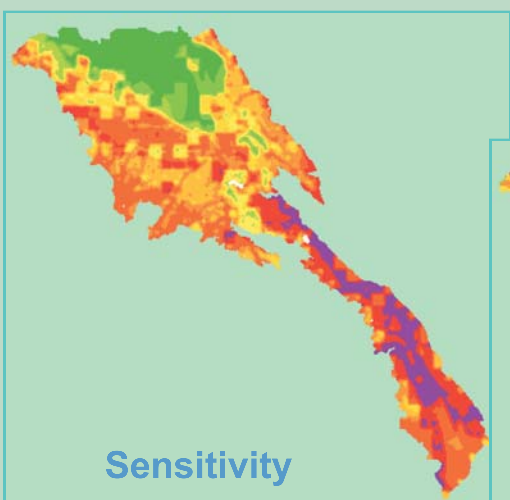
Revised Final
Groundwater Vulnerability Study
Santa Clara County, California

October 2010

Todd Engineers

Kennedy/Jenks Consultants



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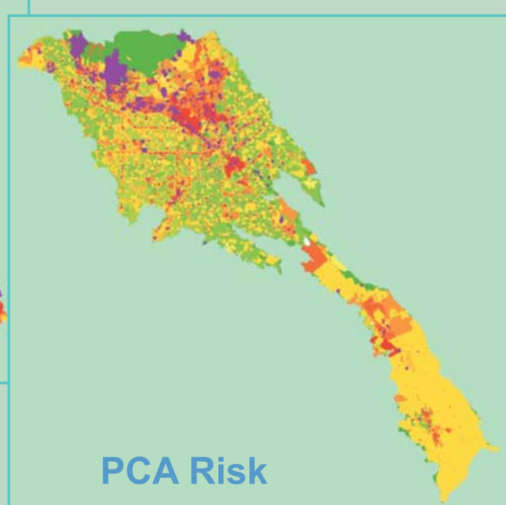

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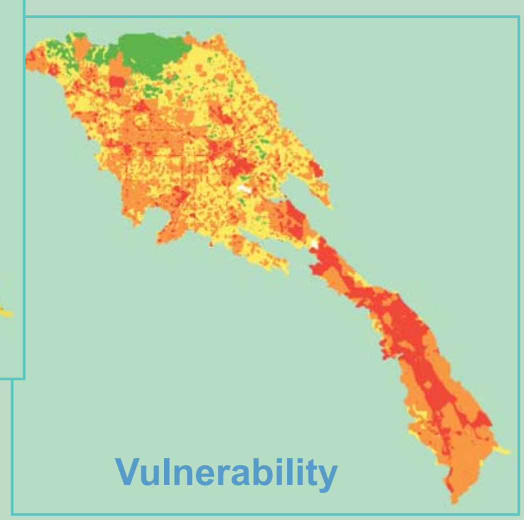

Vulnerability

Santa Clara Valley Water District
San Jose, California

Revised Final
Groundwater Vulnerability Study

Santa Clara County, California

October 2010

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Executive Summary

The Santa Clara Valley Water District (District) is the primary water resources agency in Santa Clara County. This Groundwater Vulnerability Study was conducted to predict the vulnerability of groundwater to potentially contaminating land use activities to aid the District in its management and protection activities. Groundwater vulnerability is comprised of two key components: 1) groundwater sensitivity and 2) potentially contaminating activities. Groundwater sensitivity is generally defined as the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest based on the intrinsic characteristics of the aquifer and the overlying unsaturated materials. Groundwater sensitivity is combined with the potentially contaminating activities risk to characterize overall groundwater vulnerability.

The Study Area is comprised of three groundwater subbasins: the Santa Clara, the Coyote, and the Llagas. Each has unique hydrogeologic characteristics as well as unique current and historic land uses. Water-bearing units in the Study Area have been grouped into two major aquifer systems, the Shallow Aquifer and Principal Aquifer. Groundwater vulnerability was assessed separately for each aquifer. Generally, the Shallow Aquifer occurs above regional confining layers. The Principal Aquifer lies beneath the Shallow Aquifer and supplies most of the groundwater produced for beneficial uses in the Study Area. The Principal Aquifer occurs under semi-confined to confined conditions. In areas where confining layers do not exist or are not laterally and vertically extensive, only the Principal Aquifer occurs. Accordingly, in the recharge zones, depth to water was characterized as the first encountered groundwater for both the Shallow and Principal aquifers. In contrast, the Shallow and Principal aquifers were uniquely defined in the confined areas with the Shallow Aquifer characterized by the first encountered groundwater and the Principal Aquifer defined by the top screened interval of wells tapping the primary groundwater production zone.

The southern area and lateral margins of the Santa Clara Subbasin are unconfined recharge areas. An extensive regional aquitard occurs in the northern interior portion of the subbasin. The Santa Clara Subbasin is currently highly developed with residential, commercial, and industrial areas. Due to the high density of urban land uses including major industrial manufacturing and processing facilities, point-source contamination is prevalent but generally contained in the Shallow Aquifer. This is due, in part, to the protection offered by the significant confining layers found in the northern portion of the subbasin. The Santa Clara Subbasin is currently undergoing continued urban expansion and redevelopment of formerly industrial areas to residential use.

No significant laterally extensive confining layers exist in the Coyote Subbasin, and groundwater generally occurs under unconfined conditions. Compared with the Santa Clara Subbasin, the Coyote Subbasin is relatively rural, undeveloped, and mostly unincorporated with far fewer industrial/commercial contaminant release sites. Due to generally unconfined conditions, the Coyote Subbasin is hydrogeologically sensitive to groundwater contamination. Existing water quality impacts are related to agricultural practices and rural (e.g., septic) land use. Coyote Valley has a high potential for future residential and commercial development.

Groundwater in the Llagas Subbasin occurs under unconfined to confined conditions. Generally unconfined recharge areas are found in the northern portion of the subbasin, while confining layers become more frequent and laterally and vertically extensive in the southern areas. Accordingly, the northern portion of the subbasin is relatively more hydrogeologically sensitive to groundwater contamination compared with the southern subbasin. The Llagas Subbasin has urban development focused in the north and south with the central portion of the subbasin comprised predominantly of agricultural development and large residential parcels. The Llagas Subbasin is currently impacted by high levels of nitrate associated with rural land use and agriculture and perchlorate from historic releases from a flare manufacturer.

A comprehensive literature review was conducted to identify established methods to conduct vulnerability assessments. Based on the evaluation of available groundwater sensitivity assessment methods and an understanding of available hydrogeologic and water quality information for the Study Area, a statistical method was selected to quantify the sensitivity to contamination of the Shallow Aquifer and Principal Aquifer. Water quality data (i.e., nitrate concentrations and distribution) were used for calibration and verification purposes to identify and rank groundwater sensitivity factors. Based on the logistic regression statistical analysis, four factors were found to be the most important in characterizing groundwater sensitivity. These include 1) soil media characteristics in the vadose zone, 2) groundwater recharge, 3) depth to top of screen, and 4) annual groundwater production. Groundwater recharge in the Study Area includes a significant amount of artificial recharge conducted by the District. Traditionally, artificial recharge and groundwater production would not be considered intrinsic aquifer characteristics. However, for this Study, groundwater sensitivity did include consideration of quasi-intrinsic characteristics such as artificial recharge and production.

In addition to the objective statistical analysis, subjective refinements relative to artificial recharge areas and characterization of depth to water/aquifer were applied based on observation, technical judgment, and limitations in the nitrate data set. These refinements included subjectively ranking areas near artificial recharge areas as highly sensitive and using depth to first encountered groundwater to represent the depth to water factor for the Principal Aquifer in the recharge zones. This results in higher sensitivity in the recharge areas for the Principal Aquifer.

Figures ES-1 and ES-2 show the sensitivity of the Shallow and Principal aquifers, respectively. Not surprisingly, the sensitivity assessment found that the Shallow Aquifer is more sensitive than the Principal Aquifer. In addition, the analysis indicates that the sensitivity of the Shallow and Principal aquifers is generally highest in the Llagas Subbasin, followed by the Coyote Subbasin, and Santa Clara Subbasin. Despite the protection afforded by the regional confining layer in the southern portion of the Llagas Subbasin, both the Shallow and Principal aquifers are highly sensitive to contamination due to high recharge rates and permeable soils. The sensitivity of the Shallow and Principal aquifers in the Coyote Subbasin are also relatively high due primarily to shallow aquifer conditions, high recharge rates, and large amounts of groundwater production. Although the confined zone in the Santa Clara Subbasin affords relatively good protection from surface contamination, the outer western confined zone appears to be highly sensitive to contamination due to the significant groundwater production in this area.

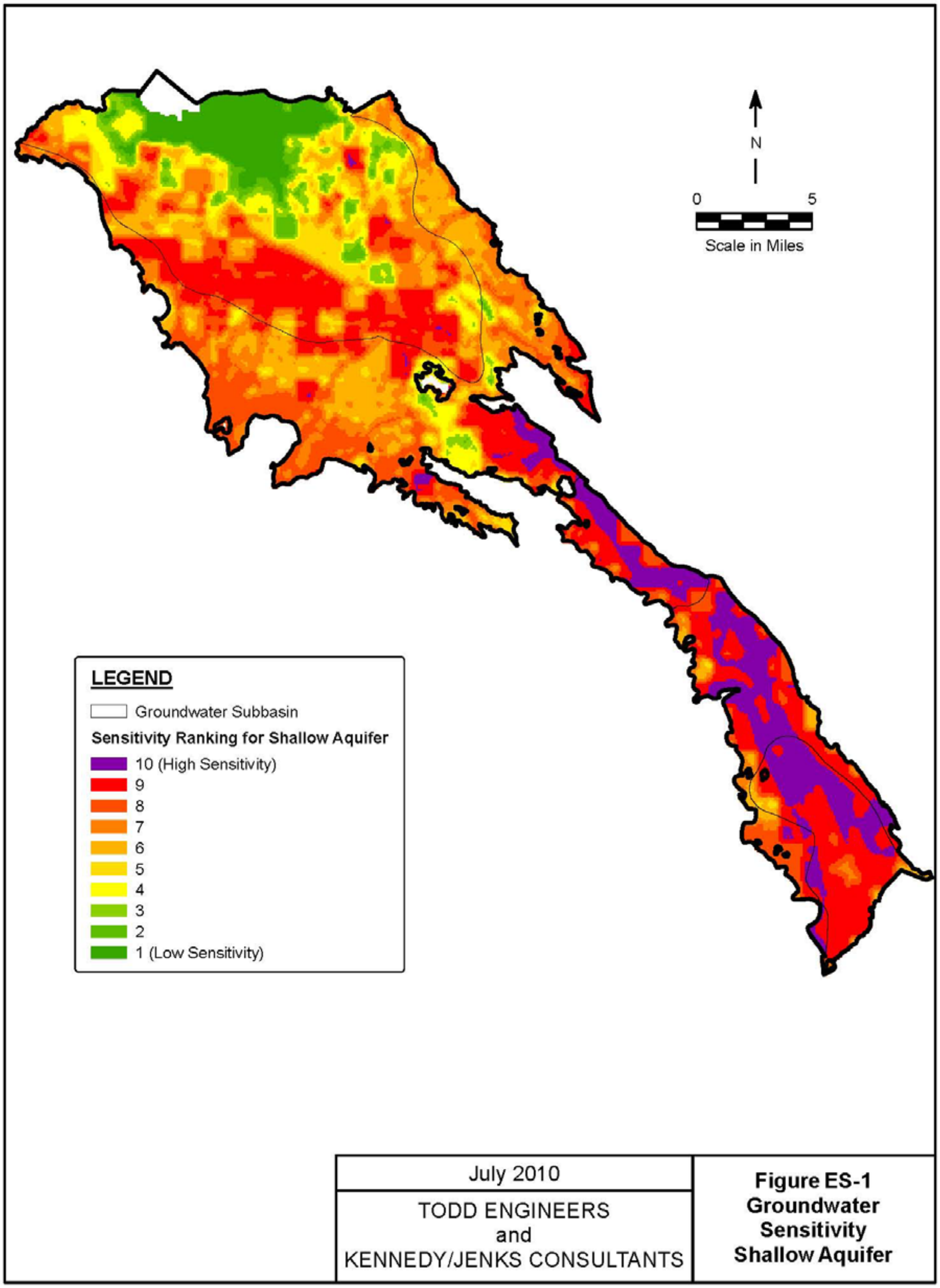
Unlike the sensitivity assessment, it is not possible to statistically calibrate potentially contaminating activities risk. Accordingly, potentially contaminating activities are commonly identified and ranked based on subjective observation and experience (e.g., California Drinking Water Source Assessment and Protection Program). For the potentially contaminating activities risk ranking, emphasis was placed on accurately characterizing the maximum risks so as not to underestimate potential risks. The potentially contaminating activities risk analysis included four main risk factors or categories—general plan land use, potentially contaminating business activities, known contaminated sites, and supplemental data. Twenty-nine land use categories were selected and ranked with respect to groundwater impacts. Relative risk ranks were developed for 48 categories of business activities. Known and open contamination sites were given the highest ranking with a lower ranking for closed sites. Additional supplemental data for irrigated agriculture, septic system density, mines, landfills, and petroleum pipelines were also ranked and included in the analysis. These various risk factors were combined to generate the overall potentially contaminating activities risk distribution map.

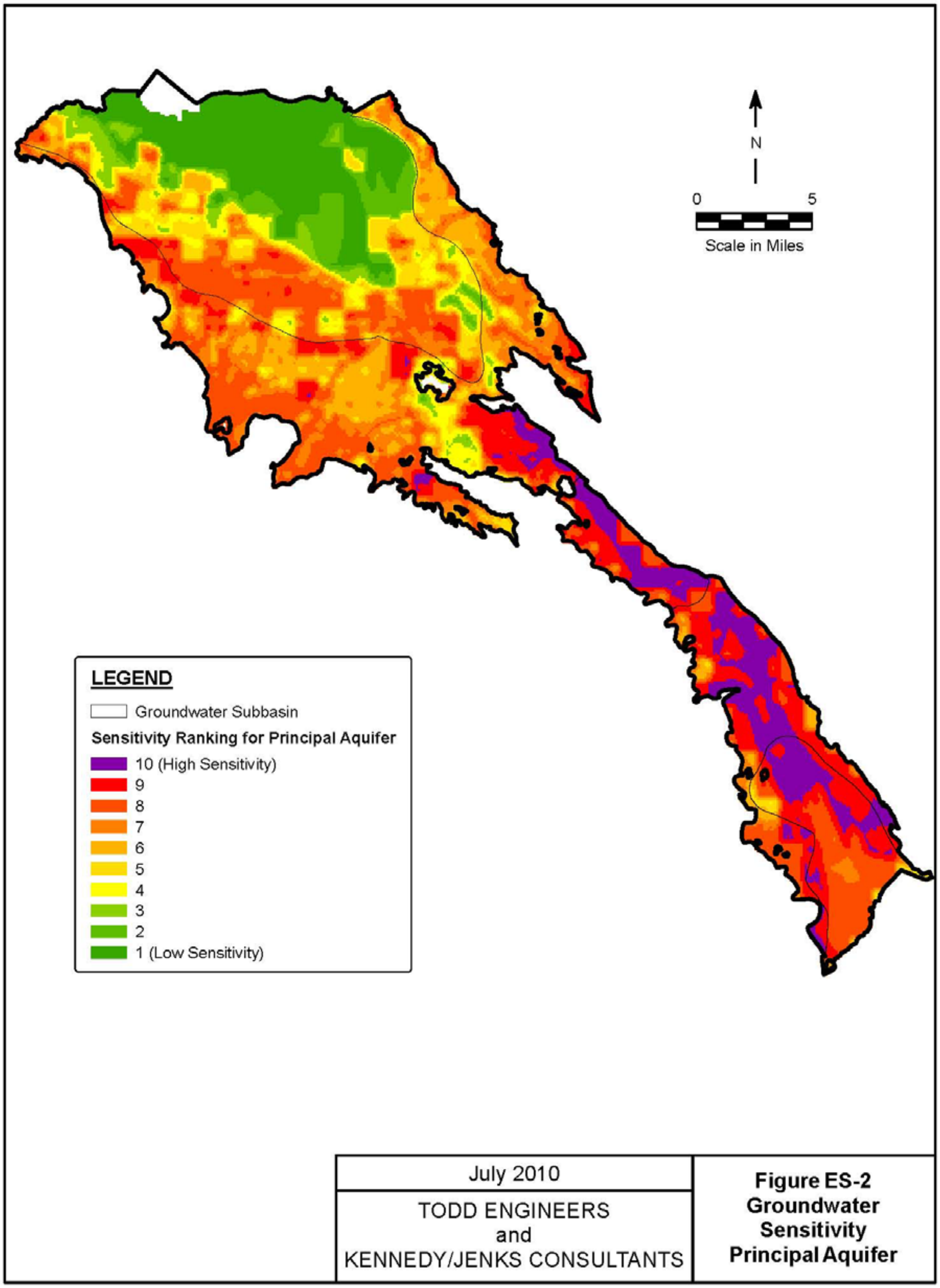
The potentially contaminating activities risk analysis found large portions of the Santa Clara Subbasin are at high risk due to its high level of development with commercial and industrial areas and many associated industrial and commercial contaminant release sites along with the lingering impacts of agricultural releases. Relatively lower overall risks are associated with the Coyote Subbasin, which is relatively rural, undeveloped, and mostly unincorporated with far fewer industrial/commercial contaminant release sites. Nonetheless, most of the subbasin shows a moderate level of risk associated with irrigated agriculture. It is important to note that the Coyote Valley has the most potential for future development and thus the most potential for an increase in risk in the future. Relatively lower overall potentially contaminating activities risk (compared with the Santa Clara Subbasin) is found in the Llagas Subbasin due to its more rural nature. Areas of relatively higher risk are associated with commercial and industrial development in the vicinity of the cities of Morgan Hill and Gilroy. Moderate risk is found in the central portion of the subbasin associated with irrigated agriculture. While continued conversion of rural to urban land use in the vicinity of the cities of Morgan Hill and Gilroy in the future will likely increase risk in these areas, the central portion of the subbasin is expected to remain relatively unchanged with respect to risk, given the established zoning.

The sensitivity assessment and potentially contaminating activities risk were combined to create the overall vulnerability maps for the Shallow and Principal aquifers. Figures ES-3 and ES-4 show the vulnerability of the Shallow and Principal aquifers, respectively. As might be expected, the vulnerability of the Shallow Aquifer is greater than the Principal Aquifer in areas of confinement in the Santa Clara Subbasin. The density of commercial/industrial sites and known contamination release sites in the northern Santa Clara Subbasin make the Shallow Aquifer highly vulnerable to contamination. The Principal Aquifer has fewer areas of very high vulnerability compared with the Shallow Aquifer due to the relative lower sensitivity of the Principal Aquifer.

The Llagas and Coyote subbasins exhibit high to very high groundwater vulnerability in both the Shallow and Principal aquifers. The high vulnerability is driven primarily by the high sensitivity in these two subbasins. Given the potential for future development in the Coyote Subbasin, the high degree of vulnerability of the subbasin requires the highest level of effort directed toward protection.

Following completion of the vulnerability assessment, a web-based geographical information system tool was developed, which incorporated the sensitivity, potentially contaminating activities risk, and vulnerability maps. Additional maps are also provided to enhance the usefulness of the tool. The tool enables District staff to work interactively with the vulnerability study analysis. The tool enables District staff to evaluate potential impacts of land use changes, prioritize basin management activities, prioritize review of known contamination sites, update existing data layers, update or modify risk factors, and add supplemental data layers.


N
0
5
Scale in Miles
LEGEND
Groundwater Subbasin
Sensitivity Ranking for Shallow Aquifer
10 (High Sensitivity)
9
8
7
6
5
4
3
2
1 (Low Sensitivity)
July 2010
TODD ENGINEERS
and
KENNEDY/JENKS CONSULTANTS
Figure ES-1
Groundwater
Sensitivity
Shallow Aquifer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Groundwater Subbasin
Sensitivity Ranking for Principal Aquifer
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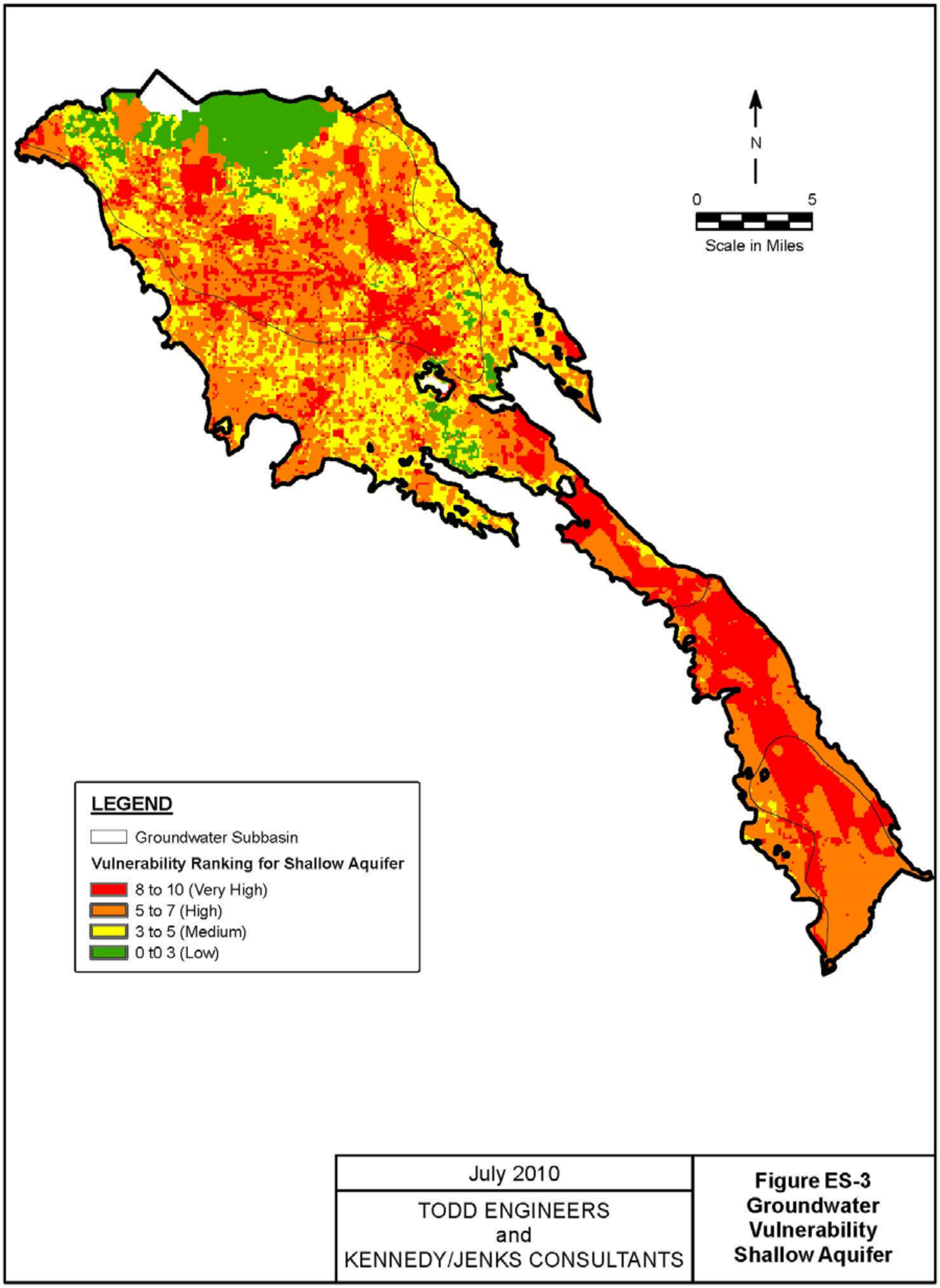
Figure ES-2
Groundwater
Sensitivity
Principal Aquifer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Scale in Miles
LEGEND
Groundwater Subbasin
Vulnerability Ranking for Shallow Aquifer
8 to 10 (Very High)
5 to 7 (High)
3 to 5 (Medium)
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Figure ES-3
Groundwater
Vulnerability
Shallow Aquifer

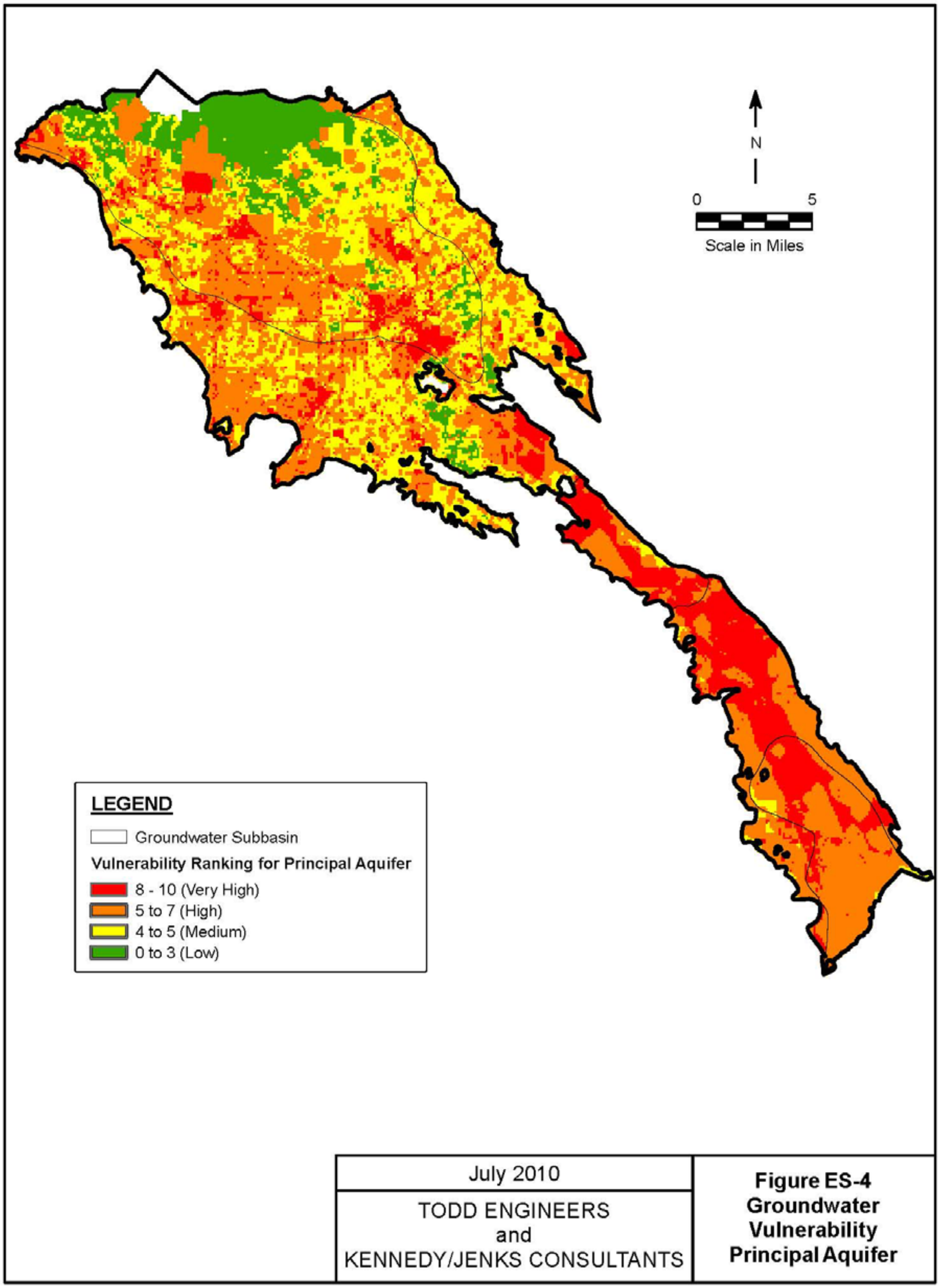

Figure ES-4
Groundwater Vulnerability Principal Aquifer

1 Introduction

1.1 Background

The Santa Clara Valley Water District (District) is the primary water resources agency in Santa Clara County (County). Since 1929, the District has been responsible for water supply, flood protection, and watershed management across Santa Clara County's 1,300 square mile area. Groundwater in the County is found primarily in three groundwater subbasins including the Santa Clara, Coyote, and Llagas. In a typical year, groundwater accounts for 40 to 50 percent of the water used in the County.

