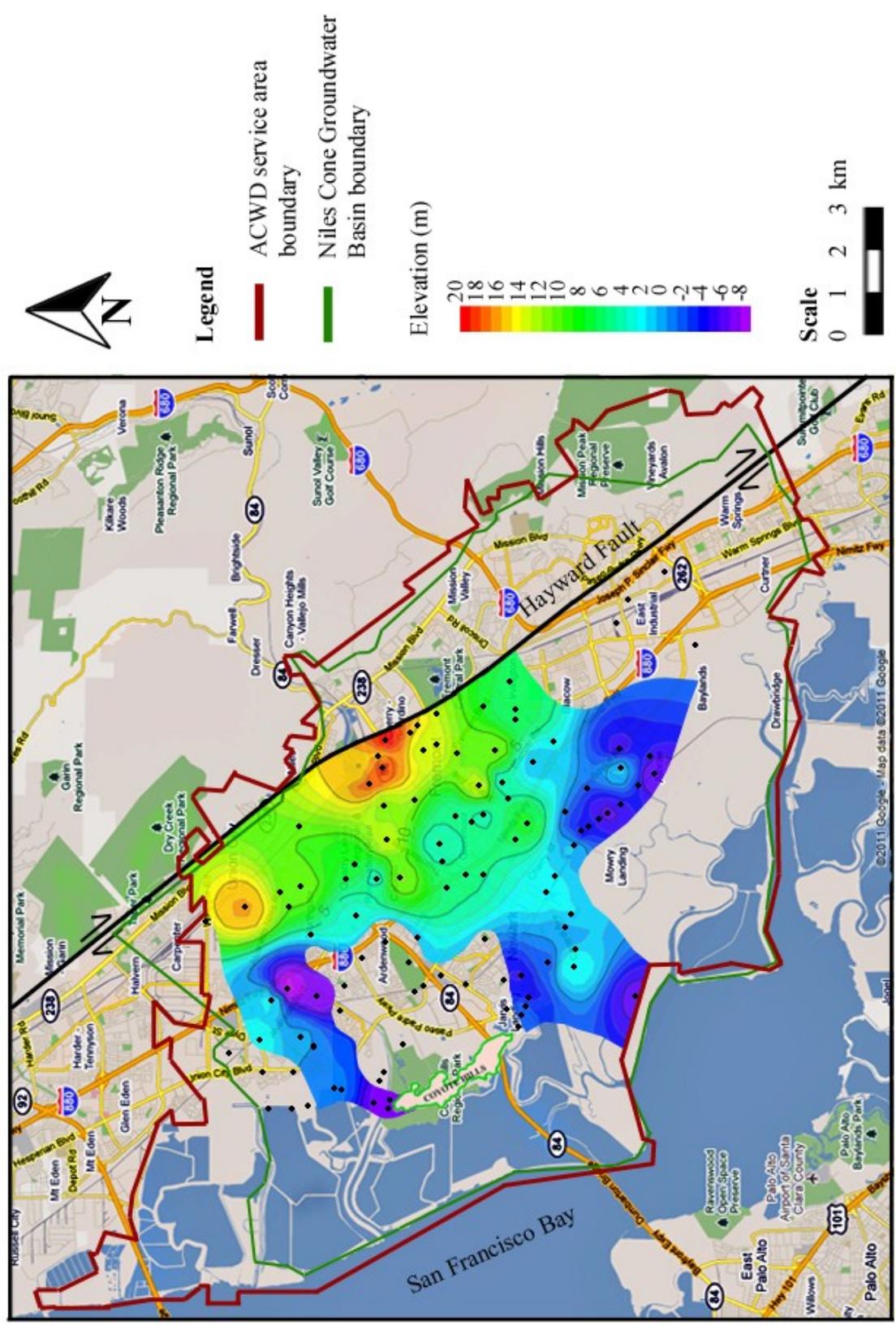


Figure 11. Stratigraphic surface map of the Shallow Aquifer.