The District's groundwater management objectives are to recharge the groundwater basin, conserve water, increase water supply, and prevent waste and diminution of the District's water supply with the end goal of ensuring that water resources are sustained and protected.

Protection of groundwater from contamination is an important component of ensuring a reliable water supply for Santa Clara County. Over the past 20 years the District, in cooperation with other research and governmental agencies, has managed numerous investigations and developed comprehensive groundwater monitoring and protection programs.

This Groundwater Vulnerability Study (Study) was conducted for the District in order to predict sensitivity and vulnerability of groundwater to contaminating land use conditions and practices using existing groundwater quality, hydrogeologic, and land use data to aid the District in its management and protection activities. *Groundwater sensitivity* is defined as the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest. Traditionally, it has been characterized based on the intrinsic characteristics of the aquifer and the overlying unsaturated materials. For this Study groundwater management activities that modify these intrinsic characteristics have also been included for consideration in the groundwater sensitivity analysis. Groundwater management activities considered include pumping and artificial recharge. Groundwater sensitivity is not dependent on land use and contaminant characteristics. On the other hand, *groundwater vulnerability* is defined as the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest under a given set of land use management practices, contaminant characteristics, and groundwater sensitivity conditions (USEPA, 1993). Groundwater may be highly sensitive to contamination, but the characterization of contaminant sources is needed to determine its vulnerability to contamination.

This Study is designed to produce a technically-sound and scientifically-defensible vulnerability map of the Study Area along with a user-friendly Geographical Information System (GIS) tool, which will allow the District to better focus groundwater management programs. The tool will also allow the District to readily assess potential groundwater quality impacts from future changes in land use.

1.1 Vulnerability Overview

As described above, groundwater vulnerability is defined by the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest under a given set of land use management practices. These components are combined to characterize the overall vulnerability of the aquifer. Accordingly, this report describes the current and historic land use and hydrogeologic conditions in the Study Area. The methodology, rationale, validation, and results of the sensitivity, potentially contaminating activities (PCA) risk, and vulnerability analyses are presented. The groundwater vulnerability tool is briefly described including recommendations for maintenance. Data gaps are identified and conclusions and recommendations are provided.

1.2 Purpose and Objectives

The District commissioned this Groundwater Vulnerability Study to improve its ability to:

- Prioritize groundwater protection efforts and focus resources on the most vulnerable areas of the county;
- Provide information on groundwater vulnerability to decision makers at the District, land use agencies, and regulatory agencies to improve groundwater protection activities;
- Evaluate potential groundwater impacts from proposed development projects or changes in permit requirements for existing sites; and
- Provide a basis for development of guidelines and Best Management Practices to protect groundwater.

In keeping with the District's goals, Todd Engineers and Kennedy/Jenks Consultants conducted this Study with the following goals:

- Develop a technically-sound and scientifically-defensible groundwater sensitivity and vulnerability methodology approach, which will reliably predict groundwater vulnerability;
- Characterize the groundwater vulnerability based on the most current, comprehensive, and reliable data available;
- Generate sensitivity, potentially contaminating activity risk, and vulnerability maps;
- Prepare a regional scale, screening-level GIS based tool, which allows the District to easily and quickly access the Study data and utilize the tool to direct and inform groundwater management and protection activities. The tool may also potentially be used by land use planners and the District to assess water quality impacts associated with land use changes.
- Prepare a project report that clearly justifies and documents the methodology, findings, conclusions, and recommendations.

1.3 Acknowledgements

This Study was conducted by staff from Todd Engineers and Kennedy/Jenks Consultants. Dr. Dennis Helsel of Practical Stats provided statistical expertise in development of the

sensitivity methodology. District staff provided invaluable support in providing a significant portion of the data relied on in the Study as well as review of project reports. Many other agencies generously provided their time and data including: the California Department of Public Health, the San Francisco Regional Water Quality Control Board, State Water Resources Control Board, the Santa Clara County Department of Public Health, Lawrence Livermore National Laboratory, University of California (Davis) Information Center for the Environment, and the cities of Campbell, Cupertino, Los Gatos, Milpitas, Morgan Hill, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, and Sunnyvale.

1.4 Report Contents

Section 1 provides the Study background, goals, and acknowledgements. Section 2 describes the Study Area current and historic land use. Section 3 summarizes the Study Area hydrogeologic conditions. Section 4 summarizes water quality conditions. Section 5 presents the sensitivity analysis approach and findings. Section 6 presents the PCA risk analysis approach and findings. Section 7 presents the vulnerability approach and findings. Section 8 discusses the vulnerability tool. Section 9 describes additional data that were not included in development of the vulnerability map, but that the District may find useful when implementing the tool. Section 10 identifies data gaps. Sections 11and 12 summarize conclusions and recommendations, respectively. Section 13 lists all references reviewed for the Study.

Appendix A includes the preliminary Evaluation of Assessment Methodologies report for the Vulnerability Study, which evaluated applicable methodologies presented in the literature and proposed the general approach used for this Study. The draft report was provided to the District for review in October 2008. The District's comments were addressed and incorporated into the report provided in Appendix A.

Appendix B includes the Literature and Data Review Summary report for the Vulnerability Study, which describes the data sources reviewed and summarizes the review findings. The draft report was provided to the District in December 2008. The District's comments were addressed and incorporated into the report provided in Appendix B. This report provides the basis for many of the sections included herein. The references reviewed section to the Literature and Data Review Summary report is identical to Section 12 of this report and is therefore not included in Appendix B.

Appendix C presents the logistic regression analysis model outputs used for the sensitivity analysis.

2 Current and Historic Land Use

An understanding of both current and historic land use in the Study Area is important in assessing potential contaminating activities. The Study Area is comprised of three groundwater subbasins: the Santa Clara, the Coyote, and the Llagas as shown in Figure 2-1. Each has unique current and historic land uses as discussed below. The cities and major roads in the Study Area are illustrated in Figure 2-2.

2.1 Santa Clara Subbasin

Land use in the Santa Clara Subbasin has changed dramatically over the last 60 years, from a largely rural, agricultural area to a highly developed urban area. Prior to the 1900s, most land in the Santa Clara Valley was used for grazing cattle and dry-land farming. In the early 1900s, agriculture was the chief economic activity. The release of nitrate associated with historic agricultural and rural (e.g., septic) land use is a continuing groundwater concern in the subbasin. As in most coastal basins in California, urbanization since the late 1940s resulted in the transfer of agricultural lands to residential and commercial uses. Groundwater level declines of more than 200 feet and land subsidence occurred from groundwater development from the early 1900s to the mid-1960s (Poland and Ireland, 1988). Groundwater levels in the Santa Clara Subbasin have been recovering since the mid-1960s as a result of better resource management, conservation, imported water, and artificial recharge. Water use has also changed from predominantly agricultural prior to the 1960s to almost completely urban and industrial water use since the mid-1960s. The valley is currently undergoing continued urban expansion and redevelopment of formerly industrial areas to residential use. The Santa Clara Subbasin is currently highly developed with residential, commercial, and industrial areas and many associated industrial and commercial contaminant release sites along with the lingering impacts of agricultural releases.

2.2 Coyote Subbasin

Compared with the Santa Clara Subbasin, the Coyote Subbasin is relatively rural, undeveloped, and mostly unincorporated with far fewer industrial/commercial contaminant release sites. Coyote Valley has the most potential for future residential and commercial development. The Coyote Valley Specific Plan calls for a total of at least 26,400 residential units and 55,000 new jobs to be developed in Coyote Valley utilizing forecasted water demand of 18,500 acre-feet per year (AFY). Future development of the Coyote Valley is presented in the City of San Jose’s 2020 General Plan, which defines three distinct land use designations: the North Coyote Campus Industrial Area encompassing 1,444 acres in the northern portion of the valley; the Coyote Valley Urban Reserve encompassing 2,072 acres in the central portion of the valley; and the Coyote Valley Greenbelt encompassing 3,621 acres in the southern portion of the valley (City of San Jose, March 2007). Existing water quality impacts in the subbasin are related to agricultural practices and rural (e.g., septic) land use. Due to unconfined groundwater conditions, shallow depth to groundwater, and high permeability in the subbasin, it is highly vulnerable to contaminant releases at the ground surface. Future development in the subbasin will need to consider this vulnerability if groundwater resources are to be protected.

2.3 Llagas Subbasin

Residential and commercial development in the Llagas Subbasin is focused in the City of Morgan Hill in the north and the City of Gilroy in the south where water is supplied through large municipal wells and wastewater is handled at a municipal wastewater treatment facility. In contrast, the central portion of the subbasin in the vicinity of San Martin is comprised predominantly of agricultural development and large (five to ten acre) residential parcels relying on individual wells and onsite septic systems. Based on the Santa Clara County 1995 General Plan, the Llagas Subbasin was 40 percent agricultural, 25 percent urban, 20 percent rural, 10 percent mixed use, and 5 percent open space. There has been an ongoing conversion of agricultural land to urban use in the subbasin over the past 30 years (LLNL, July 2005; CH2M HILL, May 2005).

Due to unconfined conditions and high permeability in some areas, portions of the subbasin are highly vulnerable to contaminant releases at the ground surface. The subbasin is currently impacted by high levels of nitrate associated with rural land use and agriculture and perchlorate from historic releases from a flare manufacturer.

3 Hydrogeology

Similar to the situation with land use and development, each of the three subbasins in the Study Area also has unique hydrogeology. The subbasin boundaries and the areas of confined and unconfined conditions are shown in Figure 2-1. The hydrogeology of each subbasin is summarized below and presented in more detail in Appendix B.

Where confining conditions exist in the Study Area, both shallow and deep groundwater systems exist. These are referred to as that Shallow and Principal aquifer zones, respectively. The Principal Aquifer comprises the groundwater primarily utilized for supply. The Shallow Aquifer is not currently utilized for water supply; however, the District has recently evaluated whether this zone can be utilized for beneficial uses. Accordingly, the vulnerability of each zone was assessed separately.

3.1 Santa Clara Subbasin

The South Bay Area of Santa Clara Valley Groundwater Basin is identified as Basin No. 2-9.02 by DWR (2004) and includes both the Santa Clara and Coyote subbasins. Located in the northern portion of Santa Clara County, the Santa Clara Subbasin covers 225 square miles and extends from the County's northern boundary to the Coyote Narrows at Metcalf Road to the south (Figures 2-1 and 2-2). The subbasin is approximately 22 miles long and ranges from about 15 miles in width in the north to about one-half mile at the Coyote Narrows, where the two mountain ranges nearly converge (Fostersmith et al., 2005). In general, coarser-grained sediments occur in the upper alluvial fan areas along the lateral edges of the subbasin, while thick silt/clay units inter-bedded with thin sand/gravel units are found towards the interior of the subbasin. Basin fill deposits range in thickness from about 150 feet near the Coyote Narrows to greater than 1,500 feet in the interior of the subbasin (Iwamura, 1995).

Both confined and unconfined conditions exist in the Santa Clara Subbasin as shown in Figure 2-1. The southern area and lateral margins of the Santa Clara Subbasin are unconfined areas or recharge areas. An extensive regional aquitard occurs within the northern areas of the subbasin with depths to the top of the unit ranging from 75 feet near the recharge area to 160 feet in the northern interior portion of the subbasin (CH2M Hill, July 1992). The principal water supply aquifers are mainly located under confining layers (Principal Aquifer). Shallow groundwater occurs above confining layers in some areas (Shallow Aquifer), and the District is currently evaluating potential beneficial uses for this historically under-used resource.

Groundwater in the Santa Clara Subbasin typically flows in the general direction of ground surface topography, towards the interior of the subbasin and northerly towards San Francisco Bay. Except during periods of extended drought and significantly lowered water levels in the Principal Aquifer, the vertical gradient in the confined part of the subbasin is upward (see Figure 3-1). The vertical gradient in the recharge areas is downward. Groundwater levels in the Shallow Aquifer range from less than 10 feet below ground surface (ft-bgs) in the central and southern portions of the subbasin to greater than 100 ft-bgs along the lateral edges of the subbasin (Pierno, 1999).

Drinking water supply in the subbasin is provided by groundwater, and treated local and imported water. Production wells in the subbasin range in depth from 200 to 1,200 feet with yields ranging from 300 to 2,500 gallons per minute (gpm). Hydraulic conductivities in the Principal Aquifer typically range from about 10 to 500 feet per day. Based on age dating data, LLNL (Moran et al., 2004) provided a rough estimate of groundwater velocities in the subbasin. A rate of 1.4 feet per day was estimated in the Principal Aquifer; although, it was noted that flow rates are likely to be highly variable over short distances, and the groundwater flow velocity is likely to be highest in the Shallow Aquifer and may be significantly higher than 1.4 feet per day in the shallow sediments of the recharge area.

The valley is drained to the north by tributaries to San Francisco Bay, including Coyote Creek, the Guadalupe River, and Los Gatos Creek. Sources of recharge include deep percolation of precipitation, leakage from uncontrolled streams, subsurface inflow from surrounding hills and the Coyote Subbasin, and recharge operations managed by the District in specific areas that are hydraulically connected to the Principal Aquifer. The District operates a variety of manmade mechanisms including in-stream and off-stream recharge facilities to actively recharge both local and imported water. The District operates a complex network of facilities to supply, treat, and distribute water to their customers. A total of 18 major manmade recharge systems exist (primarily along the Los Gatos Creek, Guadalupe River and Coyote Creek drainages). The off-stream facilities are comprised of 15 percolation pond systems. Based on data collected between 1994 and 2006 and provided by the District, an average of approximately 80,000 AFY of water was recharged to the Santa Clara Subbasin through artificial recharge; this included 43,000 AFY through off-stream ponds and 37,000 AFY through the in-stream recharge program.

3.2 Coyote Subbasin

The Coyote Subbasin is identified by DWR (2004) as part of the South Bay Area (Basin No. 2-9.02) of the Santa Clara Valley Groundwater Basin. The Coyote Subbasin extends from the Coyote Narrows in the north, where it borders the Santa Clara Subbasin, to Cochrane Road in the south where it borders the Llagas Subbasin. The surface area of Coyote Subbasin is approximately 15 square miles, or about 10,000 acres. The principal water bearing formations in the Coyote Subbasin are alluvial deposits of unconsolidated and semi-consolidated sediments. The alluvial deposits in the Coyote Subbasin range in thickness from about 500 feet in the south to 150 feet in the north near the Coyote Narrows (Iwamura, 1995).

Unlike portions of the Santa Clara and Llagas subbasins, no significant laterally extensive clay layers exist in the Coyote Subbasin, and groundwater occurs under unconfined conditions throughout the basin. Although, perched groundwater occurs in the northwest end of the subbasin as a result of shallow, discontinuous clay deposits. The perched groundwater tends to impact low-lying areas, including the Coyote Recharge Ponds just north of the Coyote Subbasin (City of San Jose, January 2007).

The direction of groundwater flow through Coyote Subbasin is north to northwest towards the Coyote Narrows, where groundwater exits the basin and enters the Santa Clara Subbasin (Fostersmith et al., 2005). To the south, the Coyote Subbasin extends to about Cochrane Road, where it meets the Llagas Subbasin at a boundary defined by a groundwater divide. Depth to groundwater ranges from about 75 feet in the south to less than 5 feet in the north near the Coyote Narrows and is commonly less than 20 feet throughout the subbasin (Pierno, 1999).

Groundwater is the sole source of drinking water supply in the subbasin. Groundwater production in the Coyote Subbasin is primarily from domestic and agricultural wells. Although, the installation and operation of several large retailer wells has resulted in a significant increase in groundwater pumping over the past several years. Hydraulic conductivities in the subbasin range from about 5 to 570 feet per day (McCloskey and Finnemore, December 1996). Using a hydraulic gradient of 0.002 (Fostersmith, et al, January 2005), a hydraulic conductivity of 100 ft/d, and an effective porosity of 0.08 (DWR, May 1981; Abuye, November 2005) yields a groundwater velocity of 2.5 ft/d.

Coyote Valley is drained to the north by two tributaries to San Francisco Bay – Coyote Creek and Fisher Creek. Coyote Creek flows most of the length of the Coyote Subbasin along its eastern side. Coyote Creek is downstream of and benefits from controlled releases from the Anderson and Coyote reservoirs, which are situated east of the subbasin in the Diablo Range. Lower Coyote Creek recharges an average of about 3,400 AFY (1994 to 2006). Coyote Creek is a losing stream throughout the year, whereby surface water percolates through the stream bed and recharges local groundwater. Fisher Creek flows north along the western portion of the Coyote Subbasin. Fisher Creek is a variably gaining and losing stream. During conditions of high groundwater, Fisher Creek receives groundwater discharge from much of the Coyote Valley floor. Fisher Creek joins Coyote Creek near Coyote Narrows, where it exits the Coyote Subbasin (Fostersmith et al., 2005).

3.3 Llagas Subbasin

The Llagas Subbasin extends from the groundwater divide at about Cochrane Road, near Morgan Hill, to the north to the Pajaro River (the Santa Clara-San Benito County line) to the south. The Llagas Subbasin is approximately 15 miles long, three miles wide along its northern boundary, and six miles wide along the Pajaro River. DWR (2004) identifies the Llagas Subbasin as part of the Gilroy-Hollister Groundwater Basin (Basin No. 3-3). The thickness of alluvial fill and the underlying Santa Clara Formation varies from about 500 feet at the northern groundwater divide to about 1,800 feet at its south end.

The water-bearing sediments that make up the Llagas Subbasin occur in discontinuous and heterogeneous lenses that do not form well-defined laterally continuous layers. The paleochannels deposited by the ancestral Coyote Creek are thicker and more coarse-grained along the axis of the subbasin east of Highway 101 and provide preferential pathways for groundwater flow. Groundwater in most of the Llagas Subbasin occurs under unconfined to semi-confined conditions. Due to the lenticular and discontinuous distribution of fine- and coarse-grained materials, local areas of confinement occur throughout the subbasin. Toward the south end of the subbasin, confining layers become more frequent and laterally and vertically extensive. Thus in the vicinity of the Pajaro River the aquifer system is mostly confined (DWR, 1981).

Under natural conditions, groundwater in the Llagas Subbasin moves from the boundary with the Coyote Subbasin in the north to the southeast toward the Pajaro River, roughly in the same direction as the surface water drainage. Groundwater is thought to flow south beneath the Pajaro River toward pumping depressions in the Bolsa Subbasin (Yates, December, 2002). Depth to groundwater in an index well in the subbasin has varied from approximately 10 to over 100 feet over the period of record (1969 to 2003) (Reymers and Hemmeter, July 2002 and January 2005; Fostersmith et al., January 2005).

Groundwater is the sole source of drinking water supply in the subbasin. Large municipal wells are located in the vicinity of Morgan Hill and Gilroy, while numerous smaller domestic and agricultural wells are located throughout the remainder of the basin. Well yields are also reportedly lower in production wells in the northern portion of the subbasin compared with the southern portion of the subbasin. Yields from Morgan Hill production wells range from about 200 to 1,500 gpm, whereas yields from Gilroy production wells range from about 1,200 to 3,000 gpm (Fugro, February 2004). Well yields are higher along the axis of the subbasin where saturated thicknesses are greater (Fugro, February 2004). Hydraulic conductivities range from less than 10 to about 460 feet per day. The average groundwater velocity is about 3 feet per day.

The Llagas Subbasin is drained to the south by tributaries of the Pajaro River, including the Uvas and Llagas creeks. Principal sources of recharge to the Llagas Subbasin include deep infiltrating precipitation, natural and artificial recharge through Uvas and Llagas creeks, recharge ponds, and irrigation return flows. A number of artificial recharge facilities have been constructed and are operated by the District to enhance recharge in the subbasin and augment local supplies. Both local water from the Anderson/Coyote, Uvas, and Chesbro reservoirs along with imported water are recharged in the subbasin. The average artificial recharge is 21,000 AFY (1998 to 2008).

4 Water Quality

Groundwater quality is controlled by natural interactions between rock minerals and water infiltrating into the subsurface. Naturally occurring contaminants are present in rocks and sediments, and when dissolved may be found in high concentrations in groundwater. Anthropogenic (man-made) chemicals released into the environment, including fertilizers, industrial solvents, fuel-related products, and others may also affect groundwater quality. Contaminants from point sources like leaking fuel tanks or toxic chemical spills may enter the groundwater and contaminate the aquifer forming distinct plumes. Chemical releases associated with pesticides and fertilizers applied to lawns and crops and septic systems represent non-point sources that can accumulate and migrate to the water table resulting in widespread detections.

The District Board Ends Policy directs staff to ensure that the groundwater subbasins are aggressively protected from contamination and the threat of contamination. In cooperation with local water retailers and cities, the California Regional Water Quality Control Boards, and other agencies, the District has implemented numerous groundwater quality protection programs to monitor groundwater quality and address specific issues, including those related to nitrate, saltwater intrusion, well construction and destruction, wellhead protection, leaking underground storage tank (LUST) systems, spills and releases of solvents and other toxic chemicals, and land use and impacts of development. Together, these activities help the District identify existing and potential groundwater quality issues and prevent and mitigate groundwater contamination.

This section summarizes water quality monitoring programs in the Study Area and the general water quality in each subbasin. District and other water quality management, protection, and oversight programs are described in Appendix B.

4.1 Groundwater Monitoring

One goal of the District is to ensure that overall water quality objectives are met for all beneficial uses (including municipal, domestic, agricultural, industrial service, and industrial process water supply uses) as designated by the Regional Water Quality Control Boards. Through its General Groundwater Quality Monitoring Program, the District monitors groundwater quality across each of the three subbasins to assess current conditions, evaluate trends, and identify areas of concern. The monitoring program also provides an indication of the effectiveness of various groundwater protection programs implemented by the District and others.

The District monitors groundwater quality in a number of wells in the Santa Clara, Coyote, and Llagas subbasins. Most of the monitoring wells are screened in the deeper Principal Aquifer (i.e., the zone tapped by water supply wells), with a smaller number of the wells having a top of screen depth less than 100 ft-bgs. As such, the monitoring well network is not designed to track shallow groundwater contamination in the Shallow Aquifer (i.e., the zone above confining layers) associated with chemical releases from regulated environmental facilities, which are overseen by other agencies including the Regional Water Quality Control Boards (San Francisco and Central Coast), California Department of Toxic Substances Control (DTSC), Santa Clara County Department of

Environmental Health (DEH), and U.S. Environmental Protection Agency (USEPA). The roles of each of these agencies are described in Appendix B.

District monitoring program wells are analyzed for major and minor ions, nitrate, general physical parameters, disinfection by-products (DBPs), radiological constituents, volatile organic chemicals (VOCs) and synthetic (non-volatile) organic chemicals (SOCs). Included in the monitoring program are eight nested monitoring wells installed as part of a cooperative study between the U.S. Geological Survey (USGS) and the District at strategic locations in the Santa Clara Subbasin. The nested wells were completed to a maximum depth of 1,000 feet at seven sites and 1,300 feet at one site allowing for depth-discrete water quality sampling. The District also monitors several well pairs in the Llagas Subbasin.

In addition to its regular monitoring program, the District has conducted special water quality studies, one of which was an extensive well testing program for nitrate in the Llagas Subbasin. In 1988 and 1998, the District sampled over 450 and 600 private domestic wells for nitrate, respectively. Since 1998, the District has offered a free nitrate analysis to all private water supply well users. More than half of the 600 wells tested have exceeded the maximum contaminant level (MCL) for nitrate.

The District's water quality monitoring program is supplemented with groundwater quality data received from the California Department of Public Health (DPH) for approximately 300 public water supply wells submitted by water retailers to comply with their Title 22 requirements.

The California State Water Resources Control Board (SWRCB) sponsors the Ambient Groundwater Monitoring and Assessment (GAMA) Program, which has collected water quality data in Santa Clara County and across the state. The GAMA Program aims to assess water quality and to predict relative susceptibility of groundwater resources to contamination throughout the state of California. The USGS and the Lawrence Berkeley National Laboratory (LLNL) have conducted three GAMA Program studies in Santa Clara County. Parameters analyzed for in these studies include ultra low-level VOCs, groundwater age, major anions and cations, nitrogen and oxygen isotopes of nitrate, dissolved excess nitrogen, tritium, pesticides, pharmaceutical compounds, wastewater indicators, perchlorate, N-nitrosodimethylamine, radioactive constituents, naturally occurring isotopes, and dissolved gases.

The California Regional Water Quality Control Board, Central Coast Region (CRWQCB) provides regulatory oversight of the Olin/Standard Fusee (Olin) contaminant release site in the Llagas Subbasin. The District works with the CRWQCB through their stakeholder process.

Water quality data (collected through 2007), obtained from the District, DPH, GAMA Program, and Olin (data that was publically available), were incorporated into a single Microsoft Access™ database for this Study. A summary of available general water quality data is provided in Table 4-1.

The SWRCB tracks regulatory data about LUST sites; Spills, Leaks, Investigations, and Cleanup (SLIC) sites; Department of Defense (DoD) sites; and landfills. In September 2004, the SWRCB adopted regulations requiring electronic submittal of information for groundwater cleanup programs. For several years, parties responsible for cleanup of leaks from underground storage tanks have been required to submit groundwater analytical data, surveyed locations of monitoring wells, and other data to the GeoTracker database over the Internet. As of January 1, 2005, electronic submittal of information has been required by all groundwater cleanup programs including LUST, SLIC, DoD, and Land Disposal programs. Analytical data collected for each of the regulated sites in Santa Clara County were obtained electronically from the SWRCB in Microsoft Access™ format for this Study. The database includes nearly 1.5 million analytical results for 7,864 monitoring locations. Analytical data include monitoring well samples, borehole samples, gas and vapor samples, groundwater grab samples, piezometer samples, stockpile samples and, samples from drinking water wells. In addition to the analytical database, the SWRCB has recently added a tool that allows for easy screening of regulated sites for methyl tert-butyl ether (MtBE) above a user-defined concentration. Search results can be downloaded electronically in Microsoft Excel™ format.

The sections below summarize the water quality conditions in each of the three groundwater subbasins in the Study Area. More detailed discussion is provided in Appendix B.

4.2 Santa Clara Subbasin

With the high density of urban land uses in the Santa Clara Subbasin (including major industrial manufacturing and processing facilities), point-source contamination is prevalent but generally contained in the Shallow Aquifer (Judd, 2001; SCVWD, December 2005). This is due to the protection offered by the significant confining layers found in the northern portion of the subbasin, and by District and other agency protection programs.

4.2.1 General Water Quality

Groundwater quality in the Santa Clara Subbasin is generally good with drinking water standards met at public water supply wells without the use of treatment methods. High mineral salt concentrations have been identified in the Shallow Aquifer (less than 100 feet deep) of the baylands adjacent to the southern San Francisco Bay (Fostersmith, et al, January 2005). Saltwater intrusion within the Shallow Aquifer is primarily attributed to historic pumping and land subsidence resulting in an inland groundwater flow direction. Saltwater intrusion has also been observed along the Guadalupe River and Coyote Creek, where saltwater (moving upstream during high tides) infiltrates into the Shallow Aquifer when this zone is pumped (Reymers and Hemmeter, July 2002).

4.2.2 Nitrate

Figure 4-1 shows the maximum nitrate concentrations detected in groundwater in the three groundwater subbasins. Typical nitrate concentrations in the Shallow Aquifer in the Santa Clara Subbasin are between 2 and 12 milligrams per liter (mg/L). Nitrate concentrations in the Principal Aquifer in the subbasin are between 13 and 16 mg/L. Higher concentrations in the Principal Aquifer are likely a result of historic nitrate sources (Fostersmith et al, January 2005).