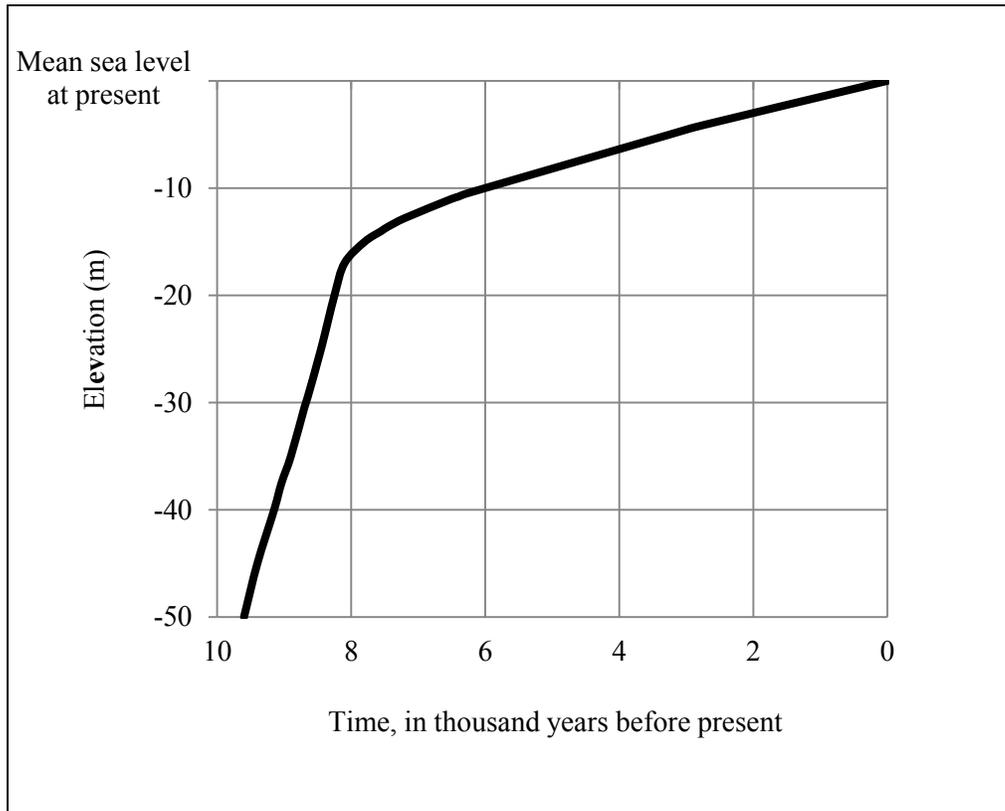


Figure 12. Sea-level changes in southern San Francisco Bay during Holocene Epoch (modified from Atwater et al., 1997).