Although current nitrate concentrations in the Santa Clara Subbasin are generally low, elevated nitrate concentrations have been observed in some areas. Table 4-1 shows that nitrate concentrations have exceeded MCLs in 24 wells since 1946. In 2002, the North Santa Clara County Nitrate Study evaluated nitrate occurrence and trends in the Principal Aquifer in the Santa Clara Subbasin. The study indicated that nitrate concentrations in the subbasin appear to have declined from 1984 to 2000. Although some individual wells showed increasing trends in concentrations, 91 percent of the wells showed no apparent trend or a decreasing nitrate concentration (Fostersmith, et al, January 2005). Since land uses affiliated with nitrate contamination are no longer present in the North County, increasing nitrate concentrations in some areas may indicate the movement of an old nitrate plume or plumes from past sources.

4.2.3 Volatile Organic Compounds

VOCs are used in a variety of commercial, industrial, and manufacturing activities, including gasoline stations, circuit board manufacturing, dry cleaning, semiconductor manufacturing, and automotive repair. VOCs are have generally been detected at only trace concentrations in public water supply wells. However, localized VOC contamination has been severe enough to cause four wells to be destroyed.

There are more than 400 SLIC sites in Santa Clara County, with the majority located in the Santa Clara Subbasin. There are 47 mapped VOC plumes in the Santa Clara Subbasin covering a total of 1,750 acres at their maximum extent (Figure 4-2). Fortunately, these sites are located in the interior portion of the subbasin where groundwater contamination is limited to the Shallow Aquifer, which is separated hydraulically from the deeper Principal Aquifer by a horizontally extensive confining unit. In fact, only three of the mapped plumes in the subbasin extend deeper than 100 ft-bgs. Of the remaining plumes, the average maximum plume depth is 40 feet. VOC contamination affiliated with the Fairchild San Jose (SLIC #43s0036) and IBM (SLIC #43s0056) sites have impacted public water supply wells in the southern recharge area.

Overall, the District's groundwater protection programs, including its well permitting, well destruction, and LUST programs, have been effective in protecting the groundwater subbasin from contamination. Table 4-1 shows that VOCs have been detected in several wells but generally meet drinking water standards. MCLs have been exceeded for carbon tetrachloride (1 well), dichloromethane (3 wells), and tetrachloroethylene (1 well). The most commonly found VOC in groundwater is 1,1,1-trichloroethane, which has been detected in 47 wells at concentrations below the MCL but above the Detection Limit for Reporting (DLR) since 1982. Of the SOCs, benzo(a)pyrene has been detected above the MCL in one well.

In 2001, the District assisted the SWRCB and LLNL in conducting a groundwater vulnerability study in Santa Clara County involving in part the sampling and analysis of VOCs in 58 public water supply wells and other monitoring wells using ultra low-level detection limits. VOCs were detected at low concentrations (below the MCL) in many of the public water supply wells indicating that groundwater has been impacted by urban development. VOCs were detected in several wells, with the most common constituents being MTBE, trihalomethanes (THMs), and tetrachloroethylene. The results indicate that contamination pathways exist allowing for migration of VOCs into the Principal Aquifer;

however, the low concentrations of VOCs also indicate that water quality management and monitoring programs have, for the most part, been successful in protecting the Principal Aquifer from anthropogenic sources of contamination.

4.2.4 LUST Sites

Of the more than 2,000 LUST sites in the County, most are located in the Santa Clara Subbasin. The majority of the LUST sites are closed; although, several hundred LUST sites in the subbasin are currently undergoing active investigation, monitoring, and/or soil and groundwater remediation. Shallow Aquifer groundwater has been impacted in nearly all of the active cases. Historic MTBE contamination has caused impacts to two public water supply wells located in the recharge area of the subbasin.

4.3 Coyote Subbasin

Currently, the Coyote Subbasin is predominantly rural and is thus generally not impacted by most commercial and industrial sources of pollution. With no significant separation between the land surface and groundwater, aquifers in the Coyote Subbasin are considered vulnerable to point and non-point source contamination, including agricultural drainage and sewer collection systems. As the Coyote Subbasin becomes more urbanized in the future, new potential contamination sources (e.g., urban runoff, gas stations, dry cleaners, leaking sewer lines, etc.) are expected to pose a threat to groundwater quality. To address these concerns, the District has recommended steps above and beyond those required by state and federal law including the following: 1) avoiding high-risk land uses such as underground chemical storage; 2) establishing wellhead protection zones and locating the most hazardous land uses far away from and downgradient of drinking water supply wells; 3) implementing best management practices with respect to collection, conveyance, and treatment of urban storm water runoff; 4) enforcing rigorous commercial and industrial pre-treatment programs to minimize discharges to the sanitary sewer system; and 5) constructing deep excavations and facilities to standards that prevent hydraulic connection between surface water and groundwater (SCVWD, April 2005). The District also requires advance treatment of any recycled water used for irrigation in Coyote Valley.

4.3.1 General Water Quality

Groundwater quality in the Coyote Subbasin is good and is in compliance with primary drinking water standards with the exception of nitrate. Currently, the Coyote Subbasin is predominantly rural and is thus not impacted by most commercial and industrial sources of pollution.

4.3.2 Nitrate

Elevated nitrate levels occur in the southern half of the Coyote Subbasin, where nitrate sources associated with agriculture and septic systems are concentrated (Figure 4-1). The typical concentration range of nitrate in the Coyote Subbasin is from 10 to 47 mg/L (Reymers and Hemmeter, July 2002). With no significant separation between the land surface and groundwater, aquifers in the Coyote Subbasin are vulnerable to non-point nitrate source of contamination, including agricultural drainage and septic systems. Table

4-1 shows that of the 91 wells in the Coyote Subbasin sampled for nitrate, 29 wells have exceeded the MCL at least once.

4.3.3 Volatile Organic Compounds

Of the historic regulated environmental sites in the subbasin, none are SLIC sites. However, there are ongoing investigations and remediation at a closed rocket manufacturing plant (United Technologies Corp. Chemical Systems, SLIC #43s0286a) located in the hills immediately north of Anderson Reservoir and east of the subbasin.

Table 4-1 shows that VOCs and SOCs have not been detected above MCLs in wells sampled in the Coyote Subbasin and Figure 4-2 shows no groundwater contamination plumes in the subbasin.

4.3.4 LUST Sites

All of the regulated environmental sites in the subbasin are LUST sites; however, none of the sites are currently active. If and when the Coyote Subbasin becomes more urbanized, new potential contamination sources, including potential LUST sites, are expected to pose a threat to groundwater quality.

4.4 Llagas Subbasin

The Llagas Subbasin is less developed than the Santa Clara Subbasin, with far fewer industrial and commercial contamination release sites. Residential and commercial development in the subbasin is focused in the City of Morgan Hill in the north and the City of Gilroy in the south. The central portion of the subbasin is comprised predominantly of agricultural development and large residential parcels, which rely on onsite septic systems. The northern portion of the subbasin is unconfined and is considered vulnerable to contamination releases, while confining layers in the south offer some protection from local sources. Widespread nitrate contamination, predominantly associated with current and historic agricultural practices, and a significant perchlorate plume from a historic flare manufacturing site, are major water quality concerns in the subbasin.

4.4.1 General Water Quality

Natural groundwater quality within the Llagas Subbasin is generally good and is acceptable for potable, irrigation, and livestock uses. Nitrate and perchlorate represent significant contaminants in the subbasin, while solvents and petroleum hydrocarbons are rarely detected in the Principal Aquifer.

4.4.2 Nitrate

Nitrate is widely detected in the Llagas Subbasin above the MCL (Table 4-1 and Figure 4-1). Elevated levels of nitrate in the subbasin are thought to be due primarily to synthetic fertilizer application (LLNL, July 2005). As of the 1995 Santa Clara County General Plan, approximately 40 percent of the subbasin area was agricultural, which is a potential source of fertilizers. Other sources of nitrate in the subbasin include septic systems, greenhouse operations, urban runoff, manure used for fertilizers, feedlots and dairies, egg farms, food packaging operations, cogeneration facility, and treated wastewater disposal.

Trends in land use include a gradual retiring of agricultural land to suburban housing, an increase in nursery and greenhouse operations, reduction in the number of feedlots and dairies, improvements in municipal wastewater treatment, and increased volumes of treated wastewater disposed and recycled water use. The areas of the subbasin between the cities of Gilroy and Morgan Hill and on the outskirts of the cities rely on onsite septic systems for wastewater handling, while wastewater from the cities of Morgan Hill and Gilroy is treated at the Gilroy-Morgan Hill Municipal Wastewater Treatment Facility (WWTF) located in the southern portion of the subbasin.

In 2001, nitrate was detected above its MCL in almost half of the 93 wells sampled in the Llagas Subbasin. A comparison of 1988 and 1998 water quality data indicates that overall nitrate levels in the subbasin are increasing (Reymers and Hemmeter, July 2002). The median nitrate concentration in the Llagas Subbasin in 1998 was 47.1 mg/L (Hemmeter, January 2002). LLNL (July 2005) found that deep production wells in the Llagas Subbasin have increasing nitrate concentrations even though the District initiated implementation of a Nitrate Management Program in 1997 (SCVWD, 1996), with more complete implementation in 2000. However, recent nitrate trend analyses (1999 to 2008) indicate that nitrate levels are beginning to decline. For wells in the Shallow Aquifer, 16 exhibited no apparent trend, three showed an increasing trend, and two showed a decreasing trend. For wells in the Principal Aquifer, 32 wells showed no apparent trend, two showed an increasing trend, and 11 showed a decreasing trend.

Nitrate concentrations are consistently higher in shallow monitoring and production wells compared with wells screened at greater depths. Wells with top perforations deeper than 250 feet have near zero nitrate concentrations (LLNL, July 2005). The decline in nitrate concentrations with depth may be the result of denitrifying conditions or hydrogeologic factors (i.e., presence of aquitards that separate shallow, younger, contaminated water from deeper, older pristine water). Nitrate concentrations are highest east of Highway 101 in the central and southern subbasin with some of the highest concentrations in the southeast part of the subbasin (LLNL, July 2005).

Nitrate levels in wells with an isotopic signature of recharge water from artificial recharge operations are extremely low indicating that the District's recharge operations may dilute nitrate in the subbasin (LLNL, July 2005).

4.4.3 Volatile Organic Compounds and LUST Sites

Of the LUST sites in the Llagas Subbasin, more than 50 are open cases undergoing active assessment, remediation, and/or verification monitoring. Most of the open cases are located in the cities of Morgan Hill and Gilroy and along Highway 101. Although MTBE has been detected above the MCL in four shallow wells in the subbasin (see Table 4-1), based on the District's and DPH-required monitoring data, there have been no detections of petroleum hydrocarbons or MTBE above MCLs in the Principal Aquifer used for water supply.

Due to the relatively rural and residential nature of the subbasin, there are only a handful of active SLIC sites. Figure 4-2 shows the two main contamination plumes in the subbasin. Based on the District's and DPH-required monitoring data, VOCs associated with SLIC sites have not been detected above MCLs in the Principal Aquifer. One of the plumes shown in Figure 4-2 is a small area of trichloroethylene (TCE) at concentrations greater than MCLs associated with the Castle Vegtech site located near Morgan Hill (DBD, July 2007). In addition, tetrachloroethylene (PCE) has been recently detected below the MCL in two active City of Gilroy production wells, but the source has not been determined and there is no associated plume.

Based on the available data, there are no vertically and laterally extensive VOC groundwater plumes in the Principal Aquifer (i.e., water supply zones) in the Llagas Subbasin.

4.4.4 Perchlorate

The most significant single environmental release in the Llagas Subbasin is the perchlorate contamination associated with the Olin site. The California MCL for perchlorate is six micrograms per liter (µg/L). Perchlorate concentrations greater than the MCL extend approximately nine miles downgradient from the site in the Principal Aquifer (MACTEC, January 30, 2009b). The site has been undergoing remediation since 2004 and the number of domestic supply wells with concentrations above the MCL has declined over time. Contamination in private and municipal water supply wells has been addressed through installation of well head and at-tap water treatment systems and provision of bottled water (MACTEC, June 2006). District artificial recharge operations in the subbasin appear to be contributing to dilution of the perchlorate plume.

5 Sensitivity Analysis

As mentioned previously, groundwater vulnerability is defined by the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest under a given set of land use management practices. Groundwater vulnerability is thus comprised of two key components: 1) groundwater sensitivity and 2) the types and distribution of potentially contaminating activities. These two components are combined to characterize the overall vulnerability of the aquifer. This section describes the groundwater sensitivity component, including definition of the aquifers of interest, selected methodology, implementation approach, and assessment results. Maps depicting the sensitivity to contamination of the Shallow Aquifer and Principal Aquifer were prepared. Because the sensitivity assessment may be used for various groundwater management and land use planning purposes yet to be determined, recommended and alternative sensitivity maps and supporting information are presented and discussed. The assessment of PCAs in the Study Area is described in Section 6. Together, the groundwater sensitivity assessment and PCA risk analysis were used to determine the vulnerability of the three Study Area groundwater subbasins to contamination, which is described in Section 7.

5.1 Definition of Groundwater Sensitivity

Groundwater sensitivity is defined as the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest. Traditionally, it has been characterized based on the intrinsic characteristics of the aquifer and the overlying unsaturated materials. For this Study groundwater management activities that modify these intrinsic characteristics have also been included for consideration in the groundwater sensitivity analysis. Thus groundwater sensitivity for this Study is a function of the aquifer properties (i.e., hydraulic conductivity, porosity, and hydraulic gradient) and the associated sources of water and stresses to the groundwater system (i.e., recharge, travel through the unsaturated zone, and well pumping). Sensitivity assessments do not target specific natural or anthropogenic sources of contamination but consider only the physical factors affecting the flow of water to and through the aquifer system (Focazio, et al., 2002).

5.2 Aquifers of Interest

Water bearing units in the Study Area have been grouped into two major aquifer systems, the Shallow Aquifer and Principal Aquifer. The sensitivity to contamination of both aquifers was assessed for this Study. The Shallow Aquifer occurs above regional confining layers under unconfined to semi-confined conditions across the Study Area and, as such, is highly sensitive to contaminant releases on or near the land surface. The Principal Aquifer lies beneath the Shallow Aquifer and supplies most of the groundwater produced for beneficial uses in the Study Area. The Principal Aquifer occurs under semi-confined to confined conditions and is generally considered less sensitive to contamination than the Shallow Aquifer. In areas where confining layers do not exist or are not laterally and vertically extensive, only the Principal Aquifer occurs. These areas include the southern portion and east and west margins of the Santa Clara Subbasin, all of the Coyote Subbasin, and the northern portion of the Llagas Subbasin. Accordingly, in the recharge zones, depth to water was characterized as the first encountered groundwater for both the Shallow and Principal aquifers. In contrast, the Shallow and Principal aquifers were uniquely defined in the confined areas with the Shallow Aquifer characterized by the first encountered groundwater and the Principal Aquifer defined by the top screened interval of wells tapping the primary groundwater production zone.

The Shallow Aquifer and Principal Aquifer are hydraulically separated by a laterally extensive and thick confining layer in the northern interior of the Santa Clara Subbasin and in the southern portion of the Llagas Subbasin. The generalized extent of the major confining layer in the Santa Clara and Llagas subbasins as mapped by the California Water Resources Board (1955) is shown on Figure 2-1. The extent of the confining layer in the Santa Clara Subbasin was reduced during calibration of the District's numerical groundwater flow model developed for the Santa Clara Subbasin (CH2M Hill, 1992).

5.2.1 Shallow Aquifer

Figure 5-1 shows the estimated depth to first encountered water in the Shallow Aquifer in the Study Area. This figure was developed by the District using depth to the shallowest water measurements for shallow monitoring wells associated with regulated LUST facilities (Pierno, 1999). In the Santa Clara Subbasin, depths range from less than 5 ft-bgs in the northern interior of the subbasin and immediately north of the Coyote Narrows to greater than 100 ft-bgs along the western and eastern margins of the subbasin due to the gradual rise in ground elevation in these areas. In the Coyote Subbasin, depths range from less than 5 ft-bgs in the northern portion of the subbasin south of the Coyote Narrows to 75 ft-bgs in the central portion of the subbasin. In the Llagas Subbasin, depths range from less than 5 ft-bgs along the western and northern margins of the subbasin to 100 ft-bgs in the central and eastern portion of the subbasin.

5.2.2 Principal Aquifer

Figure 5-2 shows the estimated depth to the Principal Aquifer. Due to the strong hydraulic connectivity between shallow and deep groundwater in the recharge zone, it was determined that the depth to the Principal Aquifer in the recharge zone is more appropriately represented by the depth to first encountered groundwater (rather than depth to the top of the shallowest screen in public water supply wells). Therefore, depth to the Principal Aquifer was represented by the depth to the top of the first (or shallowest) screen of public water supply wells in the confined areas and depth to first encountered groundwater in the recharge areas.

Depth to top of shallowest well screen in the confined zones was developed using well construction information for public water supply wells identified in the District's database, the locations of which are shown on the figure. In areas with a high density of public supply wells, the shallowest well screen for a local well cluster (identified by two or more wells located within a distance of 500 feet of each other) was honored and other wells deleted to prevent unrealistically steep gradients. For areas between wells, the depth to the Principal Aquifer was interpolated using the inverse distance squared method in GIS. This interpolation method ensured minimal variability in the surface representing the depth to the Principal Aquifer, an important interpolation feature particularly for areas with no nearby public water supply wells (i.e., in the northern and northeastern portions of the Santa Clara Subbasin).

As shown in the figure, the Principal Aquifer is shallowest, less than 100 ft-bgs, in the recharge areas, including the Coyote Subbasin. Typically, the depth to the Principal Aquifer in the confined areas is less than 200 ft-bgs in the Llagas Subbasin and from 200 to 570 ft-bgs in the Santa Clara Subbasin.

5.3 Development of Assessment Methodology and Rationale

Numerous tools have been developed to assist governmental, academic, and private organizations in assessing the sensitivity of groundwater to contamination. The process used to screen available sensitivity assessment methods and the criteria and approach used to implement the selected sensitivity assessment methodologies are described below. Advantages and disadvantages of each method evaluated are applicable to sensitivity and vulnerability assessments.

5.3.1 Evaluation of Sensitivity Assessment Methods

Based on specific objectives and available resources, sensitivity assessment approaches may concentrate on individual wells (i.e., source water assessments for wellhead protection) or entire aquifer systems and may target the sensitivity of groundwater to contamination in general or to a specific contaminant. An example of an assessment approach concentrating on individual wells is the method developed by the DPH for the Drinking Water Source Assessment and Protection (DWSAP) Program (DPH, 1999). The DWSAP program includes both sensitivity and PCA risk components. Although some DWSAP guidelines were used in this Study, the regional scope and groundwater management objectives of this Study warranted an assessment that characterized the sensitivity (and vulnerability) of the regional groundwater system as a whole.

As part of the screening process, a comprehensive literature review was conducted to identify available methods developed to assess groundwater sensitivity and select the most appropriate method to meet the primary objectives of the Study. Results of the literature review are documented in the report titled, Evaluation of Assessment Methodologies (Appendix A), and are summarized below.

Three general categories of methods for conducting groundwater sensitivity assessments were identified. These included subjective rating (index and hybrid), statistical, and process-based methods. Each assessment method type was evaluated based on its ability to incorporate the physical processes that govern contaminant fate and transport in the subsurface on a regional scale and to produce scientifically-defensible groundwater sensitivity maps.

Table 5-1 provides a summary of the groundwater sensitivity assessment methods (index and hybrid methods are differentiated in the table). Generally, the more sophisticated assessments methods require more detailed knowledge of the groundwater system. Simpler methods incorporate more approximations and are less precise, but require less detailed information. Key advantages and disadvantages of each assessment method type are summarized below.

5.3.1.1 Index Methods

Advantages: For a regional-scale assessment, subjective index methods are conceptually appropriate in that they address explicitly the multivariate nature of groundwater sensitivity. Index methods rely on readily available information and can be easily implemented with GIS tools to produce regional groundwater sensitivity maps.

Disadvantages: Subjective methods rely largely on data availability and expert judgment with less emphasis on detailed processes controlling groundwater contamination. One set of variable weights suitable for one region may not be appropriate for another region. Because categories and weighting factors are pre-defined and rigid, they cannot be calibrated to match local conditions. As a consequence, the effectiveness of sensitivity maps produced using index methods in explaining contaminant distribution is limited.

5.3.1.2 Hybrid Methods

Advantages: Hybrid methods are suitable for groundwater assessment studies covering broad regional areas where error characteristics in water quality datasets compiled from diverse sources limit multivariate analysis but more reliable results than that provided by index methods are sought (Nolan et al., 1997). Hypothesis testing can be used to select, eliminate, or calibrate ratings and weights for variables addressed in index methods. Such methods may be categorized as *objective hybrid methods*.

Disadvantages: Although occurrence data can be used to verify user-defined sensitivity categories, results of hybrid methods are not correlated directly to probability. As a consequence, resolution of results may be coarser compared to results obtained from statistical methods.

5.3.1.3 Statistical Methods

Advantages: The complexity and local nature of water quality make it difficult to establish a set of variables important in all cases. The important parameters may differ in different parts of the country and within a county, watershed, or groundwater basin. The variety of statistical methods available for treating various types of data makes statistical approaches inherently flexible. Typically, no assumptions are made about the list of candidate variables to be included in a statistical model, nor do the results attempt to identify cause-effect relationships. Statistical methods can more easily deal with differences in scale than other methods that are based on the description of physical relationships. Overall, the integrity and confidence in assessment results can be bolstered using developmental and validation datasets to confirm variable selection and weighting in a statistical method.

Disadvantages: High quality data are needed to ensure statistical model input and parameters errors are minimized to acceptable levels. Because statistical methods rely strictly on correlation to explain physical-based processes, a disciplined approach combined with knowledge of fundamental groundwater processes is necessary to prevent mistreatment of statistical methods. Although final sensitivity equations can be easily incorporated in GIS, statistical relationships between variables should be re-evaluated when additional data become available.

5.3.1.4 Process-Based Methods

Advantages: Process-based methods use first order equations to model contaminant fate and transport processes. Uncertainty can be minimized if data requirements for inputs are met. Process-based methods can be used to address multiple interacting physical processes and identify the most important factor in groundwater sensitivity. Similar to objective hybrid methods and statistical methods, occurrence data in process-based methods can be used to calibrate and verify model outputs, thereby reducing uncertainty to acceptable levels.

Disadvantages: Sophisticated process-based methods do not necessarily provide more reliable outputs. Since data for many of the required input parameters for sophisticated models are not always available, their values often must be estimated by indirect means using surrogate parameters or extrapolated from data collected at other locations. Errors and uncertainties associated with such estimates or extrapolations may be large and may negate the advantages gained from using a rigorous method that simulates physical processes. The effort and cost of gathering data needed to estimate (or later refine) many of the parameters used in process-based models for regional scale assessments may be prohibitively large.

5.3.2 Groundwater Sensitivity Assessments and Water Quality

One essential feature of any scientifically-defensible groundwater sensitivity assessment is the calibration or verification of assessment parameters and results to a selected water quality dataset. The type of assessment method dictates the manner in which water quality data can be incorporated in a groundwater sensitivity assessment. Assessments based on subjective rating methods are limited to using water quality data to verify the effectiveness of the final subjective sensitivity maps in explaining contaminant distribution. The verification process informs the assessor whether the prescribed list of hydrogeologic parameters suspected of being indicators of groundwater sensitivity, the pre-defined ranking system, and final sensitivity categories are meaningful with respect to the groundwater system being assessed. For assessments based on objective hybrid methods, water quality data can be further utilized to calibrate variable ranking systems to ensure that final sensitivity results are objective and reflect local conditions. Assessments using statistical methods may also use the relationship between physical parameters and water quality data to check the significance of potential explanatory variables and eliminate from consideration those variables that do not help explain variations in water quality. For assessments using strictly process-based methods (models based on first-order processes), water quality data could be used in these assessments for both calibration and verification purposes. As a consequence of when water quality data is incorporated in a groundwater sensitivity assessment, the correlation observed between assessment results and water quality data can vary greatly. Correlations between final sensitivity results and water quality data are typically strongest in studies using statistical and process-based methods, moderate for those using objective hybrid methods, and weakest using subjective rating methods.

Irrespective of the assessment method applied, recognition of the assumptions and limitations when using water quality data for calibration or verification purposes are critical to interpreting and applying sensitivity assessment results. Similar to groundwater sensitivity, water quality data may be influenced not only by intrinsic hydrogeologic parameters but also by anthropogenic stresses to the groundwater system. Therefore, as many potential variables as possible should be considered in the assessment. Additionally, the fact that water quality measured in a well is a function of the hydrogeologic properties associated with the well, vertical as well as horizontal dimensions should be recognized. Understanding and addressing the limitations of water quality data used in a groundwater sensitivity assessment assists in the interpretation of final results and quantification of uncertainty.

5.3.3 Logistic Regression

Based on the evaluation of available groundwater sensitivity assessment methods and an understanding of available hydrogeologic and water quality information for the Study Area, a statistical method was selected to provide an objective framework within which to identify the local factors that most influence contaminant transport and, in turn, quantify the sensitivity to contamination of the Shallow Aquifer and Principal Aquifer.

The statistical method selected for the sensitivity methodology is called logistic regression. Logistic regression has been used in health sciences since the 1960s to predict a binary response from explanatory variables and more recently in the environmental sciences to assess multiple variables that may help explain the occurrence of groundwater contamination. Logistic regression is a promising method for assessing groundwater sensitivity as it can be used to treat large numbers of censored values (i.e., concentrations below laboratory detection levels) to identify the level of influence of potential variables on the probability of an event and it is well-suited to determine the parameters and their coefficient values that best identify the wells that have elevated contaminant concentrations. Other regression techniques, such as multiple linear regression, may be largely influenced by data that are near background levels.

Previous researchers have successfully applied logistic regression to produce probability-based groundwater sensitivity maps (Tesoriero and Voss, 1997; Eckhardt and Stackelberg, 1995; Eckhardt et al., 1988; Ayotte et al., 2004; and Squillace and Moran, 2000).

The form of a logistic regression model is shown below:

$$P = \frac{e^{(b_o + bX)}}{1 + e^{(b_o + bX)}}$$

where P is the probability of an event (i.e., probability of groundwater at a certain location exceeding a critical contaminant concentration), X is a vector of n explanatory variables, b_o is a scalar intercept parameter, and b is a vector of slope coefficient values, such that $bX = b_1X_1 + b_2X_2 + \ldots\ldots b_nX_n$. Potential explanatory variables can be either continuous (e.g., well depth in feet) or binary (e.g., presence of absence of a certain variable within a prescribed radius). A transformation, called the logit transformation, is then performed to yield a linear function:

$$\ln \frac{P}{1-P} = b_o + bX$$

Values of b_o and b are calculated using an iterative procedure contained in traditional statistical packages that tests each variable for significance and produces a best-fit regression model based on user-defined criteria.

5.3.4 Water Quality

Selecting an appropriate water quality dataset with which to calibrate the logistic regression analysis was essential to developing scientifically-defensible groundwater sensitivity maps. Based on an evaluation of water quality data in the Study Area, nitrate was selected to evaluate the sensitivity of the Shallow Aquifer and Principal Aquifer using logistic regression for the following reasons:

1. Based on historic land uses in the Study Area, elevated concentrations of nitrate are likely caused by anthropogenic activities (e.g., crop fertilization and domestic onsite sewage disposal).
2. Compared to most organic constituents, nitrate is a relatively conservative constituent in groundwater.
3. Nitrate has been successfully used as a tracer in other groundwater assessment studies.
4. Elevated nitrate concentrations are relatively common compared to the frequency of detection of other constituents, such as pesticides and VOCs. As a historically widespread contaminant in the Study Area, nitrate represents possibly the best indicator of environments sensitive to contamination.
5. Nitrate has been analyzed in over 1,150 wells in the Study Area, of which 470 have reliable well construction information. With the exception of perchlorate, a contaminant generally constrained to the Llagas Subbasin, the total number of wells analyzed for nitrate is greater and the distribution is broader than of any other constituents in the Study Area.

Groundwater age data were initially considered as an alternative calibration water quality dataset. However, attempts to develop a regression model for groundwater sensitivity based on groundwater age were unsuccessful due to the limited distribution of data and the complications associated with age signatures (i.e., reported age of water samples represents the average age of modern water and does not consider the pre-modern fraction of the water sample, which is often a large component).