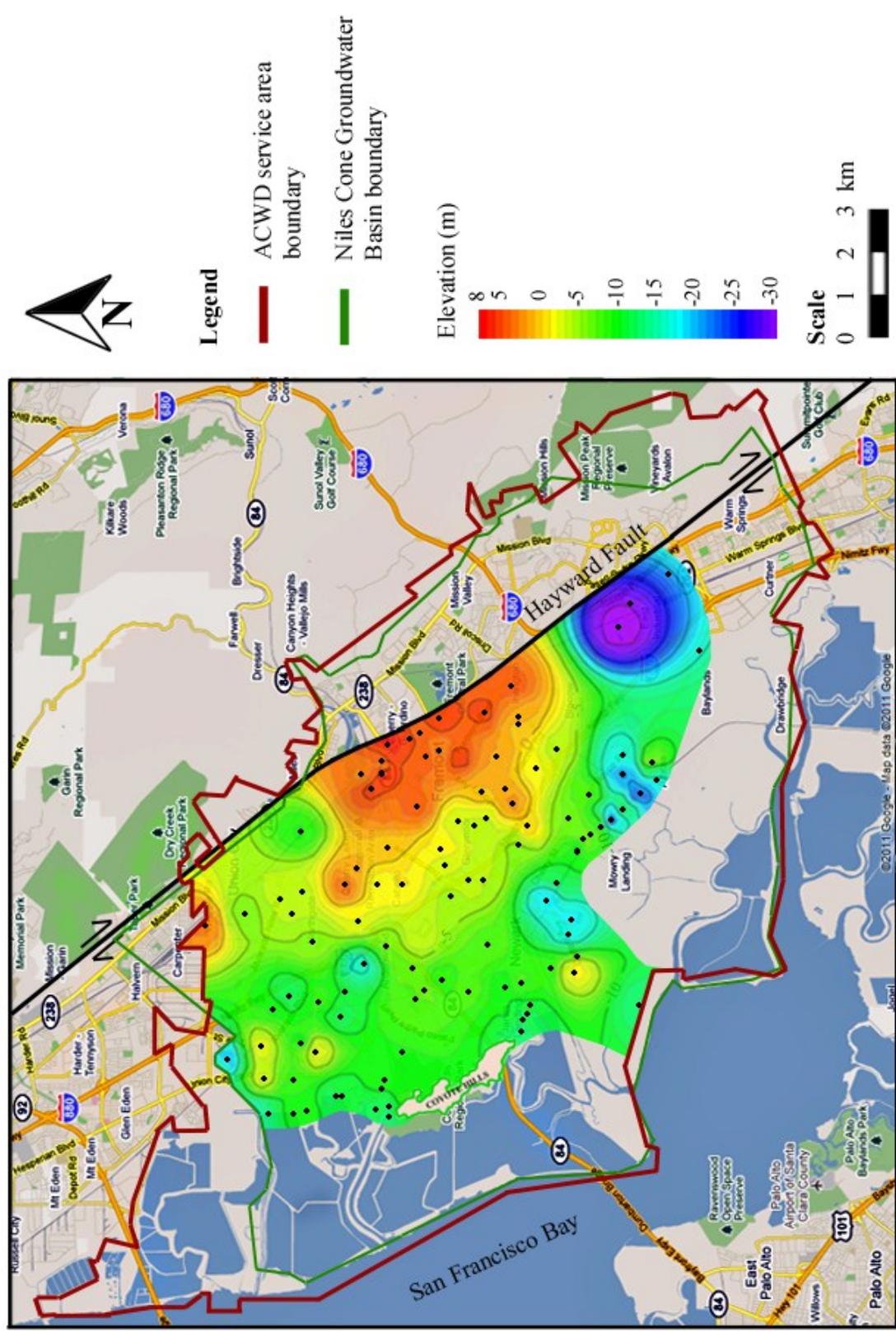


Figure 14. Stratigraphic Surface Map of the Newark Aquifer.

Hydrostratigraphic Cross-sections

In examining the cross-sections, it is useful to keep in mind that the vertical exaggeration is 100-fold. Tick marks along the top edge of the sections indicate the location of the boreholes whose logs are the basis for the hydrostratigraphy. Figure 7 shows the locations of the cross-sections.

The hydrostratigraphic sections in Figures 15 through 19 generally illustrate that the Shallow Aquifer is not uniformly distributed throughout the Niles Cone Groundwater Basin. Cross-section A-A' (Figure 15), which is parallel to and near the Hayward fault, shows that the Shallow Aquifer is only present in the mid-section, the Forebay area near where Alameda Creek exits Niles Canyon, and in the north as part of the apex of the Dry Creek alluvial fan. Both aquifer deposits are exposed at the ground surface. The Shallow Aquifer is significantly absent in the southern part of the section and the Newark Aquifer occurs at greater depths.

Cross-section B-B' in Figure 16 runs parallel to section A-A', but is located near the bayshore. It shows that the Shallow Aquifer is likewise discontinuous, localized, and thin. The section also indicates that the Shallow Aquifer was deposited at depths slightly above the present sea level at this location, but between thick aquitards. The section indicates the absence of hydraulic connection between the Shallow Aquifer and the underlying Newark Aquifer.

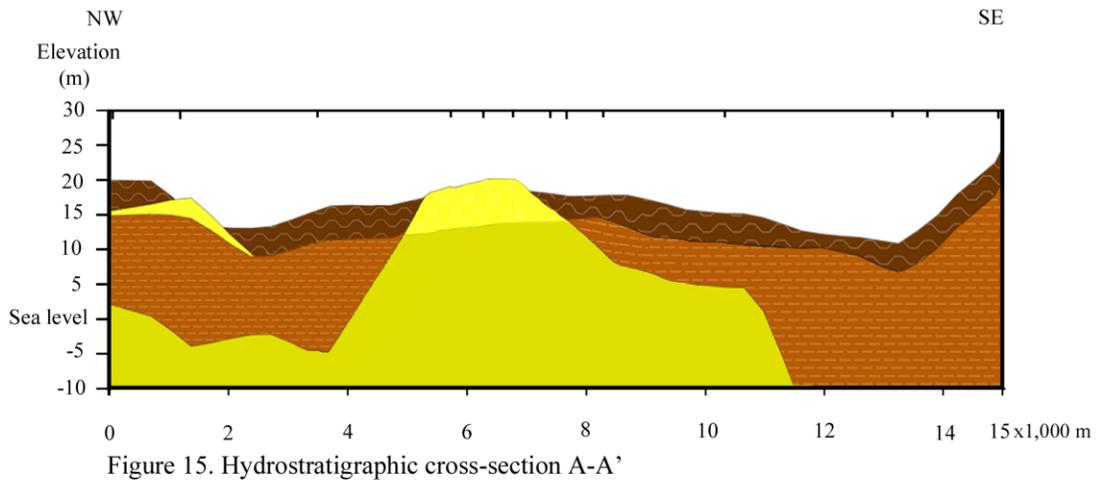


Figure 15. Hydrostratigraphic cross-section A-A'