Figures 5-3 shows the distribution of nitrate (as NO_3) for the 470 wells in the Study Area with well construction information (concentrations depicted are median concentrations by well). The 470 well nitrate dataset was selected for initial logistic regression analysis to determine whether a vertical component of a well (i.e., well depth or screen depth) helped to explain observed variations in nitrate concentration. Because a vertical component of the well was found to be a significant factor, the remaining 680 wells analyzed for nitrate without reliable well construction information (primarily private domestic wells located in the Llagas Subbasin) were not used in the sensitivity assessment.

The median nitrate concentration in each well ranges from less than the common detection limit for reporting (2 mg/L) to 137.5 mg/L. Ten percent of the wells have median concentrations of nitrate that are below the detection limit for reporting. The median concentration of the 470 well dataset is 14 mg/L. Because most of the 470 wells in the nitrate water quality database are screened in the Principal Aquifer, there is a greater degree of certainty associated with the calculated sensitivity for the Principal Aquifer compared with the Shallow Aquifer.

The median concentration of nitrate was selected for the logistic regression analysis to address limitations associated with the time-dependent nature of anthropogenic nitrate releases in the Study Area. Use of the median concentration (versus most recent concentration) reduces the possibility of underestimating sensitive areas of the subbasins where historic nitrate releases have been flushed through the groundwater system from natural recharge zones to discharge zones. An additional shortcoming of using the most recent nitrate concentration is that the calibration dataset would have spanned a period of roughly thirty years. Evaluation of the median concentration versus maximum concentration also reduced the likelihood of the logistic regression model being influenced by data outliers.

In order to convert nitrate concentrations from a continuous variable to a binary variable suitable for logistic regression analysis, a nitrate concentration was needed to separate events (wells with concentrations greater than or equal to a selected concentration) from non-events. An evaluation was conducted to assess the significance of the concentration selected to differentiate between naturally occurring and anthropogenic nitrate on the logistic regression analysis. To do so, five alternative nitrate concentrations (10, 15, 20, 30, and 40 mg/L as NO_3) were used to divide the 470 well nitrate dataset into events (wells with median concentrations above the respective concentration threshold) and non-events (wells with median concentrations at or below the respective concentration threshold). Figure 5-4 shows the nitrate dataset for each of the threshold concentrations evaluated. Logistic regression analysis was performed on each of the four binary datasets to identify the hydrogeologic factors of significance as well as overall model predictive capability. Results of the evaluation are summarized below.

- Based on 95 percent confidence criteria, a statistically significant correlation between the probability of elevated nitrate concentrations and groundwater recharge rate, depth to aquifer, and the presence of nearby groundwater production wells was identified for threshold concentrations up to 30 mg/L.

- Soil type was found to be insignificant at nitrate threshold concentrations above 10 mg/L.
- Topography, depth to water, and aquifer type are not significantly correlated to the probability of elevated nitrate concentrations at any of the evaluated threshold concentrations.
- The statistical correlation between the probability of elevated nitrate concentrations and groundwater recharge rate and depth to aquifer strengthens with increasing nitrate threshold concentration.
- The statistical correlation between the probability of elevated nitrate concentrations and the presence of nearby groundwater production wells weakens with increasing nitrate threshold concentration. The presence of nearby groundwater production wells was found to be insignificant at a nitrate threshold concentration of 40 mg/L.
- The predictive capability of the logistic regression model generally increases with increasing nitrate threshold concentration (based on Akaike's Information Criteria (AIC)) with only one exception. The regression model based on the 15 mg/L threshold dataset has the lowest predictive capability of all regression models.

Results of the evaluation suggest that a higher nitrate concentration threshold for the logistic regression analysis is supported statistically; however, review of the nitrate distribution across the Study Area indicates that the statistical trends are primarily a result of median well nitrate concentrations being much higher in the Llagas Subbasin (see Figure 5-4). Higher median nitrate concentrations in the Llagas Subbasin may be a reflection of 1) the relatively high recharge rate and shallow occurrence of aquifers in the subbasin, 2) greater anthropogenic nitrate loading in the Llagas Subbasin over time, 3) a strong downward vertical gradient, or 4) a combination of all factors. Regardless, it is evident that selection of a higher nitrate threshold concentration clusters the number of statistical events and, in turn, biases the overall sensitivity analysis to conditions observed in the Llagas Subbasin. This evaluation highlights the importance of selecting a meaningful nitrate concentration threshold for logistic regression analysis that maximizes the use of available data across the Study Area and allows for clear interpretation of statistical outcomes.

In addition to the nitrate threshold evaluation, a literature review was conducted to identify the concentration of nitrate typically considered to be of anthropogenic origin. Previous studies have suggested a level of 3 mg/L nitrate as nitrogen (N) (or 13 mg/L nitrate as NO_3) as a concentration indicative of anthropogenic activities (Madison and Brunett, 1985; Canter, 1997). A recent USGS study that evaluated the fate and transport of anthropogenic nitrate in groundwater in Modesto, California (McMahon et al., 2008) supports the use of a low nitrate concentration, on the order of 10 mg/L as NO_3, to differentiate between naturally occurring and anthropogenic nitrate in groundwater. Based on the results of the nitrate threshold evaluation and literature review, the logistic regression model was calibrated to the nitrate threshold concentration of 10 mg/L as NO_3

for the groundwater sensitivity analysis. Thus, the 10 mg/L threshold is deemed that most appropriate level based on both statistical analysis and review of data available from other studies of the concentration indicative of anthropogenic influences.

Figure 5-5 shows the same 470 wells characterized as having naturally occurring nitrate (10 mg/L or less) and anthropogenic nitrate (greater than 10 mg/L). Under this criterion, of the 470 wells, 307 wells (or 65 percent) have been impacted by anthropogenic nitrate.

By initially calibrating the logistic regression analysis to median nitrate concentrations, the following assumptions are made:

- Median well nitrate concentrations less than 10 mg/L indicate natural background conditions. This condition is used to define areas of lower sensitivity.
- Median well nitrate concentrations above 10 mg/L indicate an area where surface contamination has reached groundwater. This condition is used to define areas of higher sensitivity.
- Historic releases of anthropogenic nitrate have occurred across the Study Area. A well with a median nitrate concentration below 10 mg/L is assumed to be correlated to the lower sensitivity associated with the capture zone of the well and not because anthropogenic nitrate releases in this area are absent.

Limitations of equating nitrate occurrence data to groundwater sensitivity include the following:

- The sensitivity to contamination of an area where anthropogenic nitrate sources are absent may be underestimated.
- The sensitivity of an area where a small, short-term release of anthropogenic nitrate in groundwater has been quickly flushed through that area may be underestimated.
- The sensitivity of an area where anthropogenic nitrate in groundwater has been flushed through that area by artificial recharge of clean water may be underestimated.
- The sensitivity of an area where anthropogenic nitrate in groundwater has been retarded may be underestimated. Retardation of nitrate was not evaluated in the Study.
- Modeled relationships observed between nitrate occurrence data and explanatory variables assigned to each well are limited by the lack of a detailed well capture zone analysis.

5.3.5 Hydrogeologic Parameters

The intrinsic aquifer properties, sources of water, and aquifer stresses considered in the logistic regression analysis to explain the variability of nitrate concentrations observed in the selected 470 well nitrate calibration dataset are described in this section.

For all variables, GIS information layers were created to depict assigned variable ratings across the Study Area groundwater subbasins. Initial variable ratings were either obtained directly from or created using existing information developed by the District and others.

A key source of information for initial variable ratings was the District's evaluation of the Study Area groundwater subbasins using the DRASTIC method (herein referred to as the District's DRASTIC Study (Pierno, 1999)). Original layers and ratings from the District's DRASTIC Study were evaluated directly and in some instances refined to produce alternative rating schemes. Refinements were based on relevant information contained in hydrogeologic investigation and groundwater modeling reports as well as artificial recharge operations and groundwater production data. Data attributes for each GIS information layer were joined spatially with the existing 470 well nitrate dataset.

The description of and justification for evaluating each potential explanatory variable using logistic regression is presented in the following sections. For convenience, intrinsic aquifer properties have been grouped and are presented in the order of the seven variables identified in the DRASTIC method believed to influence groundwater sensitivity. These include **D**epth to Water, **R**echarge, **A**quifer Media, **S**oil Media, **T**opography, **I**mpact of Vadose Zone, and Aquifer Hydraulic **C**onductivity. The influence of artificial recharge operations and groundwater production on groundwater sensitivity is discussed in the Recharge and Conductivity sections, respectively.

5.3.5.1 Depth to Water (and Depth to Top of First Screen)

<u>Depth to Water</u>. Depth to water is considered an important variable with respect to groundwater sensitivity, because it represents the distance a contaminant must travel through the unsaturated zone before reaching the water table or top of first screen.

For each of the 470 wells in the nitrate dataset, the associated depth to water rating assigned to the well location in the District's DRASTIC Study was identified. For all seven of the variables used in the DRASTIC method, a rating scale of 1 to 10 is used. For depth to water, areas with a shallow water table are assigned a higher rating (to signify high sensitivity), while areas with a deep water table are assigned a lower rating (to signify low sensitivity).

The depth to water map used in the District's DRASTIC Study reflects 1999 conditions and was developed using depth to first encountered water measurements in shallow monitoring wells associated with regulated environmental facilities (Pierno, 1999). The District more recently mapped the depth to water for the Santa Clara Subbasin to reflect conditions observed in 2003. However, comparison of the 1999 and 2003 depth to water maps for the Santa Clara Subbasin indicate relatively small changes across the subbasin. Depth to water conditions in 2003 were not assessed for the Coyote and Llagas subbasins, and the 2003 depth to water map for the Santa Clara Subbasin was not available digitally. For these reasons, the 1999 depth to water map was used for this Study.

Figure 5-6 shows the depth to first encountered water map along with median nitrate concentrations for each of the 470 wells with well construction information. Depth to first encountered groundwater was used to represent the depth to water factor for the Shallow Aquifer across the Study Area and to represent the depth to water factor for the Principal Aquifer in the recharge areas. The USEPA DRASTIC rating assigned to the depth to water map was applied directly in the logistic regression analysis.

Figure 5-7a shows boxplots depicting the relationship between the nitrate concentrations of wells grouped by depth to first encountered water rating. Each boxplot is a graphical representation of the statistical summary of the nitrate data for each depth to water rating, and depicts the smallest observation, lower quartile, median, upper quartile, and largest observation. The number of observations (wells) associated with each rating category is designated above each boxplot. To assess whether the nitrate observations for neighboring depth to water rating categories come from the same or different distributions, the non-parametric Wilcoxan Rank Sum test was applied. The results of the test are summarized in the p-statistic value shown above the pairs of neighboring categories, where a p-value less than 0.05 represents a better than 95 percent confidence that the two groups of observations come from different distributions (larger p values indicate less confidence).

The boxplots indicate that median nitrate concentrations are inversely related with the depth to first encountered water rating assigned to each well. The inverse relationship is counter-intuitive since in the DRASTIC method a higher depth to water rating is assigned to areas with a shallow water table (perceived high sensitivity), and a lower depth to water rating is assigned to areas with a deeper water table (perceived low sensitivity). An inverse relationship most likely indicates a lack of correlation between the nitrate data and depth to first encountered water ratings, which is not surprising given the large variation in well screen depths for each well. Median nitrate concentrations for depth to first encountered water rating categories 1 through 7 are all above 10 mg/L, ranging from 12 to 21 mg/L. The figure also indicates that nitrate concentrations in wells assigned a depth to first encountered water rating of 2 through 9 possibly come from the same nitrate distribution (i.e., differences between these depth to water ratings is not statistically significant). Since data used in the District's DRASTIC Study were not evaluated in this Study, the range of assigned values for each hydrogeologic variable evaluated in the District's DRASTIC Study was preserved in the logistic regression analysis.

<u>Depth to Top of First Screen</u>. Because the nitrate calibration dataset is comprised primarily of wells screened in the Principal Aquifer, separate nitrate datasets for the Shallow Aquifer and Principal Aquifer were not available to conduct individual logistic regression analyses. To differentiate between the sensitivity of the Shallow Aquifer and Principal Aquifer using a single calibration dataset, a variable that represents the vertical distance a contaminant must travel through the unsaturated and saturated zone was needed. For this Study, the depth to the top of the first screen in ft-bgs for each well was evaluated with this purpose in mind. Alternative variables, including average well screen depth and total well depth, were also considered. However, because neither of these variables provided a significantly better correlation with the nitrate dataset than the depth to top of the first screen, they were not included in the logistic regression analysis. Depth to top of first screen was used to represent the depth to water factor for the confined areas of the Principal Aquifer.

Figure 5-8 shows the 470 wells in the nitrate calibration dataset symbolized according to the identified depth to top of first screen for each well, which ranges from 7 to 890 ft-bgs with an average of 240 ft-bgs.

Figure 5-7b shows boxplots depicting the distribution of median nitrate concentrations of wells grouped into six selected depth intervals. The boxplots show a fairly strong inverse relationship between nitrate concentrations and the depth to top of first screen (in ft-bgs) identified for each well. This is expected as water drawn from deeper wells generally has a longer travel time than water from shallow wells because of the combined effects of travel through both the unsaturated and saturated zones. The boxplots also indicate that nitrate concentrations in wells assigned a depth to top of first screen less than 400 ft-bgs may possibly come from the same nitrate distribution.

5.3.5.2 Groundwater Recharge

Groundwater recharge is considered one of the most important factors controlling groundwater sensitivity because recharge is the primary vehicle by which a contaminant is transported from the ground surface to groundwater. Groundwater recharge to an unconfined aquifer is a function of precipitation, runoff, and evapotranspiration related to vegetative/soil type. Groundwater recharge to a confined aquifer is generally more complex, as consideration must be given to the location of the recharge zone and the influence of any confining layers, vertical gradients, and groundwater pumping on the rate of recharge/leakage to the aquifer.

For the sensitivity assessment, groundwater recharge from precipitation and artificial recharge operations and the influence of groundwater production were evaluated (groundwater production is presented in Section 5.3.5.7 Aquifer Hydraulic Conductivity, since it also affects groundwater flow velocity). Recharge from water distribution and sanitary sewer line losses were not considered in the Study due to their relatively small volumes and the lack of water quality data and understanding of where such losses occur. The seven recharge rainfall zones identified during the development of the District's numerical groundwater flow model of the Santa Clara Subbasin (CH2M Hill, 1992) were initially considered in the recharge variable. However, preliminary comparison of nitrate concentrations to rainfall zones indicated a similar correlation observed between nitrate concentrations and the recharge map developed for the District's DRASTIC study. As a result, groundwater model rainfall zones were not further evaluated in the logistic regression analysis.

In order to assign an appropriate recharge value to each well in the 470 well nitrate dataset, available estimates of net recharge from precipitation were first obtained and refined. In the end, four alternative recharge scenarios were considered and evaluated in the logistic regression analysis.

<u>Recharge (Alternative 1)</u>: Figure 5-9 shows a map of the estimated groundwater recharge for the Study Area developed for the District's DRASTIC Study (herein referred to as Recharge Alternative 1) along with the median nitrate concentrations for the 470 well nitrate calibration dataset. The Recharge Alternative 1 map was generated on a parcel by parcel basis using an average annual rainfall isohyetal map and rainfall retention factors weighted to the relative percentage of land use cover (Pierno, 1999). Assigned DRASTIC ratings were evaluated directly in the logistic regression analysis. The DRASTIC method uses a recharge rating scale of 1 to 10, whereby areas receiving less groundwater recharge are assigned a lower rating (perceived low sensitivity), while areas receiving more groundwater recharge are assigned a higher rating (perceived high sensitivity).

Figure 5-7c shows boxplots depicting the relationship between nitrate concentrations and Recharge Alternative 1 ratings. The figure shows a generally strong positive relationship between nitrate concentrations and the Recharge Alternative 1 rating assigned to each well. With the exception of wells assigned a recharge rating of 8 and 9, nitrate concentrations for all ratings likely represent different nitrate distributions, taking into consideration that only one well was assigned a recharge rating of 1.

Recharge (Alternative 2): Because several wells in the nitrate dataset are screened in the Principal Aquifer beneath the regional confining layer in the Santa Clara and Llagas subbasins, the amount of groundwater recharge associated with these wells is expected to be smaller than that estimated from rainfall isohyetal maps and retention factors. Recent studies confirmed that even with the large number of unknown abandoned wells in the confined zone of Santa Clara, widespread vertical short-circuiting in the confined zone due to abandoned wells is not evident (Moran et al., 2004). In addition to these observations, during calibration of the numerical groundwater flow model for the Santa Clara Subbasin (CH2M Hill, 1992), the areal extent of the major confining layer was reduced in the northern portion of the subbasin.

The factors mentioned above were incorporated into the recharge variable (Recharge Alternative 2) in the following way:

1. A recharge rating of 1 was assigned to wells with depth to top of first screens greater than 200 ft-bgs located within the model calibrated confined zone in the Santa Clara Subbasin.
2. A recharge rating of 2 was assigned to wells with depth to top of first screens greater than 200 ft-bgs located within the originally mapped confined zone but outside the model-calibrated confined zone in the Santa Clara Subbasin.
3. A recharge rating of 2 was assigned to wells with depth to top of first screens greater than 200 ft-bgs located within the Llagas confined zone. A recharge value of 1 was initially considered but ultimately not used due to observed perchlorate and nitrate contamination present in deeper wells in the Llagas Subbasin.

Figure 5-10 reflects the abovementioned changes to recharge ratings for deeper (Principal Aquifer) wells.

Figure 5-7d shows boxplots depicting the relationship between median nitrate concentrations and Recharge Alternative 2 ratings. The figure shows that a strong positive correlation between nitrate concentrations and Recharge Alternative 2 ratings assigned to each well. Assigning a recharge rating of 1 to wells screened in the Principal Aquifer located in the model-calibrated confined zone results in a stronger relationship between nitrate concentrations and recharge. However, assigning a recharge rating of 2 to Principal Aquifer wells located in the outer confined zone in the Santa Clara Subbasin and in the confined zone of the Llagas Subbasin weakened the relationship between nitrate concentrations and recharge.

Recharge Version 3: Based on the boxplots developed for Recharge Alternative 2 ratings, it was evident that the recharge value of 2 assigned to Principal Aquifer wells located in the outer confined zone in the Santa Clara Subbasin and in the confined zone of the Llagas Subbasin is not statistically supported. Therefore, for Recharge Alternative 3, the original DRASTIC recharge rating was used for these wells. In addition, the relationship between artificial recharge operations and nitrate concentrations was addressed.

The influence of artificial recharge operations along in-stream reaches of local creeks and in percolation ponds is evident when the District's artificial recharge facilities and the nitrate dataset are mapped together as shown on Figure 5-11. The figure shows that nitrate concentrations in wells located in the vicinity of recharge facilities, particularly along Los Gatos Creek and the Guadalupe River in the southwestern portion of the Santa Clara Subbasin and along the Coyote Creek from the Coyote Subbasin to north of the Coyote Narrows, rarely exceed 10 mg/L. LLNL (July 2005) also noted reduced nitrate concentrations in the vicinity of District recharge facilities in the Llagas Subbasin. These observations are not surprising considering the relatively large volume of clean imported water historically recharged through these facilities.

Because of the strong relationship observed between artificial recharge operations and groundwater nitrate concentrations, a method was developed to ensure that wells influenced by artificial recharge did not compromise the objectivity of the logistic regression analysis. The method needed to be consistent with respect to the DRASTIC rating scale used to characterize the influence of recharge in the Study Area but also dynamic enough to account for the varying influence of each artificial recharge facility.

In the DRASTIC method, areas receiving large amounts of groundwater recharge are assigned a higher rating (equating to perceived high sensitivity) based on the premise that a contaminant can more easily reach groundwater where recharge rates are higher. However, based on visual observation, assigning a high recharge rating to wells influenced by artificial recharge operations weakens the relationship between the recharge variable and nitrate occurrence data. This is because the perceived positive correlation between recharge and sensitivity in DRASTIC fails to consider that clean water percolating through an in-stream recharge reach or percolation pond actually improves groundwater quality.

To account for the dilution effect of artificial recharge in the logistic regression analysis, wells located in areas influenced by artificial recharge operations were assigned a value of 1 in Recharge Alternative 3. As a consequence, areas near artificial recharge operations are characterized as having a relatively low probability of anthropogenic nitrate occurrence.

To estimate an appropriate radius of influence for each artificial recharge facility, two factors were considered. The first factor related directly to the average annual volume recharged through each recharge facility estimated using monthly recharge volumes recorded by the District from September 1994 through December 2006. Based on the average annual volume of water recharged, each feature was assigned a value from 0 to 9 (a value of 0 was assigned to a facility with an average annual recharge volume ranging from 0 to 1,000 AFY; a value of 1 was assigned to a facility with an average annual recharge volume ranging from 1,001 to 2,000 AFY; and so forth up to a value of 9, which was assigned to a recharge facility with an average annual recharge volume greater than 9,000 AFY. The second factor considered the total depth of water recharged per year and was calculated by dividing the average annual volume of recharge by the infiltrating surface area of the artificial recharge facility (a width of 40 feet was assumed for in-stream recharge reaches).

The direct product of the two factors was found to provide the most appropriate area of impact around each facility and took into account the expected influence of the mounding and dilution associated with each artificial recharge facility. Other calculations using the two weighting factors were considered, but none addressed the influence of artificial recharge on the nitrate distribution near the recharge facilities and satisfied the conceptual understanding of groundwater mounding and dilution around each artificial recharge facility better than the direct product of the two factors.

Figure 5-12 shows the estimated groundwater impact zone of each artificial recharge facility based on the product of the two factors described above. As shown in the figure, the impact zone of artificial recharge includes many of the wells located near recharge facilities. One of the limitations of this method is that horizontal groundwater flow direction is not considered. As such, the circular impact zones around percolation ponds may be more oblong in the direction of groundwater flow and may not include potentially impacted wells located downgradient of artificial recharge facilities (e.g., wells located downgradient of Coyote Pond near the Coyote Narrows).

Figure 5-13 reflects the changes made to the recharge coverage after incorporating the influence of artificial recharge operations.

Because the method used to develop the original recharge coverage was parcel-based, there is a high variability in recharge over relatively short distances. Since the nitrate concentration in a well is reflective of conditions within the entire capture zone of the well, the average recharge rating within a simplistic capture zone for each well was assigned to reduce the influence of sharp contrasts in recharge. For this Study, a radius of ¼ mile represented the capture of each well.

Figure 5-7e shows boxplots depicting the relationship between median nitrate concentrations and Recharge Alternative 3 ratings. The figure shows a strong positive relationship between nitrate concentrations and the Recharge Alternative 3 ratings. The boxplots also confirm that a recharge rating of 2 assigned to Principal Aquifer wells located in the outer confined zone in the Santa Clara Subbasin and in the confined zone of the Llagas Subbasin are not statistically supported. Unlike in Recharge Alternatives 1 and 2, differences in nitrate concentrations between wells assigned a recharge rating of 8 and 9 for Alternative 3 are now significant.

<u>Recharge Version 4</u>: As discussed above, the sensitivity analysis identified a strong correlation between the proximity of a well to an artificial recharge facility and low nitrate concentrations. This correlation is attributed to dilution and flushing of existing anthropogenic nitrate by low-nitrate imported water. This observation points to a limitation in the use of nitrate data to calibrate sensitivity factors. Wells near the recharge areas are clearly sensitive to potential contamination in the artificial recharge areas, but the lack of nitrate in the recharge water results in low concentrations in the wells. To address the limitations of equating the probability of anthropogenic nitrate occurrence to groundwater sensitivity, the influence of artificial recharge operations was removed from the recharge coverage used to develop elevated nitrate probability maps and the original estimates of groundwater recharge in these areas were applied to develop groundwater sensitivity maps. By removing the influence of artificial recharge, the correlation observed between the recharge rating assigned to each well and the probability of nitrate

occurrence is preserved, but the sensitivity of areas directly impacted by artificial recharge is increased. Since artificial recharge areas exist in part for their high infiltration capacity, the increased sensitivity offers additional protection of these valuable areas.

Contaminants introduced at or near the ground surface that reach groundwater in the vicinity of artificial recharge operations are likely to travel more quickly through the groundwater system potentially contaminating areas along its flow path. To further protect groundwater in the vicinity of recharge facilities, a recharge value of 9 was uniformly assigned within an area of influence around each recharge facility for sensitivity mapping. Considering the influence of groundwater mounding on groundwater velocities near recharge facilities, the median radius of influence used to calibrate the logistic regression analysis (550 feet) was determined to provide an appropriate buffer zone. This refinement effectively increases groundwater sensitivity in the area of influence. Updated groundwater recharge coverages applied to the Shallow Aquifer and Principal Aquifer for groundwater sensitivity mapping are shown on Figures 5-14 and 5-15, respectively. Alternative 4 was selected for the sensitivity analysis.

5.3.5.3 Aquifer Media

The type of aquifer media (e.g., unconsolidated sediments versus fractured bedrock) is important with respect to groundwater sensitivity because it provides an indication of the flowpath a contaminant must travel and its potential to attenuate once it reaches the aquifer.

Figure 5-16 shows the aquifer media map developed for the District’s DRASTIC Study along with median nitrate concentrations for the each of the 470 wells with well construction information. The aquifer media map was developed from the District’s Hydrographic Delineation Report (Pierno, 1999). Assigned aquifer media ratings were evaluated directly in the logistic regression analysis. The DRASTIC method uses an aquifer media rating scale of 1 to 10. Because both the Shallow Aquifer and Principal Aquifer are comprised of unconsolidated sediments, aquifer ratings ranged only from 4 to 9. Areas composed of poorly sorted silty/clayey sands were assigned a lower rating (perceived low sensitivity); while areas composed of well sorted coarse-grained sands and gravel were assigned a higher rating (perceived higher sensitivity).

Figure 5-7f shows boxplots depicting the relationship between the nitrate concentrations of wells grouped by their associated aquifer media rating. The figure generally shows a poor relationship between nitrate concentrations and the aquifer media rating assigned to each well. Median nitrate concentrations for each aquifer media category are above 10 mg/L ranging from 12 to 16 mg/L. This result is not surprising considering that the Shallow Aquifer and Principal Aquifer are comprised of relatively permeable unconsolidated deposits that are difficult to differentiate.

5.3.5.4 Soil Media

The type of soil media (e.g., clay, loam, sand) is important with respect to groundwater sensitivity because it affects the rate at which a contaminant can travel from the surface to groundwater.

Figure 5-17 shows the soil media map developed for the District’s DRASTIC Study along with median nitrate concentrations for the each of the 470 wells with well construction information. The soil media map was developed from the United States Soil

Conservation Service soil map (Pierno, 1999). Assigned DRASTIC ratings were evaluated directly in the logistic regression analysis. The DRASTIC method uses a soil rating scale of 1 to 10, whereby soils comprised of fine-grained materials (silts, clays) with higher organic content are assigned a lower rating (perceived low sensitivity), while soils comprised of coarser-grained materials (sands) with little to no organic content are assigned a higher rating (perceived higher sensitivity).

Figure 5-7g shows boxplots depicting the relationship between the nitrate concentrations of wells grouped by their associated soil media rating. At first glance, the figure appears to show a poor relationship between nitrate concentrations and the soil media rating. However, with respect to the natural/anthropogenic nitrate concentration level of 10 mg/l, a distinct difference is observed between nitrate concentrations for wells with soil ratings of 1 and 3 (median nitrate concentrations of 2 and 9 mg/L, respectively) and wells with soil ratings of 4 and 6 (median nitrate concentrations of 18 and 14 mg/L, respectively). This relationship is preserved when the same procedure used to assign the average recharge rating within a ¼ mile capture zone of each well is applied to soil media (see Figure 5-7h). (Note: Assignment of average variable ratings within a ¼ mile radius of each well was performed only to variables found to be significant after preliminary logistic regression analysis. These include recharge, soil media, and annual production. Although statistically significant, the depth to top of first screen for each well was applied directly).

5.3.5.5 Topography (Slope)

The slope of the ground surface is important with respect to groundwater sensitivity because it in part determines the potential of a contaminant to infiltrate into the ground or be transported away as surface runoff.

Figure 5-18 shows the topography rating developed for the District’s DRASTIC Study using the County digital elevation model (DEM) along with median nitrate concentrations for the each of the 470 wells with well construction information. The USEPA DRASTIC rating assigned to the topography rating was applied directly in the logistic regression analysis. The USEPA DRASTIC method uses a sensitivity rating scale of 1 to 10, whereby areas with a shallow ground surface slope are assigned a higher rating (to signify high sensitivity), while areas with a steep ground surface slope are assigned a lower rating (to signify low sensitivity).

Figure 5-7i shows boxplots depicting the relationship between the nitrate concentrations of wells grouped by their associated topography rating. The figure generally shows a poor relationship between nitrate concentrations and the topography rating assigned to each well. This is not surprising considering the small variation in topography across the Study Area (94 percent of the wells are located on the flat valley floor where the slope is less than 2 percent (topography value of 10)).

5.3.5.6 Impact of the Vadose Zone

The media that comprise the unsaturated (or vadose) zone are important with respect to groundwater sensitivity because they control the degree to which a contaminant can attenuate prior to reaching groundwater. When evaluating a confined aquifer, all of the sediments above the confined aquifer should be considered. In this case, the vadose zone is not a true vadose zone as it includes both unsaturated and saturated sediments.

Typically, sediments comprising the confining layer are selected to evaluate the impact of the vadose zone on a confined aquifer, as the confining layer sediments have great impact on the contamination potential of the confined aquifer. For this Study, two vadose zone ratings schemes were considered and evaluated in the logistic regression analysis.

Impact of Vadose Zone Alternative 1: Figure 5-19 shows the Impact of Vadose Zone map (Alternative 1) developed for the District's DRASTIC Study along with median nitrate concentrations for the each of the 470 wells with well construction information. Assigned DRASTIC ratings were evaluated directly in the logistic regression analysis. The DRASTIC method uses an Impact of Vadose Zone rating scale of 1 to 10, whereby vadose zones comprised of fine-grained materials (silts, clays) are assigned a lower rating (perceived low sensitivity), while vadose zones comprised of coarser-grained materials (sands and gravels) are assigned a higher rating (perceived higher sensitivity). The impact of vadose zone map was developed using the major confining layer to characterize the originally mapped confined zone of the Santa Clara Subbasin and confined zone of the Llagas Subbasin, as these areas were assigned a rating of 1 equating to massive clay. The model-calibrated confined zone extent of the Santa Clara Subbasin was not evaluated for the impact of vadose zone variable, as this condition was already evaluated in the recharge variable.

Figure 5-7j shows boxplots depicting the relationship between the nitrate concentrations of wells grouped by their associated impact of Vadose Zone Alternative 1 rating. The figure shows a generally poor relationship between nitrate concentrations and impact of Vadose Zone Alternative 1 ratings assigned to each well. The poor relationship is primarily due to the universal rating of 1 assigned to the 233 wells located within the confined zones of the Santa Clara and Llagas subbasins.

Impact of Vadose Zone Alternative 2: Because several wells in the nitrate calibration dataset are screened above the regional confining layers of the Santa Clara and Llagas subbasins, an Impact of Vadose Zone rating of 1 assigned to these wells is inappropriate. Because the original data for the Impact of Vadose Zone information layer developed for the District's DRASTIC Study was not available for this Study, the median vadose zone rating of 4 was assigned to wells located within the confined zones of the Santa Clara and Llagas subbasins with depth to top of first screen less than 100 ft-bgs.

Figure 5-120 reflects the changes made to the impact of vadose zone ratings for wells with screens above the major confining layers of the Santa Clara and Llagas subbasins.

Figure 5-7k shows boxplots depicting the relationship between the nitrate concentrations of wells grouped by their associated impact of Vadose Zone Alternative 2 rating. The boxplots show a relatively strong but inverse relationship between nitrate concentrations and impact of Vadose Zone Alternative 2 rating. Similar to the depth to water variable, the inverse relationship observed appears counter-intuitive as the DRASTIC method assigns a higher Impact of Vadose Zone rating to areas perceived to be highly sensitive to contamination and a lower Impact to Vadose Zone rating to areas perceived to be less sensitive to contamination. An inverse relationship most likely indicates a lack of correlation between the nitrate data and impact of vadose zone ratings, which is not surprising given the inexact assignment of ratings to shallow wells located in the confined zones of the Santa Clara and Llagas subbasins.

5.3.5.7 Hydraulic Conductivity

Aquifer hydraulic conductivity is considered an important parameter with respect to groundwater sensitivity because it indicates the rate at which a contaminant can travel through the aquifer system once it reaches the water table. For this Study three alternative Conductivity schemes were considered and evaluated in the logistic regression analysis.

Hydraulic Conductivity Alternative 1: Figure 5-21 shows the hydraulic conductivity map along with median nitrate concentrations for the each of the 470 wells with well construction information. The hydraulic conductivity map reflects the model calibrated hydraulic conductivity distribution for Layer 3 of the Santa Clara Subbasin (CH2M Hill, 1992), the single layer model for the Coyote Subbasin (Abuye, November 2005), and the average aquifer conductivity of the upper aquifer layers for the Llagas Subbasin model (CH2M Hill, May 2005). Assigned DRASTIC ratings were evaluated directly in the logistic regression analysis. The DRASTIC method uses a conductivity rating scale of 1 to 10, whereby slower hydraulic conductivity rates are assigned a lower rating (perceived low sensitivity), while higher conductivity rates are assigned a higher rating (perceived higher sensitivity).

Figure 5-7l shows boxplots depicting the relationship between the nitrate concentrations of wells grouped by their associated Conductivity Alternative 1 rating. The boxplots indicate a general lack of correlation between median nitrate concentrations and the conductivity ratings assigned to each well. Additionally, median nitrate concentrations for each hydraulic conductivity rating category are above 10 mg/L ranging from 12 to 33 mg/L. The lack of correlation is not surprising given that the average conductivity values used in model layers do not account for the likely high variation in hydraulic conductivity within each aquifer. Thin units with high conductivity are more likely to influence contaminant transport than the average conductivity value of the entire aquifer.

Hydraulic Conductivity Alternative 2: Since some of the wells in the nitrate calibration dataset are located above the major confining layer in the Santa Clara Subbasin. The initial hydraulic conductivity distribution map for Layer 1 of the groundwater flow model was used to assign a more appropriate conductivity rating for these wells. The calibrated conductivity distribution for Layer 1 was not used because the calibrated model used a uniform conductivity value of approximately 10 feet per day for Layer 1 across the entire Santa Clara Subbasin. A figure was not generated for Hydraulic Conductivity Alternative 2, but the boxplots depicting the relationship between the nitrate concentrations of wells grouped by their associated Conductivity Alternative 2 rating is shown on Figure 5-7m. The boxplots show that re-assignment of conductivity values to selected shallow wells in the Santa Clara Subbasin does not significantly improve the relationship observed between nitrate concentrations and conductivity ratings.

Hydraulic Conductivity Alternative 3 (Annual Production by Geographic Section): Given that hydraulic conductivity is often used as the sole variable to represent the rate of flow through the aquifer, it is not surprising that the relationship between conductivity and nitrate concentrations in the Study Area is weak. The rate at which a contaminant travels through the groundwater system is a function of the hydraulic conductivity and gradient as defined by Darcy’s Law. Thus understanding the hydraulic gradient, as well as hydraulic conductivity, is critical to understanding groundwater sensitivity. Although the hydraulic gradients calculated from static water level measurements are relatively low and vary little across the Study Area, such gradients do not reflect the steep horizontal and induced vertical gradients found near pumping wells. As such, the distribution of nitrate and any other contaminant in groundwater is probably highly influenced by groundwater production.

Figure 5-22 shows the average annual production reported by geographic section along with median nitrate concentrations for the each of the 470 wells with well construction information. This map was generated using groundwater production data reported from for the ten year period from 1999 through 2008. The figure shows that pumping in the Llagas and Coyote subbasins is well distributed, whereas, pumping in the Santa Clara Subbasin is more focused in the south and central west side of the subbasin.

Figure 5-7n shows boxplots depicting the relationship between nitrate concentrations and the annual production of each well by section grouped into six selected intervals. In order to address the effect of sharp boundaries separating production from non-production sections, the average annual production calculated within a ¼ mile radius was assigned to each well. At first glance, the boxplots show a near-normal distribution of nitrate concentrations versus annual production by section assigned to each well. However, with respect to the natural/anthropogenic concentration level of 10 mg/l, there is a distinct difference in nitrate distribution between wells located in or near geographic sections where average annual production is less than or greater than 100 AFY. Median nitrate concentrations of wells located in or near non-producing sections (<100 AFY) is 6.0 mg/L, whereas median nitrate concentrations of wells located in or near producing sections (>100 AFY) is 15.0 mg/L. Figure 5-23 shows the average annual production reported by geographic section with sections symbolized based on whether average annual production is greater than or less than 100 AFY. This map depicts the strong correlation observed between nitrate concentrations and annual groundwater production.

5.4 Results

This section describes the results of the logistic regression analysis using nitrate occurrence data and presents final nitrate probability and groundwater sensitivity maps for the Shallow and Principal aquifers.

5.4.1 Logistic Regression Results

Results of the logistic regression analysis are summarized in Table 5-2. Model outputs are presented in Appendix C. As reflected in the table, various combinations of hydrogeologic variables were initially evaluated to develop a regression model that best predicts the probability of elevated nitrate in the Shallow and Principal aquifers. The statistics of the six best models developed from three combinations of hydrogeologic variables are presented in the table. The three combinations reflect the iterative analysis process whereby the original variables with unaltered ratings used in the District's DRASTIC Study were initially evaluated (Scenario A) and variables determined to be insignificant were removed from consideration or, if possible, refined and re-evaluated (Scenarios B and C). For hydrogeologic variables with multiple alternatives, only one alternative was evaluated at a time to prevent the potential inclusion of two or more alternatives of the same hydrogeologic variable in the final regression model.

For each combination of hydrogeologic variables, two criteria were used to identify the set of variables that best explained the distribution of elevated nitrate occurrence in the 470 well calibration dataset. The first criterion involved testing for the statistical significance of each variable using a “cost-benefit” analysis. The “benefit” of adding a variable to a regression model is a reduction in model error as measured using a statistic called the log-likelihood. The log-likelihood reflects how likely it is (or the odds) that the observed values of a dependent variable may be predicted from the observed values of an independent variable. The “cost” of adding a variable to a regression model is a more complicated model, as measured by the available information (or degrees of freedom) in the dataset. If the net benefit of a variable is positive, the variable is preserved in the model. If the net benefit of a variable is negative, the variable is removed from consideration. This cost-benefit analysis was assessed using a statistical test with the result expressed as a p-value. Variables that provide a net benefit to the regression model are associated with small p-values. A p-value of 0.05 (representing a 95 percent confidence that the coefficient is not zero) was used to screen variables for significance.

Due to the use of the DRASTIC rating scale for most of the hydrogeologic variables evaluated in this Study, a second non-statistical criterion was used to screen those variables with p-values equal to or less than 0.05. Because a higher DRASTIC rating is assigned to an area perceived to have higher sensitivity (e.g., a high depth to water rating is assigned to an area with a shallow water table), a negatively sloped coefficient for a DRASTIC-scaled variable is counter intuitive and more likely reflects a lack of correlation rather than an inverse relationship between variable ratings and the nitrate calibration dataset. As such, any variable rated on the 1-to-10 DRASTIC scale found to have a negatively sloped coefficient (or inverse relationship with the nitrate occurrence data) was rejected from final regression models, even if the net benefit of the variable was positive. This criterion was enforced to ensure that improved model fit, as a result of including one or more variables, did not come at the expense of violating or dismissing the conceptual understanding of the influence each variable has on contaminant transport.

For each of the three combinations of variables initially considered as shown in Table 5-2, coefficients and model statistics are presented for the two sets of variables that best explain the distribution of elevated nitrate occurrence – one set of variables satisfies the statistical criterion established for this analysis (Models 1, 3, and 5) while the other model satisfies the statistical and non-statistical criteria established for this analysis (Models 2, 4, and 6).

To compare logistic regression models, a statistic called Akaike’s Information Criteria (AIC) was used. AIC allows models with diverse predictor variables to be directly compared rather than having to compare the models one variable at a time. AIC also has a cost-benefit structure. The benefit is a reduction in model error, and the cost is the number of parameters in the model. AIC is equal to G + 2p, where G is equal to -2 x log-likelihood, and p is the number of variables in the model (intercept plus slope coefficients). For a given dataset, the model with the lowest (most negative) AIC value is considered the best model. The predictive success of each logistic regression model can also be assessed by looking at the correct (concordant) and incorrect (discordant) classifications of the dichotomous dependent variable.

In relation to the criteria selected for this Study and available statistical measures of model goodness of fit, the results presented in Table 5-2 reveal the following key findings:

- The model with the highest predictive power that meets both model criteria is Model 6. This model includes only 4 variables (depth to top of first screen, recharge alternative 3, soil media, and hydraulic conductivity. This model has a relatively good model fitness (AIC = -241.7) and can explain 78.9 percent of the 470 nitrate occurrences.
- The logistic regression model with the highest predictive capability is Model 5. This model includes six variables that meet the 95 percent confidence interval criteria. This model has the best measure of model fitness (AIC = -295.8) and can explain 81.9 percent of the 470 nitrate occurrences. However, because the depth to water and impact of vadose zone variables in Model 5 are rated on the 1-to-10 DRASTIC scale and have a negative coefficient, this model did not satisfy both criteria established for this analysis.
- The relative influence of each variable in a logistic regression model can be evaluated by standardizing the variables. While the process of standardization does not change the test results, it does change the calculated slope coefficients by making them directly comparable. The variable with the largest influence is the one with its slope coefficient furthest away from 1. Of the variables in Model 6, groundwater recharge from precipitation is most influential followed by soil media type and then depth to top of first screen. Because a binary variable cannot be standardized, annual production could be not directly compared to the other variables, but its influence is relatively strong in comparison. Model results for the standardized version of Model 6 are provided in Appendix C.
- Revisions to ratings reflected in Alternative 3 of groundwater recharge and hydraulic conductivity help to explain the distribution of elevated nitrate occurrence better than either Alternatives 1 or 2 for both variables.
- Models 5 and 6 both incorporate the influence of artificial recharge and groundwater production in the Study Area. In comparison, the best logistic regression model that satisfies both model criteria and is developed only from original DRASTIC variables and ratings (Model 2) has a predictive capability of only 51.7 percent, or 27 percent less than Model 6. Model 2 also has a relatively poor measure of model fitness (AIC = -60.0).
- The original DRASTIC variables and ratings for aquifer media, topography (slope), and hydraulic conductivity Alternative 1 do not help to explain the distribution of elevated nitrate occurrence. These results are not surprising given the relationships depicted in boxplots for each of these variables (Figure 5-7f, -7i, and -7l).

5.4.2 Nitrate Probability Maps

Maps depicting the probability of elevated nitrate concentrations for the Shallow Aquifer and Principal Aquifer are shown in Figures 5-24 and 5-25, respectively. These maps were generated in ArcGIS by applying the coefficients from Logistic Regression Model 6 (Table 5-2) to the assigned values of the four variable information layers mapped across the Study Area. For the depth to top of first screen variable, the depth to the top of the Shallow Aquifer and Principal Aquifer were substituted. Probabilities were calculated on a 500 foot by 500 foot grid by applying the following formula:

$$P = \frac{e^{(b_o + bX)}}{1 + e^{(b_o + bX)}}$$

where b_o = -3.26206

b_1X_1 = -0.00260 x Depth to Top of First Screen / First Encountered Groundwater (ft-bgs)

b_2X_2 = 0.26859 x Groundwater Recharge Alternative 3 Rating (1 to 10)

b_3X_3 = 0.37750 x Soil Media Rating (1 to 10)

b_4X_4 = 1.51076 x Hydraulic Conductivity 3 Binary Rating (0 or 1)

To address sharp boundaries between areas of predicted low and high probability of elevated nitrate occurrence (observed along the boundary of groundwater impact zones for artificial recharge operations and along geographic section lines coinciding with production and non-production boundaries), resulting probability surfaces were smoothed using the Neighborhood Statistics Tool in ArcGIS using a radius of 1,000 feet. This tool assigns the average probability of all grid cells located within a 1,000-foot radius of each 500 foot by 500 foot grid cell.

The nitrate probability maps are dependent on two underlying assumptions: 1) the influence of average annual production values (0 to 1) is equivalent in both the Shallow and Principal aquifer nitrate probability maps, and 2) because the depth to the top of first screen was found to be significantly correlated to elevated nitrate probability and the depth to water removed due to violation of one model criteria, the estimated depth to the top of the Shallow Aquifer or Principal Aquifer represents a hypothetical depth to top of first screen of a Shallow Aquifer or Principal Aquifer well.

The nitrate probability maps show that elevated (anthropogenic) nitrate is most likely to occur in the Llagas Subbasin followed by the Coyote Subbasin and the Santa Clara Subbasin. For the Shallow Aquifer, this trend in probability is due largely to the combination of higher groundwater recharge rates estimated for the Llagas Subbasin, shallow water table conditions in the Coyote Narrows area (see Figure 2-1), and the influence of artificial recharge operations in the Santa Clara Subbasin. For the Principal Aquifer, the generally lower probability of elevated nitrate occurrence predicted in the Santa Clara Subbasin is a result of the influence of the regional confining layer on groundwater recharge, relatively deep aquifer conditions, and dilution effect from artificial recharge operations.

As expected, the probability of elevated nitrate occurrence is higher in the Shallow Aquifer than the Principal Aquifer. However, differences in probability between the two aquifers are relatively small across the Study Area. In the Llagas Subbasin, higher estimated groundwater recharge rates result in relatively high probability of elevated nitrate occurrence in both aquifers. In the vicinity of the Coyote Narrows, the combination of a relatively shallow Principal Aquifer and active production contributes to the high probabilities of elevated nitrate occurrence in both aquifers. Differences in elevated nitrate probability between the two aquifers are greatest in the western recharge zone of the Santa Clara Subbasin due to the deepening of the Principal Aquifer relative to the Shallow Aquifer and in northern interior of the Santa Clara Subbasin due to the protection from anthropogenic nitrate afforded to the Principal Aquifer by the regional confining layer. Perhaps the most surprising result of the sensitivity assessment are the high probabilities of nitrate occurrence predicted in the outer western portion of confined zone of the Santa Clara Subbasin. It is here that the influence of groundwater production is most pronounced, supporting the theory that the rate at which contamination is transported from the surface to groundwater is highest in the vicinity of groundwater production wells, where vertical gradients are steepest and groundwater velocities are highest.

5.4.3 Groundwater Sensitivity Maps

Figures 5-26 and 5-27 show the final groundwater sensitivity maps developed for the Shallow Aquifer and Principal Aquifer, respectively. Percent probability scales used in the nitrate probability maps were translated to a scale of 1 to 10 to prepare the sensitivity assessment results for inclusion in the final vulnerability analysis. Areas where the probability of elevated nitrate occurrence is less than 15 percent were assigned a sensitivity ranking of 1, while areas having a probability between 16 and 25 percent were assigned a sensitivity value of 2, and so forth.

The final sensitivity maps generally depict the same relationships as identified in the nitrate probability maps for both aquifers. The primary difference between the two sets of maps is that the sensitivity of areas located near artificial recharge facilities on the sensitivity maps are subjectively ranked as more highly sensitive (in contrast to the nitrate probability maps).

5.4.4 Conclusions

Based on the results of the groundwater sensitivity assessment, the following conclusions can be made regarding the sensitivity of the Shallow and Principal aquifers across the three Study Area groundwater subbasins:

- Evaluation of intrinsic aquifer properties and aquifer stresses using logistic regression analysis and nitrate occurrence data revealed that the following hydrogeologic variables were significantly correlated to groundwater sensitivity:
    - Groundwater recharge from precipitation
    - Annual groundwater production
    - Soil media type
    - Depth to top of first screen
- The sensitivity of the Shallow Aquifer to contamination is greater than the Principal Aquifer in all three groundwater subbasins due primarily to the relative depth of each aquifer in the confined zones.

- The sensitivity of the Shallow and Principal aquifers is generally highest in the Llagas Subbasin, followed by the Coyote Subbasin, and Santa Clara Subbasin.
- Despite the protection afforded by the regional confining layer in the southern portion of the Llagas Subbasin, both the Shallow and Principal aquifers are highly sensitive to contamination due to high recharge rates and permeable soils.
- The sensitivity of the Shallow and Principal aquifers in the Coyote Subbasin are also relatively high due primarily to shallow aquifer conditions, high recharge rates, and large amounts of groundwater production.
- Although the confined zone in the Santa Clara Subbasin affords relatively good protection from surface contamination, the outer western confined zone appears to be highly sensitive to contamination due to the significant groundwater production in this area.

6 Potentially Contaminating Activities (PCA) Risk Analysis

6.1 Introduction

Risk of groundwater contamination from human activities at the ground surface is the second half of the groundwater vulnerability assessment. Potentially contaminating activities (PCAs), some of which pose considerable contamination risk, arise from many activities. PCAs are defined for this Study as human activities at the ground surface that are actual or potential sources of contamination for groundwater. PCAs include sources of both microbiological and chemical contaminants that could have adverse effects upon human health (DPH, 1999). It is the use of land for various purposes that ultimately creates the risk of groundwater contamination. In the broadest sense, PCAs can be grouped into three broad categories that are tied to land use: future (planned) use, current use, and past use.

Several studies suggest that a single data source, such as land use information meant for planning purposes, is usually insufficiently detailed for evaluating PCA risk (e.g., Johansson, et. al., 1999; Eckhardt and Stackelberg, 1995; and others). Accordingly, eight PCA-risk factors were used in this Study to characterize overall PCA risk. In combination, these factors conservatively predict the potential for groundwater contamination associated with human activity.

6.2 Objectives

The objective of the PCA Risk Analysis is to compile a comprehensive database of potentially contaminating activities in the Study Area and to develop a technically-sound and scientifically-defensible ranking of those activities. The PCA-risk map generated on a 500 foot by 500 foot grid is intended to illustrate the relative risk to groundwater quality associated with land use activities. In developing the ranking methodology, emphasis is placed on accurately characterizing the maximum risks. Thus, the ranking will be conservative and will not underestimate potential risks.

6.3 Methodology

Data for this Study were obtained from various public and private sources as described in detail in Appendix B. Many data sources were necessary to characterize PCA risk because groundwater contamination from human activities arises from many origins. For example, contamination may occur at a chemical manufacturing plant at a specific location (point source), but it may also occur due to an abundance of septic systems and the use of agricultural chemicals in a given area (nonpoint source).

Inherent to the use of third-party data are difficulties associated with different formats and variables and sometimes unknown data quality. The use of multiple PCA-risk factors, a cornerstone of the approach described herein, improves overall data quality. The improvement in data quality is achieved as a consequence of redundancies among datasets.

The PCA-risk analysis considers four main risk factors or categories—general land use (GLU), potentially contaminating business activities (PCBA), known contaminated sites (KCS), and supplemental data. The supplemental data captures activities that do not fit neatly into the other three foundational risk factors. The supplemental data consists of five separate PCAs, which were included as a series of individual GIS layers. Risk-rankings determined by the PCBA analysis were used to rank the supplemental data.

A separate, regional-scale GIS layer was developed for each PCA-risk factor. A grand total of eight data layers were used to calculate the overall PCA risk:

- Data layer 1: General Land Use (GLU)
- Data layer 2: Potentially Contaminating Business Activities (PCBA)
- Data layer 3: Known Contaminated Sites (KCS)
- Supplemental Data Layers
    - Data layer 4: Irrigated agriculture
    - Data layer 5: Septic-system density
    - Data layer 6: Mines
    - Data layer 7: Landfills
    - Data layer 8: Petroleum pipelines

Conceptually, GLU should be thought of as the base layer, because it exists as areal data, it includes the full range of risk rankings from low to high (with the exception of "known to be contaminated", because no municipal entities in the Study Area use "contaminated" as a land use category), and it is mapped contiguously on a regional scale. PCBAs, KCSs, and the supplemental data are used to identify locations of moderate- to high-risk activities.

The risk ranks were determined by a systematic, reproducible procedure in which every attempt was made to minimize subjectivity. The overall PCA risk was determined by merging the individual GIS layers and mapping the results to a regional grid. Risk ranks were determined for each on a scale of 1 to 10 (Table 6-1).

Calculating the overall PCA risk is accomplished by integrating the multiple, independent risk factors listed above. Some overlap exists between the individual PCA-risk factors. A concerted effort was made to avoid the inadvertent exclusion of a potential risk factor from the calculation of overall PCA risk. The built-in redundancy across datasets helps prevent such exclusions. Moreover, integration of individual data layers facilitates identification of the principal driver of PCA risk for areas of concern.

6.3.1 Method for Ranking Cells in the Regional Grid

The PCA-risk map for the Study Area is based on a uniform grid with 500 foot by 500 foot cells—each of the eight data layers is gridded. Each layer has one type of data associated with it:

- Layers with polygon data
    - Cells that do not straddle polygon boundaries are assigned the risk rank of the underlying polygon

    - Cells that straddle more than one polygon are assigned the risk rank of the highest ranked polygon

- Layers with point data
    - Cells that contain one point are assigned the risk rank of that point
    - Cells that contain more than one point are assigned the risk rank of the highest ranked point

- Layers with linear data (pipelines only)
    - Cells that are touched by a linear feature are assigned the risk rank of that feature.

The overall PCA-risk ranking takes into account all eight data layers. The PCA analysis drills though all eight gridded layers for each cell. The maximum risk rank in a given cell over the eight layers becomes the overall PCA risk rank for that cell (Figure 6-1).

6.3.2 Rationale for Ranking Cells in the Regional Grid

Cells that straddle more than one polygon or contain more than one data point require a procedure for determining the risk rank. Various weighted-average schemes were evaluated to calculate a cell risk-rank. The problem with weighted averages is that high values may be averaged away if lower values are present in the population sample. In keeping with the goal of accurately characterizing the maximum risks, reduction of even a single high risk rank in a cell is undesirable, even if one high-risk point is outnumbered by several low-risk points. Given that one large accidental release of a hazardous substance is capable of causing significant damage to the groundwater resource, it would is prudent honor all high-risk points in the calculating the cell risk rank.

To avoid inadvertent reductions of cell-wide risk rankings, the highest risk rank of all points or polygons within a cell's borders is assigned to be the risk rank for the entire cell. For the pipelines layer, if the pipeline touches the cell the risk rank of the pipeline is assigned to that cell.

The rationale for using the highest risk rank from all eight layers to assign the overall PCA risk rank for each cell follows the same logic as was used for the assigning risk ranks to each cell in individual layers.

6.3.3 General Land Use (GLU)

6.3.3.1 Method

General plan land use data were obtained from thirteen entities within the three subbasins that comprise the Study Area:

- Campbell
- Cupertino
- Los Gatos
- Milpitas
- Morgan Hill
- Mountain View
- Palo Alto
- Santa Clara

- Santa Clara County
- Santa Clara Valley Water District
- San Jose
- Saratoga
- Sunnyvale

GIS files from Gilroy were not available for this Study; therefore, land uses were classified using the County parcel database Land use for Los Altos was also classified from the County parcel database.

Each of these entities uses slightly different names to describe similar general plan land use categories. Thus, each data set required transformation to a standard set of land use descriptions. Twenty-nine land use categories were selected for this Study to account for the range of land uses (Table 6-2). The transformed classification scheme employs names commonly used for zoning and land use planning. The transformed scheme is an intersection of the thirteen raw datasets; although some categories did not correlate directly. Figure 6-2 shows the relative GLU risk rankings for the Study Area using the transformed classification scheme.

6.3.3.2 Rationale

There is no consistent ranking scheme in the literature that can capture the relative PCA risk for the transformed classification scheme used for this Study. To devise a consistently objective ranking scheme, the risk rank for each category was derived from the sources listed in Table 6-2.

Some of the land use categories in the transformed classification scheme (or close approximations thereof) were assigned risk ranks in the DWSAP program guidelines (DPH, 1999). If so ranked, the risk rank assigned to that category in this Study was adopted directly from the DWSAP guidelines (see Table 6-2).