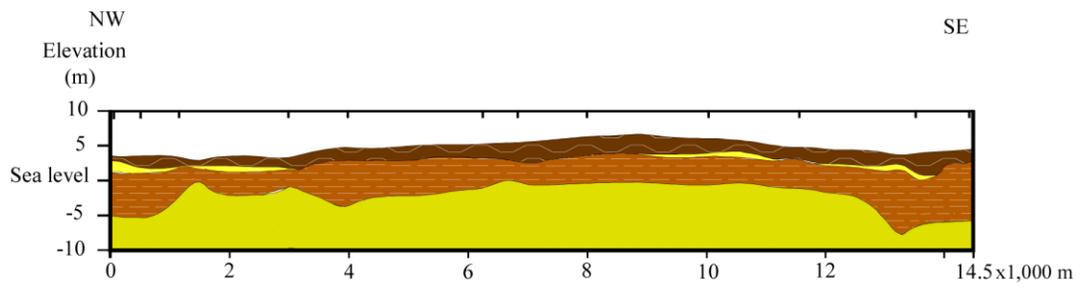


Figure 16. Hydrostratigraphic cross-section B-B'

- Legend:**
-  Upper Aquitard
 -  Shallow Aquifer
 -  Newark Aquitard
 -  Newark Aquifer

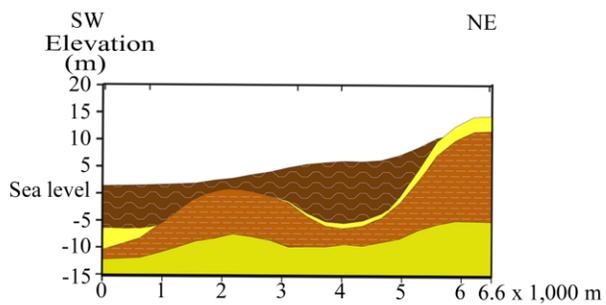


Figure 17. Hydrostratigraphic cross-section C-C'

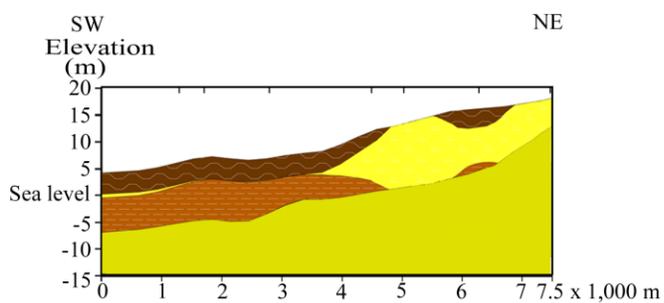


Figure 18. Hydrostratigraphic cross-section D-D'

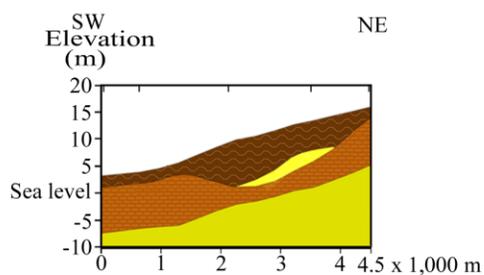


Figure 19. Hydrostratigraphic cross-section E-E'

Legend:

-  Upper Aquitard
-  Shallow Aquifer
-  Newark Aquitard
-  Newark Aquifer

The hydrostratigraphic cross-section C-C' (Figure 17) in the northernmost part of the study area cuts the exposed Shallow Aquifer deposits of the smaller Dry Creek alluvial fan, which is underlain by the Newark Aquitard. The section also indicates a Shallow Aquifer deposit near the bayshore; it lies about 8 m below present sea level with a thin underlying aquitard of about 2 m thickness but with a thick Upper Aquitard above it. This indicates that in the western part of the northern section of the study area the thick aquitard shields the hydraulically connected Shallow Aquifer and Newark Aquifer from contamination.

Cross-section D-D' in Figure 18 extends from the Coyote Hills towards the Forebay area. It significantly shows missing Upper and Newark Aquitards in the Forebay area, hence exposing the Shallow Aquifer deposit at the ground surface. The section also displays the hydraulic connectivity of the Shallow Aquifer with the underlying Newark Aquifer, thus indicating vulnerability of the Forebay area to surface contamination. Although an isolated Shallow Aquifer deposit is present in the southwestern end of the section near the shoreline, it is thickly overlain and underlain by aquitards, thus downward movement of potential contaminants to the underlying aquifer would be greatly impeded.

Cutting across the study area, approximately along Stevenson Blvd. from Boyce Road to Fremont Blvd. in the city of Fremont (Figure 7), is cross-section E-E' (Figure 19). It primarily shows thick aquitard deposits with a localized, confined Shallow Aquifer. This section further indicates that the Shallow Aquifer is a discontinuous deposit.

DISCUSSION

The figures presented in the previous section can be interpreted to answer questions about the sensitivity of the aquifers to contamination and about the depositional history of the Shallow Aquifer. The data set used for this study did not include the many wells installed at environmental cleanup sites. If those wells or non-geologic factors (e.g., abandoned wells, man-made structures, etc.) had been included, it is possible that other areas sensitive to contamination would have been identified. It is also possible that such areas exist where no investigation has taken place.