Categories not ranked by the DWSAP program required further research. Each land use category is defined by the types of permitted activities within it. There are slight variations in permitted activities from municipality to municipality, but by and large equivalent categories are similar. For example, some municipalities allow gas stations in areas designated for mixed-use, while others may not (APA, 2009; City of Sunnyvale, 2007). If the majority of data sources for a particular land use category permit a given business type, the inclusion of that business type in the category was considered valid for risk-ranking purposes.

For commercial, municipal, and industrial categories not ranked by the DWSAP program, the risk-rank of the highest risk permitted activity in the category was assigned to be the risk rank of the category in question. Note that the risk ranks for particular business types were determined in the PCBA analysis, which is described below.

6.3.4 Potentially Contaminating Business Activities (PCBA)

6.3.4.1 Method

Regional-scale studies of groundwater vulnerability that consider a wide range of PCAs are rare. In general, previous methods for groundwater vulnerability assessment—that incorporate multiple PCAs—were focused on a single well or well field. True regional-scale groundwater vulnerability assessments have also been performed. Such studies have focused on the contamination risk from a single class of potential contaminants, such as pesticides (Loague et al., 1996).

Accordingly, given the size of the Study Area and the overall goals for the Study, it was necessary to develop a new methodology that could assess many different PCAs across a large area. For the method developed in this Study, three independent components were combined to determine the PCA risk posed by businesses operating in the Study Area—a regulatory component, a historical component, and a technically-supported subjective component. Each component in this new hybrid objective-subjective method was evaluated separately and ranked on a scale of 0 – 3. The three components were then combined to provide an overall PCBA risk on a scale of 1 – 9. The results of the risk-ranking procedure used for the PCBAs are also used to rank the mines, landfills, and pipeline risk factors.

Names, locations, and other attributes of PCBAs were obtained from the search company InfoUSA. The search was performed for postal zip codes within the Study Area. Thousands of businesses were found within these zip codes. The InfoUSA search was focused by searching for only those activities indentified as very high risk, high risk, and moderate risk by the DWSAP program (DPH, 1999). InfoUSA data includes U.S. Department of Labor's Standard Industrial Classification (SIC) codes for each business. The SIC selection process used for the InfoUSA search is described in Appendix B. The search produced 9,622 records, with approximately 9,600 unique businesses (e.g., Moffett Field has 15 separate entries, but is considered a single site for the present purpose).

The regional-scale screening tool described in this report employs groupings of related business types. A balance between parsimony and defining too many groups was achieved by using the SIC code system (USDOL, 2009), which is a hierarchical scheme.

The highest levels of organization in the SIC system are 10 Divisions—there are ten divisions, denoted by the letters A – J. The Divisions are subdivided into 83 Major Groups. The Major Groups are subdivided into hundreds of Industry Groups, which are subsequently subdivided into thousands of business types. The SIC system uses a six-digit code to identify each business type. The Major Group is denoted by the first two digits of the SIC code; the Industry Group is denoted by the next two digits; and the last two digits of the SIC code represents the actual business type.

Consider the following two examples. The first example shows how gas stations and truck stops are classified, while the second example shows how an auto repair facility is classified.

Example 1

- Division A: Retail Trade
    - Major Group 55: Automotive Dealers and Gasoline Service Stations
        - Industry Group 5541: Gasoline Service Stations
            - 5541-01: Service station—gasoline and oil
            - 5541-03: Truck stops and plazas

Example 2

- Division I: Services
    - Major Group 75: Automotive Repair, Services, and Parking
        - Industry Group 7538: General Automotive Repair Shops
            - 7538-01: Automotive repair and services

Using the Division level to group and rank businesses would result in fewer groups but cause too many dissimilar businesses to be lumped together. In such a case, risk ranking becomes less meaningful. On the other hand, using the Industry Group level would result in an enormous number of groups and would make the task of risk ranking onerous. The Major Group level is thus used as basis for classification and ranking of the PCBAs in the Study Area. This level within the SIC system allows sufficient separation of business types, while making the task of assigning risk ranks manageable.

Because many of the 83 Major Groups in SIC system pose no risk of groundwater contamination, a subset of 48 Major Groups was selected. Selection was based on PCAs ranked very high, high, and moderate risk by the DWSAP program. A relative risk rank was determined for each of the 48 Major Groups.

Regulatory Component: DWSAP

Each PCA on the DWSAP list was assigned a SIC Major Group code. The DWSAP risk rankings were then transformed to a scale of 1 to 3, where 1 represents moderate risk, 2 represents high risk, and 3 represents very high risk. No changes to DWSAP risk ranks were made by the transformation (DPH, 1999). A few of the selected Major Groups were not ranked directly by DWSAP. These Groups were assigned the DWSAP rank of the closest related PCA. The PCBA risk rankings derived from the DWSAP program are shown in Table 6-3.

Objective Component: Historical Assessment

The historical assessment was based on the database of known contaminant sites (KCS). The KCS database identifies the type of contamination site (i.e., Superfund, SLIC, LUFT, etc.) as well as the status of the site (e.g., open or closed). LUFT sites represent 73 percent of the sites in the KCS database. Because both past and present LUFTs are included in the database, and no distinction is made between the two, LUFTs occur ubiquitously throughout the Study Area. Moreover, they are associated with a wide assortment of business activities.

Because of the undifferentiated mix of past and present sites in the KCS database and their widespread occurrence spatially and across industries, LUFT sites by themselves are not considered to be an accurate historical indicator of PCA risk. However, the fact that they are ubiquitous in the Study Area allows LUFT sites to be used as a comparative factor for determining the historical portion of PCBA risk rank. Such a comparison is valid under the assumption that non-LUFT sites pose a more serious risk of groundwater contamination than do LUFT sites.

To perform the comparative historical assessment, the numbers of LUFT and non-LUFT sites within each Major Group were tabulated and their relative percentages calculated. If the percentage of LUFT sites was less than 50 percent of the total number of sites in a given Major Group, that Group was assigned a risk rank of 3. If the percentage of LUFT sites was greater than 50 percent of the total number of sites but less than 100 percent, the Group was assigned a risk rank of 2. If a particular Major Group had 100 percent LUFT sites, it was assigned a risk rank of 1. Major Groups with no KCS sites were assigned a risk rank of zero for the objective component.

The risk-ranking methodology for the historical assessment includes a provision for SIC Major Groups with large numbers of KCSs, because the risk of contamination increases as the number of sites increases. Ninety-five percent of all SIC Major Groups in this Study have less than 200 KCSs. The two Major Groups with more than 200 KCSs were assigned a risk rank of 3 (i.e., Major Group 55: Retail: Automotive Dealers & Gasoline Service Stations; and Major Group 75: Automotive Repair, Services, & Parking).

The PCBA risk rankings derived from the historical assessment are shown in Table 6-4.

Subjective Component: PCBA-Risk Matrix

To determine the risk rankings for each Major Group, six classes of risk were defined and applied to each group. Each Major Group was ranked on a scale of 0 to 3 for each class of risk and the rankings for the six classes were summed using a weighted average, with the first four risk classes weighted higher than the last two. The risk rank of zero is used only for the last risk class, emerging issues and uncertainty. The weights for each risk class are shown in Table 6-5, as are the risk rankings from the PCBA risk matrix. Conceptually, there is some overlap between the risk classes used for the subjective component of this Study and the assessment performed by the DWSAP program. But as discussed above, the built-in redundancy in the risk-assessment methodology improves overall data quality and provides a mechanism to reduce the chance of an inadvertent omission of PCA risk. The risk classes are:

- Potential contamination risk (1=not likely, 2=likely, 3=very likely)
    - Does the PCBA pose a risk of any type of contamination?
- Potential health threat (1=not likely, 2=likely, 3=very likely)
    - Would contaminants released due to the PCBA be deleterious to human health?
- Volume generated (1=small volume, 2=moderate volume, 3=large volume)
    - Some PCBAs produce larger volumes of hazardous substances than others
    - What volume of hazardous substances is likely to be involved in an accidental release that impacts groundwater?
- Potential for aquifer impact if released (1=not likely, 2=likely, 3=very likely)
    - If an accidental release occurred, are hazardous substances likely to be sequestered in the soil or reach the water table based on fate and transport properties?
- Engineering controls at the PCBA (1=highly effective controls, 2=effective controls, 3=no controls)
    - Have new technologies reduced the likelihood of groundwater contamination due to the PCBA?

- Emerging issues and uncertainty (0=insignificant, 1=small uncertainty or potential for emerging issues, 2=moderate uncertainty or potential for emerging issues, 3=high degree of uncertainty or potential for emerging issues)
  - What is the likelihood that unforeseen contamination scenarios could develop?
  - Examples include the recognition that MTBE in gasoline was a contamination problem, the recent concern over drinking-water disinfection byproducts, and the potential for nano-contaminants.

6.3.4.2 Rationale

The task of assigning relative risk ranks to 48 categories of business activities was accomplished by combining three independent measures of risk assessment. The regulatory component provides a framework that has withstood longstanding, critical peer scrutiny. Over one hundred separate activities have been critically determined by the DWSAP program to have the potential to negatively impact water supply wells. The relative risk ranks assigned to PCAs by the DWSAP program therefore provide a well-established foundation for PCBA risk ranking in this Study.

The historical assessment (i.e., the objective component) provides insight into the potential for business activities in the Study Area to contaminate groundwater. The other two components of PCBA risk describe the risk posed by PCBAs in general at any locale. The assessment of past contamination problems in the Study Area calibrates these general risk profiles to the Santa Clara, Coyote, and Llagas groundwater subbasins.

The subjective component incorporates institutional knowledge and professional experience into the overall, relative PCBA-risk rankings. The intent of the zero rank for emerging issues and uncertainty category is to identify PCBAs that have not changed practices for a significant period of time and/or have procedures and processes that are transparent and are not complicated. This category also provides a way to increase the risk rank of PCBAs with ineffective or suspect procedures for control of hazardous substances, or risky activities for which effective controls have not been developed or implemented.

Table 6-6 summarizes the component data used to calculate the overall PCBA risk for each Major Group. Figure 6-3 shows the relative PCBA risk rankings for the Study Area.

6.3.5 Known Contaminated Sites (KCS)

6.3.5.1 Method

Known contaminated sites (KCS) were obtained from:

- EnviroStor (DTSC, 2008)
- GeoTracker (SWRCB, 2008)
- Santa Clara Valley Water District (SLIC sites).

The KCS database for the Study Area contains a total of 2,839 sites. Each of these sites belongs to one of two “status” categories—closed sites or open sites. Closed sites include any site with a status that suggests contaminated groundwater is no longer migrating offsite (e.g., case closed, no further action). Such sites are assigned a risk rank of 7. All other sites in the KCS database are considered to be open sites. The status of open indicates that a groundwater contamination issue requires some level of action. Also within the open designation are sites that are under an order of investigation, or are still conducting verification monitoring. Consistent with the conservative approach taken in this Study, open sites are assigned a risk rank of 10.

There are two different datasets for the KCSs in the Study Area:

- Point data for all KCSs
- SLIC sites mapped by parcel.

Figure 6-4 shows the relative KCS risk rankings for the Study Area for both KCS databases.

6.3.5.2 Rationale

It is assumed that at open sites the underlying aquifer is already impacted. Future activities in these areas pose a higher risk because of the added potential to reactivate or otherwise impact the existing contamination. Therefore, open sites are assigned risk rank of 10, as are all Superfund sites. Closed sites, on the other hand, have caused a groundwater impact, but currently are in an "improved" state. They have been designated as closed because the cause of the negative impact has ceased. Nevertheless, future circumstances may render the decision to close the site invalid. For example, detection limits or maximum contaminant levels may change. Furthermore, a change in land use or business type may force a closed site to be reopened. Therefore, even though the listed groundwater impact has ceased, the risk of further contamination has not disappeared. Consequently, closed KCSs are given a risk ranking of 7.

6.3.6 Supplemental Data Layers

6.3.6.1 Method

Each entry in the extensive PCBA database developed for this Study provides a point located at a single, physical address. This is useful for identifying most PCBAs, but some PCBAs do not exist at a single location. Moreover, certain PCBAs warrant a higher degree of scrutiny to ensure that they are included in the PCA risk assessment. These PCAs are not sufficiently covered by other analyses. Figures 6-5 through 6-9 show the PCA risk rankings for the supplemental data.

PCAs that warrant special consideration are:

- Septic-system density (see Table 6-7)
- Irrigated agriculture: Irrigated agriculture: Risk = 5
- Landfills: Risk = 9 (SIC Major Group 49)
- Petroleum pipelines: Risk = 7 (SIC Major Group 46)
- Mines
    - Metal mines: Risk = 9 (SIC Major Group 10)
    - Non-metal mines: Risk = 5 (SIC Major Group 14)

6.3.6.2 Rationale

With the exception of irrigated agriculture and septic system density, risk ranks were taken directly from the PCBA analysis. Risk ranks were calculated in the PCBA analysis for landfills, petroleum pipelines, and mines (Table 6-6). Irrigated agriculture was assigned a risk rank of 5, because DWSAP (DPH, 1999) ranks it as high within the two-year capture zone (Zone A) of a single well, but it is ranked as moderate for all other distances from a public water supply well. Septic-system density was ranked on a scale of 1 to 9 in a manner consistent with DWSAP rankings (Table 6-7). For this Study, more detailed rankings were determined, based on the magnitude of septic system density, than was done so for the DWSAP program. Areas serviced by individual septic systems were identified as those outside of urban service areas, as mapped by LAFCO (2001). The density of septic systems was calculated by dividing the land area by the number of households per acre based on census 2000 data (ESRI, 2000).

6.3.7 Additional Information Layers

6.3.7.1 Method

Other activities that were not included but were added to the tool as information layers included the following.

Several supplemental data layers were developed to capture generalized PCAs and PCAs not considered part of the overall PCA-risk calculation.

- Railroads
- Roads
- Contaminant plumes
- District-identified dry cleaners
- Zoning

6.3.7.2 Rationale

The supplemental data layers are included in the GIS tool as information layers, which can be viewed as overlays on the PCA-risk map. These information layers are significant, but they are not part of the overall PCA-risk calculation for the following reasons. While roads and railroads do transport hazardous chemicals, the risk of a release at a particular location is difficult to determine given the large Study Area, and can be considered equivalent to the risk of a random event. Furthermore, the percentage of passenger transportation is high, particularly on roads. For comparison, consider petroleum pipelines, which are included in the overall PCA-risk calculation. The risk of pipeline rupture at a particular location is difficult to quantify, but petroleum pipelines transport hazardous substances 100 percent of the time. Because of this difference, petroleum pipelines are part of the overall PCA-risk calculation, but roads and railroads are not.

Dry cleaners are well known to be potential contamination sources (e.g., Mohr, 2007). Dry cleaning sites that are known to be contamination are part of the KCS database. Dry cleaning facilities that actively operate plants, but have no history of contamination, are included in the PCBA databases. As such, there is no need for a separate data layer of the District-identified sites for calculation purposes.

Contaminant plumes are the result of a contamination occurrence. The transport and spreading of subsurface contamination is a function of aquifer properties and the release mass and properties. The surface locations of contaminated sites are covered by the KCS database. The plumes map is available as an information layer.

Lastly, zoning is also included as an information layer. General plan land use is considered to be more indicative of current activity. Zoning represents planned use of the land, while GLU shows, for the most part, the actual, present-day use of the land.

6.3.8 Methodology Validation

Information compiled for the DWSAP program was obtained from the DPH and used to validate the methodology used in this Study to quantify the risk of PCAs across the three Study Area groundwater subbasins. To do so, the number of “High” and “Very High Risk” PCAs identified within the two-year capture (Zone A) of each Study Area public water supply well was compared to the average Study-predicted PCA Risk within the same area. A correlation between these two independent, but related datasets provide a validation that the method used in this Study compares favorably to an established and accepted method.

The two-year capture zone was identified for 153 Study Area public water supply wells in the DWSAP database. With the exception of a few wells located in the Coyote and Llagas subbasins, most of the public water supply wells for which DWSAP assessments have been performed are located in the Santa Clara Subbasin. Figure 6-10 shows the two-year capture zones identified in the DWSAP database for the public wells located in the Santa Clara and northern Coyote subbasins. Figure 6-11 shows two sets of boxplots. The upper set of boxplots depicts the relationship between 1) the average PCA Risk associated with the two-year well capture zone and the sum of High and Very High Risk PCAs identified within the same area for the 153 wells in the DWSAP database. The boxplot indicates that the difference in the median number of PCAs for wells with an average PCA Risk of 1 to 5 is significant and lower than for wells with an average PCA Risk of 6 to 10. The lower boxplot shows that the same correlation is observed when comparing wells with an average PCA Risk of 4 to 5 to wells with an average PCA Risk of 6 to 7. These findings confirm that the method used in this Study to quantify PCA risk and the final risk categories are meaningful and correlate well to the DWSAP method.

6.4 Conclusions

Figure 6-1 shows the PCA risk map of the Study Area. As shown in the figure, large portions of the Santa Clara Subbasin are at high risk of contamination from PCAs. This is because the Santa Clara Subbasin is highly developed with residential, commercial, and industrial areas and many associated industrial and commercial contaminant release sites along with the lingering impacts of agricultural releases. High risks are associated with commercial industrial areas and areas of known groundwater contamination in the Santa Clara Subbasin.

Relatively lower overall PCA risks are associated with the Coyote Subbasin, which is relatively rural, undeveloped, and mostly unincorporated with far fewer industrial/commercial contaminant release sites. An area of higher risk in the northern part of the subbasin is associated with the Metcalf facility. Most of the subbasin shows a moderate level of risk associated with irrigated agriculture. It is important to note that the Coyote Valley has the most potential for future residential and commercial development and thus the most potential for an increase in PCA risk in the future.

Similarly, relatively lower overall PCA risk (compared with the Santa Clara Subbasin) is found in the Llagas Subbasin due to its more rural nature. Areas of relatively higher risk are associated with residential and commercial development in the vicinity of the cities of Morgan Hill and Gilroy. Moderate PCA risk in the central portion of the subbasin is associated with irrigated agriculture. While continued conversion of rural to residential and commercial land use in the vicinity of the cities of Morgan Hill and Gilroy in the future will likely increase PCA risk in these areas, the central portion of the subbasin is expected to remain relatively unchanged with respect to PCA risk given the zoning.

7 Groundwater Vulnerability Analysis

The principal objective of this Study is to determine the groundwater vulnerability for the Santa Clara, Coyote, and Llagas groundwater subbasins. Groundwater vulnerability for this Study is a function of both the potential for contamination to reach the groundwater, as defined by sensitivity analysis and the presence of a potential source of contamination, as defined by PCA risk. There are an infinite number of linear and nonlinear equations that could calculate groundwater vulnerability from aquifer sensitivity and PCA risk, many of which were evaluated as part of the Study. Ultimately, a relatively simple approach was developed, which is scientifically defensible and meets the Study goal of predicting the maximum vulnerability.

7.1 Combining Aquifer Sensitivity and PCA Risk

Aquifer sensitivity and PCA risk are two independent components. When considered together, these two components comprise groundwater vulnerability. With the exception of human impacts on groundwater flow patterns (e.g., pumping and artificial recharge), aquifer sensitivity is generally independent of human activity. For this Study, both intrinsic aquifer properties and groundwater management considerations that influence groundwater flow (e.g., pumping and artificial recharge) were considered. PCA risk arises from human activity; it is independent of aquifer sensitivity. Combining both aquifer sensitivity and PCA risk yields a more complete understanding of potential groundwater vulnerability. In addition, the PCA risk component allow for changes in land use to be evaluated for their potential contribution to groundwater vulnerability. Accordingly, this Groundwater Vulnerability Study provides a robust tool for understanding, defining, and directing water quality programs and issues.

7.1.1 Method

The approach used to determining groundwater vulnerability for this Study is consistent, rational, and accounts for all possible combinations of aquifer sensitivity and PCA risk. The primary consideration in developing the approach is whether to weight PCA risk and aquifer sensitivity equally or to weight one more heavily than the other. Below is a summary analysis of the relative limitations and advantages of different approaches.

- <u>Weighting PCA risk higher than aquifer sensitivity</u> - limits the ability to differentiate or prioritize groundwater vulnerability for locations of similar PCA risk; however, it expands the ability to differentiate groundwater vulnerability for locations of similar aquifer sensitivity. This type of approach tends to group together areas of similar PCA risk regardless of aquifer sensitivity.
- <u>Weighting aquifer sensitivity higher than PCA risk</u> - limits the ability to differentiate or prioritize groundwater vulnerability for locations of similar aquifer sensitivity; however, it expands the ability to differentiate groundwater vulnerability for locations of similar PCA risk. This type of approach tends to group together areas of similar aquifer sensitivity regardless of PCA risk.
- <u>Equal weighting of PCA risk and aquifer sensitivity</u> – provides the ability to easily differentiate the contribution of PCA risk or aquifer sensitivity in the

groundwater vulnerability. This type of approach provides the widest range of groundwater vulnerability for the full range of both PCA risk and aquifer sensitivity and is consistent with approaches used in the DWSAP program and the District's dry cleaner study (Mohr, September 2007).

The ability of the selected approach to provide a range of vulnerability results for extreme values of either sensitivity or PCA risk is an important consideration. Without such ability, the vulnerability assessment would be no better than a single component analysis.

The equally weighted approach was selected for calculating groundwater vulnerability in this Study. The arithmetic mean of each possible combination of aquifer sensitivity rank and PCA risk rank is presented in the matrix shown in Figure 7-1. The aquifer sensitivity ranks and the PCA risk ranks are the X and Y axis of the matrix, respectively. They produce the groundwater vulnerability rankings shown in the interior of the matrix. In Figure 7-1, green represents low vulnerability (rankings 1 to 3), yellow represents moderate vulnerability (rankings 4 to 5), orange represents high vulnerability (rankings 6 to 7), and red represents very high vulnerability (rankings 8 to 10).

Once the vulnerability rankings are determined, the results are mapped. Aquifer sensitivity and PCA risk have been mapped to the 500 foot by 500 foot grid that covers the entire Study Area. Groundwater vulnerability is then calculated from the two component analyses for each grid cell. The basis for any particular vulnerability ranking at any location can be readily discerned by referring to the two independent component analyses that determine groundwater vulnerability.

7.1.2 Rationale

Six criteria were defined to evaluate the success of the selected vulnerability approach. To be considered successful, the approach should:

1. Provide for the ability to differentiate groundwater vulnerability for areas of similar PCA risk over the full range of aquifer sensitivities.
2. Provide for the ability to differentiate groundwater vulnerability for areas of similar aquifer sensitivity over the full range of PCA risk.
3. Define areas of lowest groundwater vulnerability as a combination of lowest aquifer sensitivity and lowest PCA risk.
4. Define areas of highest groundwater vulnerability as a combination of highest aquifer sensitivity and highest PCA risk.
5. Define areas of high PCA risk to have a range of moderate to very high groundwater vulnerability, depending on the rank of aquifer sensitivities.
6. Define areas of high aquifer sensitivity to have a range of moderate to very high groundwater vulnerability, depending on the rank of PCA risk.

The ability of the selected vulnerability approach to meet the listed criteria can be demonstrated by examination of the groundwater vulnerability matrix shown in Figure 7-1. Criteria 1 and 2 define the goal of having the widest possible range of groundwater vulnerability ranks. Figure 7-1 shows that for every row of PCA risk or column of aquifer sensitivity, the range of groundwater vulnerability spans four or five ranks. This provides a maximum differential for the entire matrix. Weighting the matrix to either PCA risk or aquifer sensitivity would cause one parameter to have a wider range of vulnerability ranks, but at the expense of decreasing the range of ranks for the other.

Criteria 3 and 4 have the goal of defining the maximum and minimum groundwater vulnerabilities in terms of a comparable PCA risk and aquifer sensitivity. Figure 7-1 shows that the lowest groundwater vulnerability ranks are defined in the lower left-hand corner where both the PCA risk and aquifer sensitivity are low. Similarly, in the upper right-hand corner, the highest groundwater vulnerability ranks are defined where both the PCA risk and aquifer sensitivity are high. Weighting the matrix to either PCA risk or aquifer sensitivity would cause the maximum and minimum groundwater vulnerability to shift towards one side or the other. Such weighting strategies would potentially cause areas of more moderate values to have the maximum or minimum groundwater vulnerability rankings. This shifting of vulnerability ranks was not considered to provide a clear advantage for the range of potential applications of the groundwater vulnerability tool.

Criterion 5 defines the goal of being able to prioritize areas of high PCA risk with respect to a range of aquifer sensitivities. Because such areas are of high PCA risk, it would not be appropriate for them to have low groundwater vulnerability rankings. This is true even in areas of the lowest aquifer sensitivity because there is always the potential for factors that control low aquifer sensitivity on a regional scale analysis not to be applicable on a local or site-specific basis. For example, only a single improperly sealed or abandoned well located in the vicinity of a known contamination plume in a confined area could allow contamination of a low sensitivity aquifer area. Because the locations of improperly sealed and abandoned wells are not well characterized, they cannot be accurately represented in the PCA risk. The equally weighted approach allows the analysis to be conservative with respect to the potential for groundwater impacts from high risk PCAs.

Similarly, Criterion 6 defines the goal of being able to prioritize areas of high aquifer sensitivity with respect to a range of PCA risk. Because such areas are of high aquifer sensitivity, it would be inappropriate for them to have low groundwater vulnerability rankings. This is true even in areas of the lowest PCA risk, because there is always the potential for unusual or transient events that cannot be fully characterized in PCA analysis. For example, open-space areas of natural vegetation are considered to be one of the lowest PCA risks. However, if these areas are situated over the highest aquifer sensitivity, there is still potential groundwater vulnerability. For example, the open space could be used to illegally dump chemicals resulting in groundwater contamination. The equally weighted approach allows the analysis to be conservative with respect to the potential for groundwater impacts in areas of high aquifer sensitivity.

7.2 Results and Discussion

Vulnerability maps were created for both the Shallow and Principal aquifers by combining the Shallow and Principal groundwater sensitivity maps and the PCA risk map. Figures 7-2 and 7-3 show the Shallow and Principal groundwater vulnerability maps, respectively. Differences between the two maps are due to differences in aquifer sensitivity, since PCA risk does not change. As might be expected, the vulnerability of the Shallow Aquifer is greater than the Principal Aquifer in areas of confinement. Where the groundwater is unconfined there is no difference between the maps. The Santa Clara Subbasin shows the greatest difference between the two maps in the confined zone. The density of commercial/industrial sites and known contamination release sites in the northern Santa Clara Subbasin make the Shallow Aquifer highly vulnerable to contamination.

The Llagas and Coyote subbasins exhibit high to very high groundwater vulnerability in both the Shallow and Principal aquifers. The high vulnerability is driven primarily by the high sensitivity in these two subbasins. As discussed elsewhere, given the potential for future development in the Coyote Subbasin, the high degree of vulnerability of the subbasin requires the highest level of effort directed toward protection.

The Santa Clara Subbasin shows a wide range of groundwater vulnerability from low to very high in the Principal Aquifer, with the majority of the subbasin in the medium to high range. The vulnerability is primarily driven by the density of commercial, industrial, and known contaminant release sites in the subbasin.

8 Vulnerability Tool

8.1 Functionality

A web-based GIS tool was developed with existing GIS base map data and data layers created for this Study. These data were loaded into a user friendly interface that runs on the District's secured Intranet servers. The tool features sensitivity (for Shallow and Principal aquifers), PCA risk, and vulnerability maps (for Shallow and Principal aquifers). Additional maps are also provided to enhance the usefulness of the tool. Pull-down menus feature tables with explanatory fields. The tool enables District staff to work interactively with the vulnerability study analysis.

The objectives of the tool are to enable District staff to:

- evaluate potential impacts of new developments
- prioritize basin management activities
- prioritize oversight of known contamination sites.

Flexibility in the design of the tool enables to District to:

- Develop new applications
- Update existing data layers
- Update or modify risk factors
- Add supplemental data layers.

The GIS tool has several components as follows.

Database Module – A Microsoft Access™ database is the basic supporting data management tool. The data tables have tabular and spatial components to organize the sensitivity, PCA, and vulnerability factors. Metadata associated with layers created for this Study are contained with the Microsoft Access™ database. The database input can be changed by the user(s) as necessary to update or revise the data.

GIS Mapping Module – GIS is the primary organizer and visualization tool for spatial information. The spatial queries enable GIS to overlay multiple layers of data and then perform spatial modeling to synthesize vulnerability indices by parcels or grouping of parcels.

These customized queries ease the use of GIS in the analyses of data and results. The user is not required to have in-depth experience with GIS databases.

Microsoft Browser Interface – The browser interface provides full support in data entry (updates) and customized data queries in the database and GIS components described above. All data processing functions and reporting are accessed within a Microsoft web browser. Data updates and results presentation will be through the District's secured Intranet.

The tool is documented in a separate report, *Groundwater Sensitivity and Vulnerability Tool Documentation.* This report is a user's manual explaining how to access the information and how to maintain the tool.

8.2 Sensitivity Updating and Recommended Frequency

8.2.1 Depth to Aquifer

It is recommended that the depth to Shallow Aquifer data be updated every ten years. As described previously, the depth to the Shallow Aquifer information layer was developed by the District in 1999 using then-current groundwater level measurements for shallow monitoring wells associated with regulated environmental facilities. Although interpolation was presumably performed in GIS, the methodology was not documented. The depth to the water table ranges from less than 5 ft-bgs to greater than 100 ft-bgs across the Study Area. Although fluctuations in the water table elevation occur seasonally and on a year by year basis, it is unlikely that shallow water table elevations will change to such a degree that they will dramatically alter a sensitivity map unless groundwater production increases significantly in the Shallow Aquifer. Additionally, because of the broad occurrence of monitoring wells used to estimate the depth to the Shallow Aquifer, no large areas exist where additional monitoring data will dramatically reduce the uncertainty. As such, it is recommended that the Depth to Shallow Aquifer information layer be re-evaluated every ten years.

It is recommended that the depth to the Principal Aquifer be re-evaluated every five years, as needed. The depth to the Principal Aquifer information layer was developed using well construction information for 312 public water supply wells. The depth to the top of the shallowest screen in each well was used to define the depth to the Principal Aquifer. For areas with a high density of public water supply wells, the depth to the shallowest well screen for a given well cluster was used, and interpolation between well points was performed using GIS Spatial Analyst and the inverse distance squared method. This method resulted in a Principal Aquifer depth with minimal irregularities. Areas lacking public water supply wells were assigned a depth based on the nearest public supply wells. Should public water supply wells be installed in areas currently lacking such wells, the depth to the Principal Aquifer could be re–evaluated and re-contoured to reduce the uncertainty in these areas. Also, should the District wish to assign a more conservative sensitivity ranking to areas where the lack of public water supply well information results in higher uncertainty in sensitivity, then the depth to the Principal Aquifer could be manually controlled. Overall, it is recommended that the Depth to Principal Aquifer information layer be re-evaluated every five years to determine if new information or knowledge of the Principal Aquifer warrants a re-evaluation.

8.2.2 Groundwater Recharge

It is recommended that the District update the groundwater recharge data every five years or at times when significant changes in recharge operations occur. The recharge layer used to predict the probability of elevated nitrate and groundwater sensitivity (Groundwater Recharge Alternative 4) was developed from the map prepared for the District's DRASTIC Study and relied on an average rainfall isohyetal map and land use-specific retention factors. The recommended frequency of updating the recharge coverage is based primarily on the premise that land use changes since 1999 are not reflected in the recharge coverage. However, since wells used in the logistic regression are assigned the average recharge potential estimated for the area within a ¼-mile radius from the well, small land use changes will not dramatically change sensitivity maps that rely on this information layer.

The recharge map was also amended to incorporate the influence of artificial recharge facilities. Although artificial recharge operations may change dramatically on a seasonal and annual basis depending on the availability of imported water, the recharge data layer does not need to be updated on such a frequent basis for the following reasons:

- The method used to assess the impact of artificial recharge operations relies on the average recharge volume for each facility over a twelve year period (1994 through 2006).
- The use of median nitrate concentrations to develop the regression model accounts for short-term variations in nitrate concentrations in wells located near artificial recharge facilities.

8.2.3 Hydraulic Conductivity

It is recommended that the hydraulic conductivity 3 layer be updated every five years. This layer is based solely on groundwater production volume. Although groundwater production may change dramatically for a specific location depending on the distribution of pumping wells, the associated data layer is not expected to change dramatically over a short period of time for the following reasons:

- Annual production is classified into only two groups (100 AFY or less and greater than 100 AFY).
- Current production volumes represent a 10-year average (1999 through 2008).
- The distribution of production is not characterized on an individual well basis but rather by geographic section.

Because median nitrate concentrations for a given area are more likely a result of long-term production patterns, it is recommended that the District append any newer production data to the existing 1999 to 2008 dataset when updating average annual production by geographic section.

8.2.4 Soil Media

It is recommended that soil media data be updated once every 15 years. Since the soil media is not expected to change dramatically over time, and the soil media data are based on professional mapping conducted by the United States Conservation Service, the recommended frequency for updating soil media data is the least of the four variables that influence groundwater sensitivity.

8.3 PCA-Risk Updating and Recommended Frequency

The procedures for updating the GIS layers that drive the PCA risk analysis involve transferring information from one database format to another and rectifying manually any inconsistencies. Risk ranks are then assigned to the appropriate categories. Once the raw shapefiles are produced, each shapefile needs to be gridded (500 foot by 500 foot cells).

8.3.1 Land Use

It is recommended that land use data be updated when necessary. The agencies that maintain and use general plan land-use data should be contacted every two to five years regarding changes that have occurred in their respective areas. The land-use data can then be updated as appropriate. Procedures for updating the land use data include the following:

- Assemble general plan land use data in GIS format from the 13 entities used in this Study.
- Check for the availability of GIS data from Gilroy and Los Altos.
- Convert the data to the transformed classification scheme used for this Study. Each dataset has a unique transformation key.
- Assemble the individual land use coverages into a single shapefile.
- Manually rectify areas of spatial overlap or empty space.
- Apply the GLU risk rankings.
- Grid the GLU shapefile.

8.3.2 PCBAs: SIC Codes

It is recommended that the PCBAs using the SIC codes be updated every five years. Updating the PCBA database and shapefile accounts for businesses that open or close. The InfoUSA search of priority SIC codes within the zip codes in the Study Area, will need to be re-run. The Study Area zip codes and priority SIC codes are listed in Table B-6 and B-7, respectively in Appendix B. Of the many attributes for each entry, the critical attributes are:

- Business name
- Business address
- Latitude and longitude
- Primary SIC code
- Primary SIC description

To update the PCBA shapefile:

- Determine the SIC Major Group (i.e., the first two digits of the SIC code).
- Assign PCBA –risk ranks according to Table 6-6.
- Grid the PCBA shapefile.

8.3.3 KCSs: Regulated Facilities

It is recommended that KCSs be updated annually. Ongoing investigations and remedial actions will necessitate updating the KCS database and shapefile. KCS risk for point data derived from GeoTracker, EnviroStor, and the SLIC data is based on status of the case as open or closed. Therefore, the focus of the update can be limited to case status. The GeoTracker, EnviroStor, and District SLIC data can be downloaded or updates on case status can be input manually. The KCS ranking is 7 for closed cases and 10 for open cases.

KCS is also based on a shapefile of SLIC parcels created by District staff. As the status of SLIC cases change, the SLIC parcels shapefile should be recreated or updated.

When updates occur, an updated shapefile should be generated with the assigned risk ranks and the shapefile should be gridded.

8.3.4 Supplemental Data Layers

If updated information becomes available, new shapefiles will need to be obtained or created. Follow the same general procedure to assign risk ranks and generate the gridded shapefile.

9 Additional Data Provided

Data that was collected for the project, but not used in the vulnerability analysis are discussed below. These data are provided as information layers in the vulnerability tool or as databases to enhance the District's analytical capabilities for managing the groundwater basins.

9.1 DWSAP

The DPH contracts with UC Davis Information Center for the Environment (ICE) to provide technical support for the DWSAP program. DPH considers drinking water source assessments to be the first step in developing a groundwater protection program. DPH is required to complete a drinking water source assessment for each public water supply source. Some public water systems have completed their own assessments. Drinking water source assessments include an inventory of PCAs that might impact the well, the delineation of the area around a well through which contaminants might move and reach the well, and identification of PCAs that pose the greatest risk to the well. Statewide data collected as part of the DWSAP program are compiled and managed by UC Davis ICE. ICE provided the DWSAP Access™ database for Santa Clara County for this Study. This database contains information that individual well owners or DPH compiled to complete their individual DWSAP assessments. It includes data for both groundwater and surface water sources. The data are referenced to DPH system and source numbers. Well coordinates were not provided due to security concerns. Based on a cross-reference table provided by the District, locations were identified for 251 of the 341 wells in the Study Area. Select data were exported from the database to create shapefiles for viewing within the tool as follows:

- Potential barrier effectiveness (PBE) – a ranking of 1 (high), 3 (medium), or 5 (low) based on the annular seal depth and aquifer conditions (e.g., confined versus unconfined).
- PCA risk – the risk rating for each PCA identified at each well. The shapefile in the tool displays the PCAs with the highest risk ranking at each well.
- Vulnerability score – the sum of PBE, PCA risk, and zone risk (based on well capture zone). The shapefile in the tool displays the highest vulnerability score(s) for each well, and the components that comprise the score.

The entire DWSAP program database is provided to the District for its use outside of the tool application.

9.2 Dry Cleaner Study

The District provided shapefiles of active and historic drycleaners (SCVWD, 2007). The shapefile selected for the tool includes the locations of all identified drycleaners. The attribute information includes name and location of the facility and the overall Simplified SiteRank based on source strength, DRASTIC groundwater sensitivity, location relative to nearest water supply well, and well vulnerability. The mapped result is the summary rank which is a number between 1 and 5, with 1 representing a relatively low risk and 5 representing a relatively high risk of the dry cleaner facility to contaminate a water supply well.

9.3 LLNL Groundwater Age Data

The groundwater age is provided as an information layer in the vulnerability tool. The relative age was used by Moran, et al. (2004) to evaluate flow fields of the groundwater subbasins and to indicate the degree of vertical connection between near-surface sources of contamination, and deeper production zone groundwater. Data for the 173 wells in the tool include the percentage of modern water determined using the tritium-helium-3 method.

While low-level VOCs testing results were provided by the District, other data collected by LLNL were not available. Jean Moran, formerly of LLNL, provided the remaining data and those data are provided to the District in Excel™ tables.

9.4 SLIC Sites

The SLIC sites spreadsheet provided by the District did not contain the original attribute information last updated by SFRWQCB in 2001. This spreadsheet has not been maintained by SFRWQCB or the District; therefore the attribute information is out of date. However, some of the attribute data are useful for evaluating the relative risk of sites. For example, the attribute information in the original SFRWQCB database includes the leak discovery date, the contamination source, and the facility description which are useful information about the sites.

The SLIC database including the original attribute data are provided to the District as part of this Study.

9.5 Zoning Maps

Cities that maintain GIS maps of general plan land use, also provided their current zoning maps. The zoning maps are included in the vulnerability tool as an information layer.

9.6 Updated Plume Map

A GIS coverage of groundwater plumes in the Study Area was generated by the SFRWQCB (SFRWQCB et al., May 2003) for the Santa Clara Subbasin. This coverage was updated to include known plumes in the Coyote and Llagas subbasins. The updated plume map is included in the vulnerability tool as an information layer. Attribute information, created in 2000, for this layer includes facility information, VOC concentrations, plume dimensions, the year pumping started, the mass removed, and the discharge location.

10 Data Gaps

The data collected for this Vulnerability Study were adequate to support the sensitivity and PCA risk analyses. Nonetheless, the Study would have benefitted from additional data in certain areas. The sensitivity analysis relied on nitrate distribution data. Of the 1,157 wells with nitrate data, only 470 had available well construction information. Because of the necessity for understanding the vertical distribution, only wells with construction information were useful for the analysis. The analysis would have been more robust if more of the monitored wells had construction information.

The PCA analysis relied on information on environmental release sites available from different sources (GeoTracker, EnviroStor, and District SLIC data), which were compiled into a single database. Because each database is unique and information for individual sites is not consistent from site to site, combining them was difficult. A state-wide comprehensive, up-do-date environmental release site database would allow the tool to be updated more easily in the future.

The PCA analysis also relied on land use data. Because there are not county-wide land use and zoning maps, maps from various sources were compiled. County-wide up-to-date land use and zoning maps using consistent classification schemes would allow the tool to be updated more easily in the future.

Similarly, an up-to-date County-wide irrigated agriculture map would be helpful in characterizing PCA risk.

11 Conclusions

Combining both aquifer sensitivity and PCA risk yields a more complete understanding of potential groundwater vulnerability. Because the individual components (sensitivity and PCA risk) are provided as separate maps, they can be used to provide a better understanding of the factors that drive vulnerability in a given area. In addition, the PCA risk component allow for changes in land use to be evaluated for their potential contribution to groundwater vulnerability. Accordingly, this Groundwater Vulnerability Study provides a robust tool for understanding, defining, and directing groundwater quality programs and issues.

The groundwater vulnerability tool can provide consistent and cost-effective support for management efforts geared towards preventing future or mitigating existing water quality problems. The tool can be used to prioritize groundwater protection efforts. The source of a particular vulnerability ranking for a given area can be readily discerned by referring to the two independent components (sensitivity and PCA risk) that give rise to groundwater vulnerability. Contaminated areas where sensitivity is low could be assigned a lower priority for remediation than areas where sensitivity is high. Another use of the vulnerability tool is to assess the impacts that adding PCAs or changing general plan land use would have on groundwater vulnerability.

11.1 Sensitivity

Based on the results of the groundwater sensitivity assessment, the following conclusions can be made regarding the sensitivity of the Shallow and Principal aquifers across the three Study Area groundwater subbasins:

- Evaluation of intrinsic aquifer properties and aquifer stresses using logistic regression analysis and nitrate occurrence data revealed that the following parameters were significantly correlated to groundwater sensitivity:
    - Groundwater recharge from precipitation
    - Annual groundwater production
    - Soil media type
    - Depth to top of first screen
- The sensitivity of the Shallow Aquifer is greater than of the Principal Aquifer in all three groundwater subbasins due primarily to the relative depth of each aquifer in the confined zones.
- The sensitivity of the Shallow and Principal aquifers is generally highest in the Llagas Subbasin, followed by the Coyote Subbasin, and Santa Clara Subbasin.
- Despite the protection afforded by the regional confining layer in the southern portion of the Llagas Subbasin, both the Shallow and Principal aquifers are highly sensitive to contamination due to high recharge rates and permeable soils in the subbasin.
- The sensitivity of the Shallow and Principal aquifers in the Coyote Subbasin are also relatively high due primarily to shallow aquifer conditions, high recharge

rates, and large amounts of groundwater production (presumably from private wells).

- Although the confined zone in the Santa Clara Subbasin affords relatively good protection from surface contamination, the outer western confined zone appears to be highly sensitive to contamination due to the significant groundwater production in this area.

11.2 PCA Risk

The following conclusions can be made with respect to groundwater PCA risk in the Study Area:

- Large portions of the Santa Clara Subbasin are at high risk of contamination from PCAs because the subbasin is currently highly developed and has many known contaminant release sites.
- Relatively lower overall PCA risks are associated with the Coyote Subbasin, which is relatively rural, and undeveloped.
- The Coyote Subbasin has the most potential for future residential and commercial development and thus the most potential for an increase in PCA risk in the future.
- Relatively lower overall PCA risk (compared with the Santa Clara Subbasin) is found in the Llagas Subbasin due to its more rural nature. Areas of relatively higher risk are associated with residential and commercial development in the vicinity of the cities of Morgan Hill and Gilroy and an oil and gas pipeline in the southern portion of the subbasin.
- Continued conversion of rural to residential and commercial land use in the vicinity of the cities of Morgan Hill and Gilroy in the future will likely increase PCA risk in these areas.

11.3 Vulnerability

The following conclusions can be made with respect to groundwater vulnerability in the Study Area:

- Vulnerability of the Shallow Aquifer is greater than the Principal Aquifer in areas of confinement.
- The density of commercial/industrial sites and known contamination release sites in the northern Santa Clara Subbasin make the Shallow Aquifer highly vulnerable to contamination.
- The Llagas and Coyote subbasins exhibit high to very high groundwater vulnerability in both the Shallow and Principal aquifers driven primarily by the high sensitivity in these two subbasins.

- The high degree of vulnerability of the Coyote Subbasin requires the highest level of effort directed toward protection.
- The Santa Clara Subbasin shows a wide range of groundwater vulnerability from low to very high in the Principal Aquifer, with the majority of the subbasin in the medium to high range. The vulnerability is primarily driven by the density of commercial, industrial, and known contaminant release sites.

12 Recommendations

With respect to the data gaps discussed in Section 10 above, only one falls within the purview of the District. All other involve work that would need to be done by state or County agencies. The one task the District could conduct is related to well construction information. Additional well construction information would have resulted in a more robust statistical database for development of the sensitivity methodology. Thus the District may want to collect and compile all available well construction information into a comprehensive database if there were ever a need to reassess the sensitivity methodology.

During the Study meetings, a secondary tool for the use of outside entities was discussed. It is recommended that the development of this second tool be considered in the future if there is significant interest from and benefit to outside entities.

While the tool will provide the District with an easy to use method to assess sensitivity, PCA risk and vulnerability, there are several other analyses that could be conducted to direct protection efforts. For example, the District could use the sensitivity map as a screening tool to prioritize known contamination sites. For example, there are over 800 open cases within the Study Area and a simply overlay with the sensitivity map indicates that just over 60 of these occur within highly sensitive areas (i.e., areas of greater than 70 percent likelihood of nitrate exceeding 10 mg/L).

In addition, the District could use the vulnerability maps to prioritize proposed development projects that may warrant more detailed review by District staff. In recognition that land use planning decisions are made by local cities, the District may want to reach out to city planning departments to explore how best to integrate the findings of this Study into each cities' planning process. Based on the concentration of vulnerable areas, it is recommended that the District begin this work with the planning departments in the cities of San Jose, Mountain View, Sunnyvale, Gilroy, and Morgan Hill. In addition, cities and unincorporated portions of the County with high sensitivity, but relatively low PCA risk are of concern, in the event that higher risk land use activities are proposed. Highly sensitive areas with relatively low current vulnerability include the cities of Cupertino, Los Altos, Los Gatos, Santa Clara, Saratoga and unincorporated portions of Coyote and Llagas subbasins. In particular, the Coyote Subbasin is highly vulnerable and has the most potential for future development. Accordingly, it should receive the highest level of effort by the District and other appropriate entities directed to groundwater protection.

As discussed in Section 8 it is recommended that the data used for this Vulnerability Study be assessed and updated periodically as follows:

- Depth to Aquifer (every 5 to 10 years as needed)
- Soil (every 15 years)
- Recharge (every 5 years or when conditions change)
- Hydraulic Conductivity (every 5 years)
- Land Use (as needed)
- PCBAs: SIC Codes (every five years)

- KCSs: Regulated Facilities (annually)
- Supplemental Data Layers (as new data become available)

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TABLES

Table 4-1: Summary of Santa Clara County Groundwater Quality Data

Category	Constituent	MCL	DLR	Sample Dates	Wells Sampled in GW Subbasins	Santa Clara			Coyote			Llagas		
						Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL
DBP	Haloacetic Acids	0.06		2003-2007	15	9	1	**1**	0			6		
DBP	Total Trihalomethanes	0.1		1986-2007	356	285	42	**41**	16	5	**4**	55	8	**4**
Inorganic	Aluminum	1	0.05	1984-2007	484	336	223	**3**	29	10		119	40	**1**
Inorganic	Antimony	0.006	0.006	1987-2007	443	305	81	**3**	28			110	2	
Inorganic	Arsenic	0.01	0.002	1973-2007	518	368	191	**6**	29	7	**2**	121	19	**4**
Inorganic	Asbestos	7 (MFL)	0.2 (MFL)	1981-2007	142	106	14		11			25		
Inorganic	Barium	1	0.1	1972-2007	508	358	345		29	24		121	103	
Inorganic	Beryllium	0.004	0.001	1987-2007	447	307	83		27			113		
Inorganic	Cadmium	0.005	0.001	1975-2007	512	362	86	**7**	29			121		
Inorganic	Chromium (Total)	0.05	0.01	1962-2007	518	369	274	**3**	28	14		121	44	
Inorganic	Chromium (VI)		0.01	2001-2007	240	170	72		12	11		58	29	
Inorganic	Cyanide	0.15	0.1	1977-2007	303	249	5	**1**	15			39	2	**2**
Inorganic	Flouride	2	0.1	1946-2007	528	374	363	**12**	28	27		126	115	
Inorganic	Mercury	0.002	0.001	1971-2007	517	368	98	**2**	29			120	5	
Inorganic	Nickel	0.1	0.01	1987-2007	466	323	122		28			115	44	
Inorganic	Nitrite (as N)	1	2	1957-2007	263	263	78	**9**						
Inorganic	Nitrate (as NO3)	45	0.4	1946-2007	1,157	391	361	**24**	91	87	**29**	675	668	**355**
Inorganic	Nitrate + Nitrite (as N)	10		1993-2007	228	173	173		14	14	**3**	41	40	**5**
Inorganic	Perchlorate	0.006	0.004	1997-2008	2,013	200	3	**1**	26	4		1,787	1,251	**403**
Inorganic	Selenium	0.05	0.005	1973-2007	509	359	168	**1**	29			121	23	
Inorganic	Thallium	0.002	0.001	1987-2007	447	309	46	**1**	28			110		
Radionuclide	Radium 226	5[1] (pCi/L)	1 (pCi/L)	1982-2007	40	37	19		1	1		2		
Radionuclide	Radium 228	5[1] (pCi/L)	1 (pCi/L)	1982-2007	229	194	42		8	4		27	4	
Radionuclide	Gross Alpha activity	15 (pCi/L)	3 (pCi/L)	1979-2007	322	268	259	**8**	13	12		41	37	**1**
Radionuclide	Uranium	20 (pCi/L)	1 (pCi/L)	1991-2007	40	36	28		1	1		3		
Radionuclide	Tritium	20,000 (pCi/L)	1,000 (pCi/L)	1999-2003	57	57	52		0			0		

Includes data from DPH, GeoTracker, Regional Boards, and other sources
MCL = Primary Maximum Contaminant Level (values reported in mg/L unless otherwise noted)
MFL = Million fibers per liter
mg/L = milligrams per liter
pCi/L = picocuries per liter

DLR = Detection Limit for Reporting (values reported in mg/L unless otherwise noted)
DBP = Disinfection Bi-Product
GW = Groundwater
[1] MCL for Total Radium 226 + Radium 228 = 5 pCi/L

Table 4-1: Summary of Santa Clara County Groundwater Quality Data (continued)

Category	Constituent	MCL	DLR	Sample Dates	Wells Sampled in GW Subbasins	Santa Clara			Coyote			Llagas		
						Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL
SOC	2,3,7,8-TCDD (Dioxin)	3.E-08	5.E-09	1993-2007	146	115			8			23		
SOC	2,4,5-TP Silvex	0.05	0.001	1980-2007	226	162			16			48		
SOC	2,4-D	0.07	0.01	1980-2007	228	164	2		16			48		
SOC	Alachlor	0.002	0.001	1984-2007	273	190			14			69		
SOC	Atrazine	0.001	0.0005	1984-2007	262	180	1		14			68		
SOC	Bentazon	0.018	0.002	1989-2007	210	147			16			47		
SOC	Benzo(a)pyrene	0.0002	0.0001	1986-2007	255	204	1	**1**	13			38		
SOC	Carbofuran	0.018	0.005	1985-2007	211	135	3		15			61		
SOC	Chlordane	0.0001	0.0001	1986-2007	253	172			13			68		
SOC	Dalapon	0.2	0.01	1989-2007	208	145			16			47		
SOC	Di(2-ethylhexyl)adipate	0.4	0.005	1993-2007	240	192	25		13			35		
SOC	Dibromochloropropane (DBCP)	0.0002	0.00001	1986-2007	242	164	1		14			64		
SOC	Dinoseb	0.007	0.002	1984-2007	217	147			16			54		
SOC	Diquat	0.02	0.004	1986-2007	184	142			11			31		
SOC	Endothall	0.1	0.045	1986-2007	195	143	3		12			40		
SOC	Endrin	0.002	0.0001	1986-2007	276	195			13			68		
SOC	Ethylene Dibromide (EDB)	0.00005	0.00002	1986-2007	241	167	1		14			60		
SOC	Glyphosphate	0.7	0.025	1990-2007	189	128	3		14			47		
SOC	Heptachlor	0.00001	0.00001	1984-2007	248	167			13			68	4	**2**
SOC	Heptachlor Epoxide	0.00001	0.00001	1984-2007	266	185			13			68		
SOC	Hexachlorobenzene	0.001	0.0005	1984-2007	273	204			14			55		
SOC	Hexachlorocyclopentadiene	0.05	0.001	1984-2007	268	200			14			54		
SOC	Lindane	0.0002	0.0002	1980-2007	283	202			13			68		
SOC	Methoxychlor	0.03	0.01	1980-2007	274	198			13			63		
SOC	Molinate	0.02	0.002	1989-2007	217	167			13			37		
SOC	Oxamyl	0.05	0.02	1984-2007	239	163	3		15			61		
SOC	Polychlorianted Biphenyls (PCBs)	0.0005	0.0005	1989-2007	220	156	3		12			52		
SOC	Pentachlorophenol	0.001	0.0002	1984-2007	264	197			16			51		
SOC	Picloram	0.5	0.001	1989-2007	208	145	2		16			47		
SOC	Simazine	0.004	0.001	1986-2007	262	180			14			68		
SOC	Thiobencarb	0.07	0.001	1989-2007	217	167			13			37		
SOC	Toxaphene	0.003	0.001	1980-2007	264	183			13			68		

Includes data from DPH, GeoTracker, Regional Boards, and other sources
MCL = Primary Maximum Contaminant Level (values reported in mg/L unless otherwise noted)
DLR = Detection Limit for Reporting (values reported in mg/L unless otherwise noted)
SOC = Non-Volatile, Synthetic Organic Compound
GW = Groundwater mg/L = milligrams per liter

Table 4-1: Summary of Santa Clara County Groundwater Quality Data (continued)

Category	Constituent	MCL	DLR	Sample Dates	Wells Sampled in GW Subbasins	Santa Clara			Coyote			Llagas		
						Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL
VOC	1,1-Dichloroethane	0.005	0.0005	1982-2007	587	402	4		36			149		
VOC	1,1-Dichloroethylene	0.006	0.0005	1982-2007	579	394	10		36			149		
VOC	1,2-Dichlorobenzene	0.6	0.0005	1984-2007	576	391	1		36			149		
VOC	1,2-Dichloroethane	0.0005	0.0005	1982-2007	585	392	1		36			157	3	**3**
VOC	1,2-Dichloropropane	0.005	0.0005	1982-2007	579	386	2		36			157	2	**1**
VOC	1,3-Dichloropropene	0.0005	0.0005	1982-2007	367	283	1		19			65		
VOC	1,4-Dichlorobenzene	0.005	0.0005	1984-2007	576	391	1		36			149	6	
VOC	1,1,1-Trichloroethane	0.2	0.0005	1982-2007	578	393	47		36			149	6	
VOC	1,1,2-Trichloro-1,2,2-Triflouroethane	1.2	0.01	1982-2007	495	355	4		27			113		
VOC	1,1,2-Trichloroethane	0.005	0.0005	1982-2007	575	390	1		36			149		
VOC	1,2,4-Trichlorobenzene	0.005	0.0005	1984-2007	499	356	1		27			116		
VOC	1,1,2,2-Tetrachloroethane	0.001	0.0005	1982-2007	575	390	1		36			149	1	
VOC	Benzene	0.001	0.0005	1982-2007	583	390	1		36			157	3	**3**
VOC	Carbon Tetrachloride	0.0005	0.0005	1982-2007	576	391	2	**1**	36			149		
VOC	cis-1,2-Dichloroethylene	0.006	0.0005	1986-2007	500	359	2		27			114		
VOC	Dichloromethane	0.005	0.0005	1982-2007	576	391	31	**3**	36	1		149	2	
VOC	Ethylbenzene	0.3	0.0005	1982-2007	582	389	7		36			157	3	**2**
VOC	Monochlorobenzene	0.07	0.0005	1982-2007	576	391	2		36			149		
VOC	Methyl *tert* butyl ether (MTBE)	0.013	0.003	1995-2007	523	362	2		27			134	8	**4**
VOC	Styrene	0.1	0.0005	1987-2007	491	351	1		27			113		
VOC	Tetrachloroethylene	0.005	0.0005	1982-2007	575	390	12	**1**	36	1		149	5	
VOC	Toluene	0.15	0.0005	1982-2007	582	389	5		36	1		157	5	**2**
VOC	trans-1,2-Dichloroethylene	0.01	0.0005	1982-2007	576	391	2		36			149		
VOC	Trichloroethylene	0.005	0.0005	1982-2007	576	391	4		36			149	2	
VOC	Trichloroflouromethane	0.15	0.005	1982-2007	575	390	4		36			149		
VOC	Vinyl chloride	0.0005	0.0005	1982-2007	575	390	1		36			149		
VOC	Xylenes	1.75	0.0005	1984-2007	573	380	4		36	1		157	5	