Sensitivity to Contamination

A map (Figure 20) was drawn delineating where the Upper Aquitard deposits are thin (thickness 2 m or less) or absent to show areas in the Niles Cone Groundwater Basin where the Shallow Aquifer is sensitive to potential surface contamination. The map indicates that the Upper Aquitard is mainly missing in the Forebay and in the northernmost part, with thin Upper Aquitard deposits scattered across the rest of the study area. The region where the Shallow Aquifer is most sensitive to impact encompasses nearly 15% of the study area. However, contaminants from leaking pipelines and underground storage tanks could never be disregarded because they could move downwards even in areas where the Upper Aquitard is more than 2 m thick.

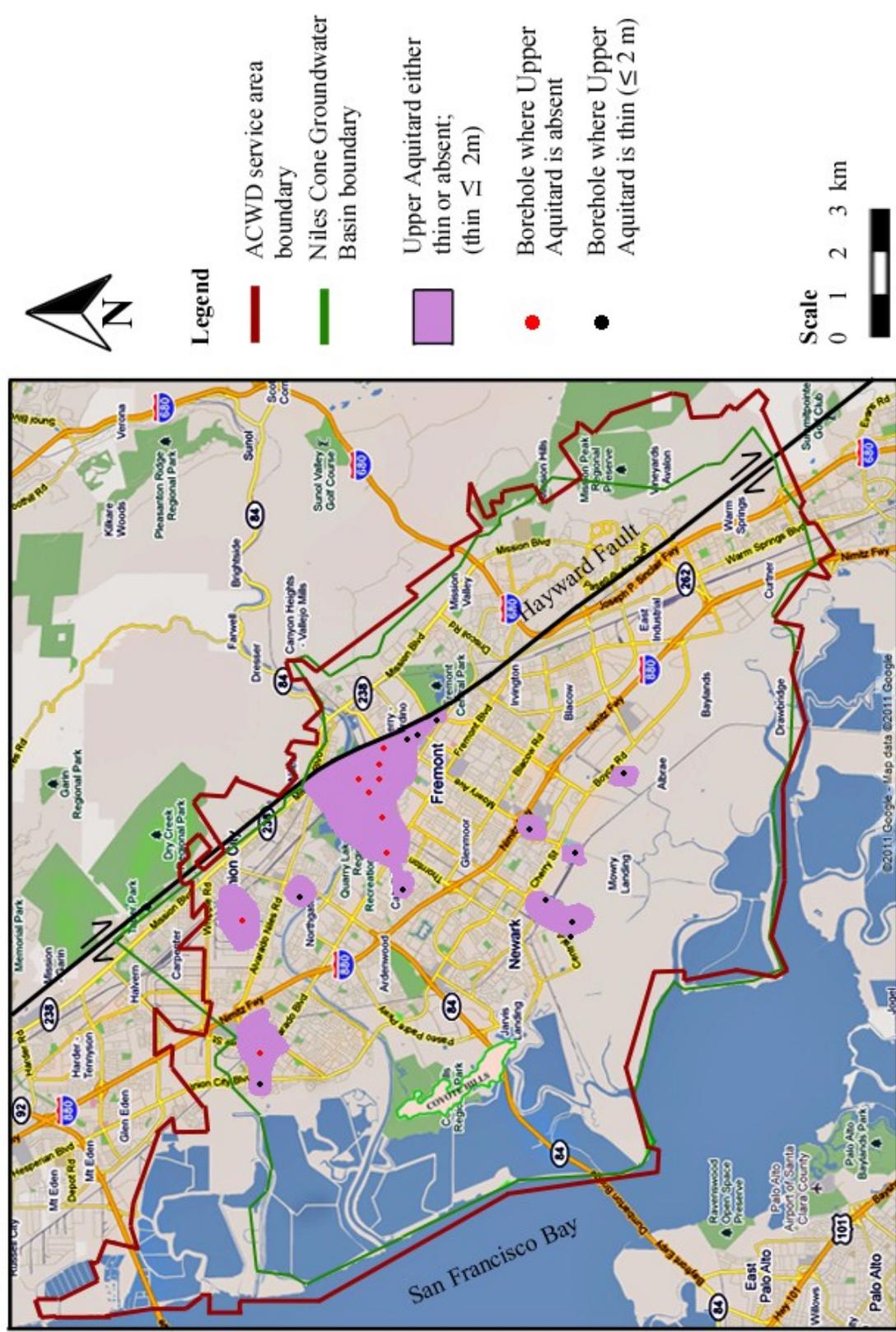


Figure 20. Map of areas where the Upper Aquitard is thin or absent.

To show hydraulic connection between the Shallow Aquifer and the underlying Newark Aquifer, the thickness of the intervening Newark Aquitard was delineated to show where the deposits are thin or absent (as illustrated in Figure 21). It shows that the Newark Aquitard is missing in the Forebay with some thin deposits irregularly distributed elsewhere in the study area. The map also indicates the locations of the potential migration pathways to the underlying Newark Aquifer if contamination occurs in the Shallow Aquifer. The region of enhanced hydraulic connectivity between the aquifers covers approximately 15% of the study area.

Figure 22 shows the area where both the Upper Aquitard and Newark Aquitard are thin (2 m or less) or absent illustrating the location in the study area that is most sensitive to surface contamination in the Niles Cone Groundwater Basin. Likewise, it identifies areas where the potential downward movement of surface contaminants to the first drinking-water aquifer would be most likely. These highly sensitive regions are localized near to some of the ACWD's production wells, indicating a potential hazard.

Recent Depositional History

To provide additional information on the development of the Niles Cone Groundwater Basin, the paleodrainage channels present during the Holocene Epoch were inferred by tracing the deposits of the shallow, coarse-grained sediments with a thickness of 1 m or greater. In Figure 23, the map of the inferred paleodrainage channels shows

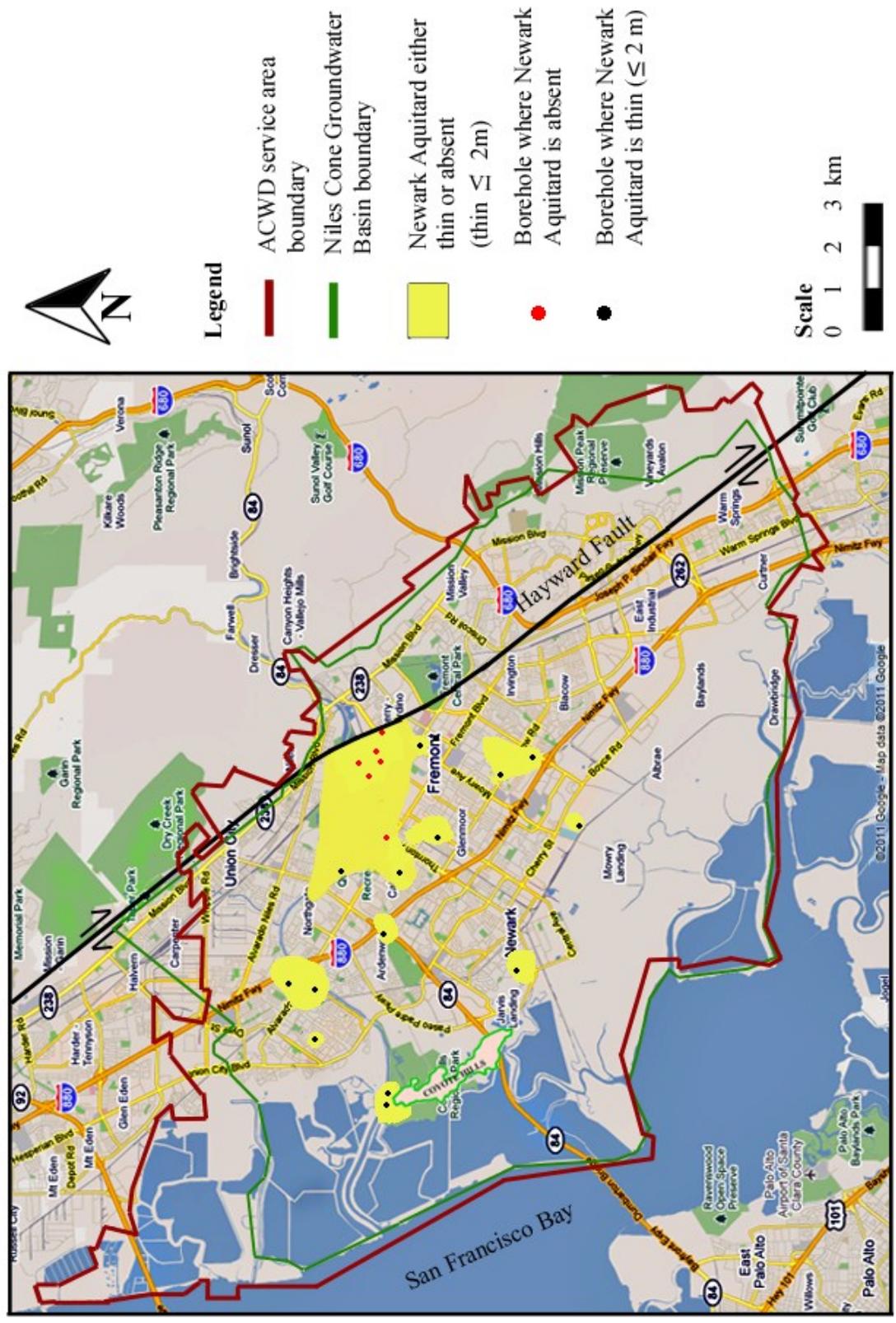


Figure 21. Map of the areas where the Newark Aquitard is thin or absent.

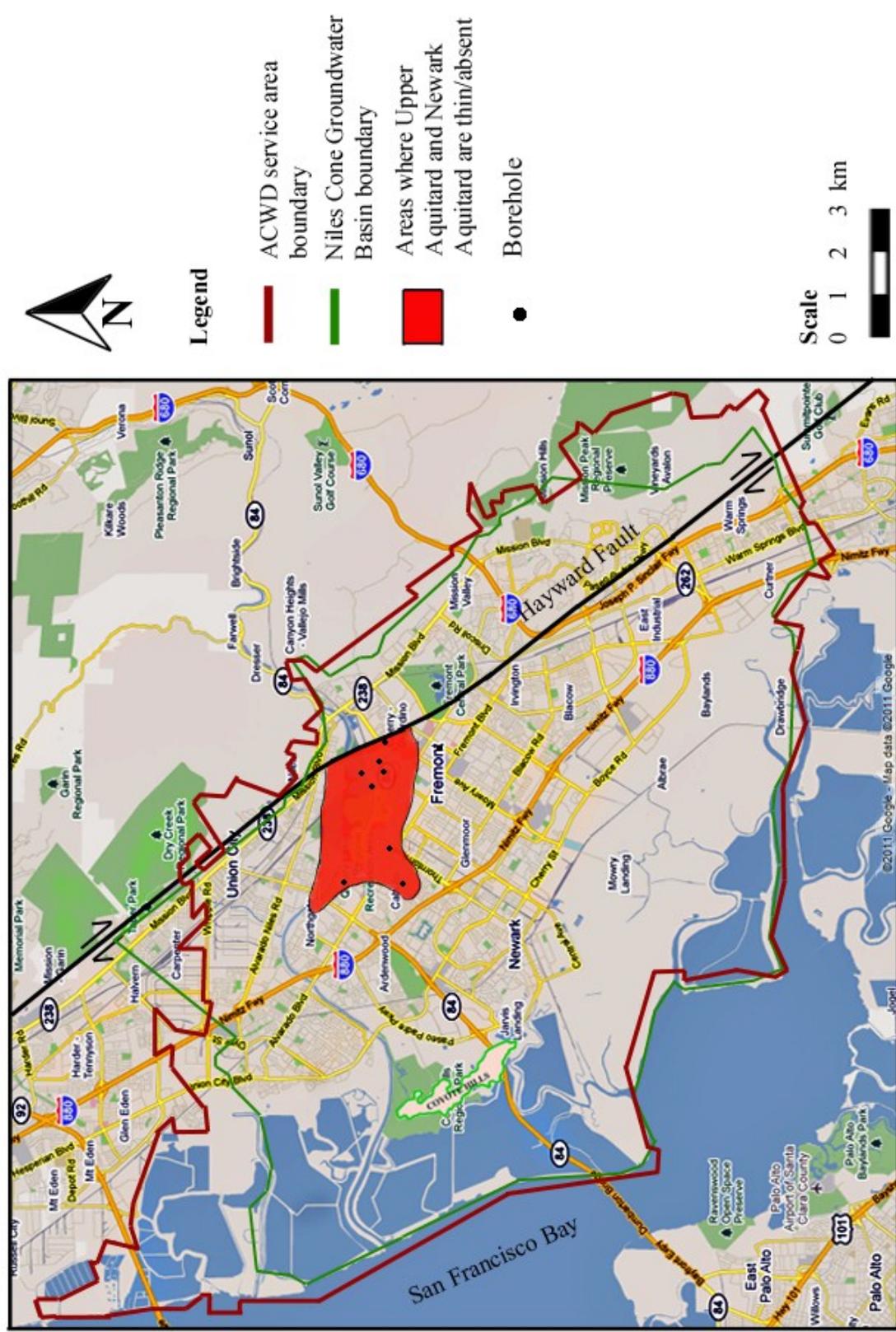


Figure 22. Map of areas most sensitive to contamination of groundwater.

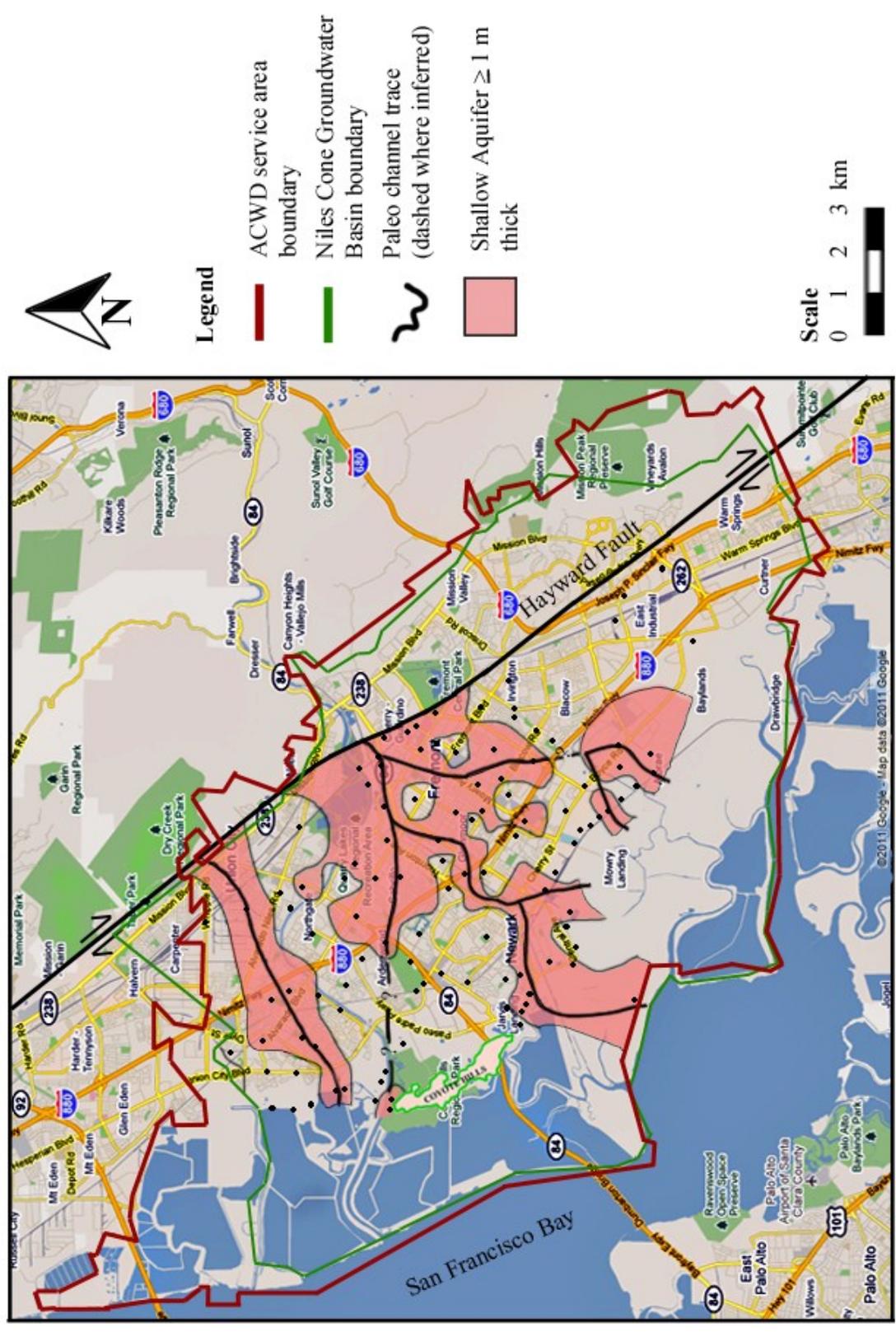


Figure 23. Map of inferred paleodrainage channels.

two ancestral streams, Alameda Creek and Dry Creek. Dry Creek in the north of the study area evidently flowed into San Francisco Bay following a single, primary pathway. The larger Alameda Creek flowed around the Coyote Hills to reach the Bay either to the north or to the south of the hills, having changed course over time.

CONCLUSION

This study identified the Forebay area and its vicinity as the most sensitive to surface contamination in the Niles Cone Groundwater Basin. The Upper and Newark Aquitards in these areas were either thin or absent. Because the Shallow Aquifer deposits in these areas were either exposed at the ground surface or thinly covered with the Upper Aquitard and hydraulically connected to the underlying Newark Aquifer, potential surface contaminants could move largely unhindered to the underlying groundwater-producing aquifers.

In addition, the study determined that the shallow, coarse-grained sediments were deposited by two paleo-stream channels, Dry Creek in the north, and Alameda Creek, the main stream channel in the Niles Cone Groundwater Basin. Some of this deposition occurred when the level of the Bay was significantly lower (as much as 12 m) than at present. The Shallow Aquifer was absent east of the Coyote Hills and in the southern part of the study area.

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