Includes data from DPH, GeoTracker, Regional Boards, and other sources
MCL = Primary Maximum Contaminant Level (values reported in mg/L unless otherwise noted)
DLR = Detection Limit for Reporting (values reported in mg/L unless otherwise noted)
VOC = Volatile Organic Compound
GW = Groundwater mg/L = milligrams per liter

Table 5-1: Summary of Groundwater Sensitivity Assessment Methods

Assessment Criteria	Index	Hybrid	Statistical	Process-Based
Size of Study Area	Regional	Regional	Site or Regional	Site or Regional
Data Requirements	Low	Low/Moderate	Moderate/High	High
Level of Uncertainty	High	High/Moderate	Moderate/Low	Moderate/Low
Targeted Contaminant	General Only	General or Specific	General or Specific	General or Specific
Use of Occurrence Data	No	Variable*	Yes	Yes
Ease of Refinement	Easy	Easy	Moderate	Difficult

*In subjective hybrid methods, user-defined vulnerability categories are not verified with occurrence data
*In objective hybrid methods, user-defined vulnerability categories are verified with occurrence data

Table 5-2: Summary of Results from Logistic Regression Analysis

		Scenario A (Alternative 1 Variables)				Scenario B (Alternative 2 Variables)				Scenario C (Alternative 3 Variables)			
	Variable Rating Scale	Variables Considered	Test for Significance ($p \leq 0.05$)	Model 1, Coefficient (b) if negative allowed	Model 2[a], Coefficient (b) if negative disallowed	Variables Considered	Test for Signficance ($p \leq 0.05$)	Model 3, Coefficient (b) if negative allowed	Model 4[a], Coefficient (b) if negative disallowed	Variables Considered	Test for Signficance ($p \leq 0.05$)	Model 5, Coefficient (b) if negative allowed	Model 6[a], Coefficient (b) if negative disallowed
Model Intercept (b_o)				-1.07065	-2.73794			2.89835	-1.04081			0.57342	-3.26206
Parameter (X)													
Depth to Water	DRASTIC (1-10)	✓	✓	-0.23152		✓	✓	-0.28720		✓	✓	-0.27759	
Depth to Top of First Screen	Continuous (ft-bgs)					✓	✓	-0.00340	(see Notes)	✓	✓	-0.00460	-0.00260
Groundwater Recharge Alternative 1	DRASTIC (1-10)	✓	✓	0.34879	0.24650								
Groundwater Recharge Alternative 2	DRASTIC (1-10)					✓	×	0.15262	0.06033				
Groundwater Recharge Alternative 3	DRASTIC (1-10)									✓	✓	0.26824	0.26859
Aquifer Media	DRASTIC (1-10)	✓	×										
Soil Media	DRASTIC (1-10)	✓	✓	0.28921	0.32125	✓	✓	0.19914	0.25610	✓	✓	0.25318	0.37750
Topography (Slope)	DRASTIC (1-10)	✓	×										
Impact of Vadose Zone Alternative 1	DRASTIC (1-10)	✓	✓	-0.20972									
Impact of Vadose Zone Alternative 2	DRASTIC (1-10)					✓	✓	-0.40012		✓	✓	-0.24808	
Hydraulic Conductivity Alternative 1	DRASTIC (1-10)	✓	×										
Hydraulic Conductivity Alternative 2	DRASTIC (1-10)					✓	×						
Hydraulic Conductivity Alternative 3	Binary (0 or 1)									✓	✓	1.51973	1.51076
Model Statistics													
-2*Log-Likelihood (G statistic)				60.3	33.0			66.6	14.3			154.9	125.9
Number of Variables (p)				5	3			6	3			7	5
Aikake's Information Criteria (AIC)				-110.6	-60.0			-121.2	-22.7			-295.8	-241.7
Concordant Pairs (%)				69.8	51.7			71.4	48.4			81.9	78.9
Discordant Pairs (%)				27.3	25.9			28.2	37.2			17.9	20.7
Ties (%)				2.9	22.4			0.4	14.4			0.2	0.3

✓= Variable considered in model scenario or variable satisfies test for significance (p value ≤ 0.05)
× = Variable does not satisfy test for significance (p value > 0.05)
Total wells in nitrate calibration dataset = 470 wells
Model event = nitrate concentration >10 mg/L = 1 (307 wells)
Model non-event = nitrate concentration ≤ 10 mg/L = 0 (163 wells)

Table 6-1: PCA Risk-Rank Categories and Associated Numerical Ranks

PCA Risk-Rank Categories	PCA-Risk Ranks
Low risk	1, 2, 3
Moderate risk	4, 5, 6
High risk	7, 8, 9
Known to be contaminated	10

Table 6-2: Land-Use Categories in the Transformed Classification Scheme with Risk Ranks

Land-Use Category	PCA Risk Rank	Rationale for Risk Rank
Agricultural	5	Average DWSAP rank (i.e., high risk in Zone A1; moderate risk all other zones)
Hotel	3	DWSAP (low risk)
Institutional	5	United States Geological Survey (USGS, 1976)
Mixed Use	5	City of Sunnyvale (2007); American Planning Association (2009)
Office	3	DWSAP (low risk)
Open Space	1	Santa Clara County (2008); City of Cave Creek, AZ (1993)
Research & Development	4	El Dorado County, CA (2009); City of Norwalk, CT (2009); Salt Lake County, UT (2009)
Rural	4	American Planning Association (1996); Iredell County, NC (2008)
Surface Water	1	DWSAP (low risk)
Sport/Recreation	4	DWSAP (moderate risk)
Utility	7	DWSAP (high risk)
Transportation	6	DWSAP (moderate risk)
Airport	9	DWSAP (very high risk)
Commercial	6	Average of the following three subcategories
Neighborhood Commercial	5	City of Santa Clara (2009); City of Midland, MI (2004)
Community Commercial	6	City of Santa Clara (2009); City of Midland, MI (2004)
Regional Commercial	7	City of Santa Clara (2009); City of Midland, MI (2004)
Industrial	8	Average of the following subcategories
Light Industrial	7	City of Santa Clara (2009); City of Midland, MI (2004)
Heavy Industrial	9	City of Santa Clara (2009); City of Midland, MI (2004)
Residential	3	Average of the following subcategories
Low-Density Residential	2	DWSAP (low risk)
Medium-Density Residential	2	DWSAP (low risk)
High-Density Residential	3	DWSAP (low risk)
Mobile Home Park	3	DWSAP (low risk)
Industrial/Commercial	7	Average of the two categories
Industrial/Commercial/Office	6	Average of the three categories
Residential/Commercial/Office	4	Average of the three categories
Industrial/Residential	6	Average of the two categories

Notes: [1]Zone A is defined by DWSAP as the two-year capture zone for a single well. Other zones used by DWSAP are B5, the five-year capture zone, and B10, the ten-year capture zone.

Table 6-3: DWSAP Risk Rankings for the 48 SIC Major Groups

SIC Major Group	Description	DWSAP Rank	Regulatory Risk-Rank for This Study
1	Nurseries, Specialty Farms, Orchards	High	2
2	Livestock & Animal Specialties	Very High	3
7	Agricultural Services	High	2
10	Metal Mining	Very High	3
13	Oil & Gas Extraction	High	2
14	Mining & Quarrying of Nonmetallic Minerals	High	2
15	Construction: Buildings & General Contractors	Moderate	1
16	Construction: Heavy Construction	Moderate	1
17	Construction: Special Trade Contractors	Moderate	1
20	Manufacturing: Food & Kindred Products	Moderate	1
24	Manufacturing: Lumber & Wood Products	High	2
25	Manufacturing: Furniture And Fixtures	High	2
26	Manufacturing: Paper & Allied Products	High	2
27	Manufacturing: Printing & Publishing	High	2
28	Manufacturing: Chemicals & Allied Products	Very High	3
29	Manufacturing: Petroleum Refining	Very High	3
30	Manufacturing: Rubber & Plastics	Very High	3
32	Manufacturing: Stone, Clay, Glass, & Concrete	Moderate	1
33	Manufacturing: Primary Metal Industries	Very High	3
34	Manufacturing: Fabricated Metal Products	Very High	3
35	Manufacturing: Machinery & Computer Equipment	High	2
36	Manufacturing: Electronic & Other Electrical Equipment	High	2
37	Manufacturing: Transportation Equipment	High	2
38	Manufacturing: Technical Instruments	High	2
40	Railroad Transportation	High	2
41	Highway Passenger Transportation	Moderate	1
42	Motor Freight Transportation & Warehousing	High	2
44	Water Transportation	High	2
45	Air Transportation	Very High	3
46	Petroleum Pipelines, Except Natural Gas	High	2
48	Communications	High	2
49	Electric, Gas, & Sanitary Services	Very High	3
50	Wholesale: Durable Goods	High	2
51	Wholesale: Non-Durable Goods	High	2
52	Retail: Building Materials, Hardware & Garden Supply	Moderate	1
53	Retail: General Merchandise Stores	Moderate	1
55	Retail: Automotive Dealers & Gasoline Service Stations	Very High	3
59	Retail: Miscellaneous	Moderate	1
65	Property Management	High	2
72	Personal Services, including Dry Cleaning	Very High	3
73	Business Services, including Photo Processing	High	2
75	Automotive Repair, Services, & Parking	High	2
79	Amusement & Recreation Services	Moderate	1
80	Health Services	Moderate	1
82	Educational Services	Moderate	1
87	Engineering, Research, & Related Services	High	2
92	Justice, Public Order, And Safety	Moderate	1
97	Military Installations	Very High	3

Table 6-4: Data Used to Calculate the Historical Assessment Risk Rank

SIC Major Group	Description	Number of KCS	Number of Non-LUFT KCS	Non-LUFT	Historical Assessment Risk Rank[1]
1	Nurseries, Specialty Farms, Orchards	33	20	61%	3.0
2	Livestock & Animal Specialties	3	0	0%	1.0
7	Agricultural Services	16	2	13%	2.0
10	Metal Mining	2	2	100%	3.0
13	Oil & Gas Extraction	0	0	0%	0.0
14	Mining & Quarrying of Nonmetallic Minerals	2	0	0%	1.0
15	Construction: Buildings & General Contractors	31	5	16%	2.0
16	Construction: Heavy Construction	14	3	21%	2.0
17	Construction: Special Trade Contractors	59	7	12%	2.0
20	Manufacturing: Food & Kindred Products	42	4	10%	2.0
24	Manufacturing: Lumber & Wood Products	4	0	0%	1.0
25	Manufacturing: Furniture And Fixtures	0	0	0%	0.0
26	Manufacturing: Paper & Allied Products	5	2	40%	2.0
27	Manufacturing: Printing & Publishing	8	2	25%	2.0
28	Manufacturing: Chemicals & Allied Products	48	29	60%	3.0
29	Manufacturing: Petroleum Refining	16	6	38%	2.0
30	Manufacturing: Rubber & Plastics	2	1	50%	3.0
32	Manufacturing: Stone, Clay, Glass, & Concrete	12	3	25%	2.0
33	Manufacturing: Primary Metal Industries	15	3	20%	2.0
34	Manufacturing: Fabricated Metal Products	45	22	49%	2.0
35	Manufacturing: Machinery & Computer Equipment	84	59	70%	3.0
36	Manufacturing: Electronic & Other Electrical Equipment	140	120	86%	3.0
37	Manufacturing: Transportation Equipment	12	9	75%	3.0
38	Manufacturing: Technical Instruments	32	26	81%	3.0
40	Railroad Transportation	10	8	80%	3.0
41	Highway Passenger Transportation	41	5	12%	2.0
42	Motor Freight Transportation & Warehousing	48	5	10%	2.0
44	Water Transportation	1	0	0%	1.0
45	Air Transportation	8	0	0%	1.0
46	Petroleum Pipelines, Except Natural Gas	1	1	100%	3.0
48	Communications	19	3	16%	2.0
49	Electric, Gas, & Sanitary Services	66	35	53%	3.0
50	Wholesale: Durable Goods	38	16	42%	2.0
51	Wholesale: Non-Durable Goods	22	10	45%	2.0
52	Retail: Building Materials, Hardware & Garden Supply	15	2	13%	2.0
53	Retail: General Merchandise Stores	17	7	41%	2.0
55	Retail: Automotive Dealers & Gasoline Service Stations	616	17	3%	3.0
59	Retail: Miscellaneous	16	5	31%	2.0
65	Real Estate	70	60	86%	3.0
72	Personal Services, including Dry Cleaning	52	41	79%	3.0
73	Business Services, including Photo Processing	28	13	46%	2.0
75	Automotive Repair, Services, & Parking	216	17	8%	3.0
79	Amusement & Recreation Services	29	6	21%	2.0
80	Health Services	19	9	47%	2.0
82	Educational Services	67	24	36%	2.0
87	Engineering, Research, & Related Services	26	24	92%	3.0
92	Justice, Public Order, And Safety	30	3	10%	2.0
97	Military Installations	84	26	31%	2.0

Note: [1]If the percentage of non-LUFT sites is greater than 50% of the total number sites in a given Major Group, that Group is assigned a risk rank of 3. If the percentage of non-LUFT sites is less than 50%, the Group is assigned a risk rank of 2. If a particular Major Group has solely LUFT sites, it is assigned a risk rank of 1. Major Groups with no KCS sites are assigned a zero risk rank. Five percent of Major Groups have more than 200 KCSs (Major Groups 55 and 75). These were automatically assigned a risk rank of 3 due to the sheer number of contaminated sites in these groups. See text for details.

Table 6-5: PCBA-Risk Matrix Weights and Ranks, Based on Scientific and Engineering Judgment

SIC Major Group	Category	Potential Contamination Risk	Potential Health Threat	Volume Generated	Potential for Aquifer Impact if Released	Engineering Controls at PCA	Emerging Issues / Uncertainty	Weighted Average
	Weights	**0.2**	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**	**1.0**
1	Nurseries, Specialty Farms, Orchards	2	2	3	2	2	2	**2.2**
2	Livestock & Animal Specialties	3	3	3	3	3	3	**3.0**
7	Agricultural Services	2	2	2	2	2	2	**2.0**
10	Metal Mining	3	3	3	3	3	3	**3.0**
13	Oil & Gas Extraction	2	3	3	2	2	1	**2.3**
14	Mining & Quarrying of Nonmetallic Minerals	1	1	3	2	3	1	**1.8**
15	Construction: Buildings & General Contractors	2	2	2	1	2	1	**1.7**
16	Construction: Heavy Construction	2	2	3	2	2	1	**2.1**
17	Construction: Special Trade Contractors	2	2	2	2	2	2	**2.0**
20	Manufacturing: Food & Kindred Products	2	2	2	1	1	2	**1.7**
24	Manufacturing: Lumber & Wood Products	3	3	2	2	2	2	**2.4**
25	Manufacturing: Furniture And Fixtures	2	2	2	2	2	2	**2.0**
26	Manufacturing: Paper & Allied Products	3	2	3	2	2	2	**2.4**
27	Manufacturing: Printing & Publishing	2	2	3	2	2	1	**2.1**
28	Manufacturing: Chemicals & Allied Products	3	3	3	3	1	3	**2.8**
29	Manufacturing: Petroleum Refining	3	3	3	3	2	2	**2.8**
30	Manufacturing: Rubber & Plastics	3	3	2	2	1	3	**2.4**
32	Manufacturing: Stone, Clay, Glass, & Concrete	1	1	2	1	2	1	**1.3**
33	Manufacturing: Primary Metal Industries	3	3	2	3	2	2	**2.6**
34	Manufacturing: Fabricated Metal Products	3	3	2	3	2	2	**2.6**
35	Manufacturing: Machinery & Computer Equipment	3	2	2	3	2	2	**2.4**
36	Manufacturing: Electronic & Other Electrical Equipment	3	3	3	3	1	2	**2.7**
37	Manufacturing: Transportation Equipment	3	2	2	2	1	1	**2.0**
38	Manufacturing: Technical Instruments	3	3	1	3	1	2	**2.3**

Table 6-5: PCBA-Risk Matrix Weights and Ranks, Based on Scientific and Engineering Judgment (continued)

SIC Major Group	Category	Potential Contamination Risk	Potential Health Threat	Volume Generated	Potential for Aquifer Impact if Released	Engineering Controls at PCA	Emerging Issues / Uncertainty	Weighted Average
40	Railroad Transportation	3	2	3	2	3	3	**2.6**
41	Highway Passenger Transportation	2	2	2	2	2	2	**2.0**
42	Motor Freight Transportation & Warehousing	3	2	2	1	1	2	**1.9**
44	Water Transportation	1	1	2	1	2	0	**1.2**
45	Air Transportation	3	3	3	3	2	2	**2.8**
46	Petroleum Pipelines, Except Natural Gas	3	3	2	2	2	1	**2.3**
48	Communications	3	3	1	1	1	1	**1.8**
49	Electric, Gas, & Sanitary Services	3	3	3	3	2	3	**2.9**
50	Wholesale: Durable Goods	1	2	1	1	2	1	**1.3**
51	Wholesale: Non-Durable Goods	3	3	3	3	3	0	**2.7**
52	Retail: Building Materials, Hardware & Garden Supply	1	2	1	1	2	1	**1.3**
53	Retail: General Merchandise Stores	1	1	1	1	2	0	**1.0**
55	Retail: Automotive Dealers & Gasoline Service Stations	3	3	3	3	3	3	**3.0**
59	Retail: Miscellaneous	1	1	1	1	2	0	**1.0**
65	Real Estate	1	1	2	1	2	3	**1.5**
72	Personal Services, including Dry Cleaning	3	3	3	3	2	1	**2.7**
73	Business Services, including Photo Processing	2	2	1	1	3	1	**1.6**
75	Automotive Repair, Services, & Parking	3	3	2	2	3	1	**2.4**
79	Amusement & Recreation Services	1	1	1	1	3	1	**1.2**
80	Health Services	2	3	1	1	1	2	**1.7**
82	Educational Services	2	1	1	1	1	0	**1.1**
87	Engineering, Research, & Related Services	2	3	1	1	1	1	**1.6**
92	Justice, Public Order, And Safety	2	1	1	1	2	0	**1.2**
97	Military Installations	3	3	3	3	2	3	**2.9**

Table 6-6: Components and Data for Overall PCBA-Risk Rankings

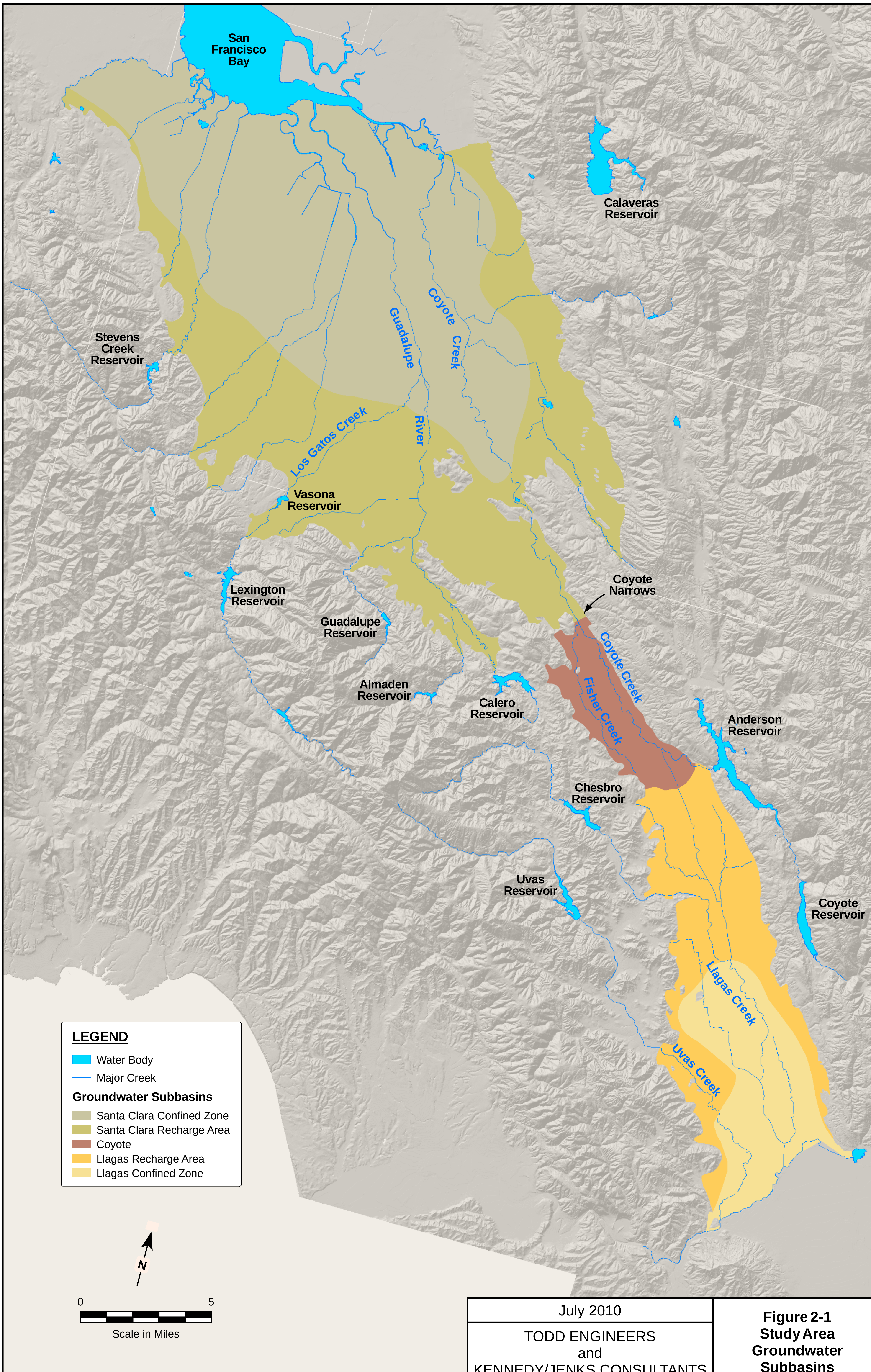
SIC Major Group	Description	Historical Assessment (Table 6-4)	DWSAP Rankings (Table 6-3)	PCBA Risk Matrix (Table 6-5)	Overall PCBA Risk Rank
1	Nurseries, Specialty Farms, Orchards	3.0	2.0	2.2	**7**
2	Livestock & Animal Specialties	1.0	3.0	3.0	**7**
7	Agricultural Services	2.0	2.0	2.0	**6**
10	Metal Mining	3.0	3.0	3.0	**9**
13	Oil & Gas Extraction	0.0	2.0	2.3	**4**
14	Mining & Quarrying of Nonmetallic Minerals	1.0	2.0	1.8	**5**
15	Construction: Buildings & General Contractors	2.0	1.0	1.7	**5**
16	Construction: Heavy Construction	2.0	1.0	2.1	**5**
17	Construction: Special Trade Contractors	2.0	1.0	2.0	**5**
20	Manufacturing: Food & Kindred Products	2.0	1.0	1.7	**5**
24	Manufacturing: Lumber & Wood Products	1.0	2.0	2.4	**5**
25	Manufacturing: Furniture And Fixtures	0.0	2.0	2.0	**4**
26	Manufacturing: Paper & Allied Products	2.0	2.0	2.4	**6**
27	Manufacturing: Printing & Publishing	2.0	2.0	2.1	**6**
28	Manufacturing: Chemicals & Allied Products	3.0	3.0	2.8	**9**
29	Manufacturing: Petroleum Refining	2.0	3.0	2.8	**8**
30	Manufacturing: Rubber & Plastics	3.0	3.0	2.4	**8**
32	Manufacturing: Stone, Clay, Glass, & Concrete	2.0	1.0	1.3	**4**
33	Manufacturing: Primary Metal Industries	2.0	3.0	2.6	**8**
34	Manufacturing: Fabricated Metal Products	2.0	3.0	2.6	**8**
35	Manufacturing: Machinery & Computer Equip.	3.0	2.0	2.4	**7**
36	Manufacturing: Electronic & Other Electrical Eq.	3.0	2.0	2.7	**8**
37	Manufacturing: Transportation Equipment	3.0	2.0	2.0	**7**
38	Manufacturing: Technical Instruments	3.0	2.0	2.3	**7**
40	Railroad Transportation	3.0	2.0	2.6	**8**
41	Highway Passenger Transportation	2.0	1.0	2.0	**5**
42	Motor Freight Transportation & Warehousing	2.0	2.0	1.9	**6**
44	Water Transportation	1.0	2.0	1.2	**4**
45	Air Transportation	1.0	3.0	2.8	**7**
46	Petroleum Pipelines, Except Natural Gas	3.0	2.0	2.3	**7**
48	Communications	2.0	2.0	1.8	**6**
49	Electric, Gas, & Sanitary Services	3.0	3.0	2.9	**9**
50	Wholesale: Durable Goods	2.0	2.0	1.3	**5**
51	Wholesale: Non-Durable Goods	2.0	2.0	2.7	**7**
52	Retail: Bldg. Materials, Hardware & Garden Sup	2.0	1.0	1.3	**4**
53	Retail: General Merchandise Stores	2.0	1.0	1.0	**4**
55	Retail: Auto Dealers & Gasoline Service Stns.	3.0	3.0	3.0	**9**
59	Retail: Miscellaneous	2.0	1.0	1.0	**4**
65	Real Estate	3.0	2.0	1.5	**7**
72	Personal Services, including Dry Cleaning	3.0	3.0	2.7	**9**
73	Business Services, including Photo Processing	2.0	2.0	1.6	**6**
75	Automotive Repair, Services, & Parking	3.0	2.0	2.4	**7**
79	Amusement & Recreation Services	2.0	1.0	1.2	**4**
80	Health Services	2.0	1.0	1.7	**5**
82	Educational Services	2.0	1.0	1.1	**4**
87	Engineering, Research, & Related Services	3.0	2.0	1.6	**7**
92	Justice, Public Order, And Safety	2.0	1.0	1.2	**4**
97	Military Installations	2.0	3.0	2.9	**8**

Table 6-7: PCA–Risk Rankings for Areas that Use Septic Systems

Septic-System Density (septic systems per acre)	Septic-System Density (acres per septic system)	DWSAP Risk Rank (Zone A)[1]	DWSAP Risk Rank (other Zones)[1]	PCA Risk Rank for This Study
> 1	< 1	Very High	Moderate	9
0.2 – 1	1 – 5	High	Low	7
0.1 – 0.2	5 – 10	High	Low	5
0.05 – 0.1	10 – 20	High	Low	3
< 0.05	> 20	High	Low	1

[1]Zone A is defined by DWSAP as the two-year capture zone for a single well. Other zones used by DWSAP are B5, the five-year capture zone, and B10, the ten-year capture zone.

FIGURES



July 2010

TODD ENGINEERS
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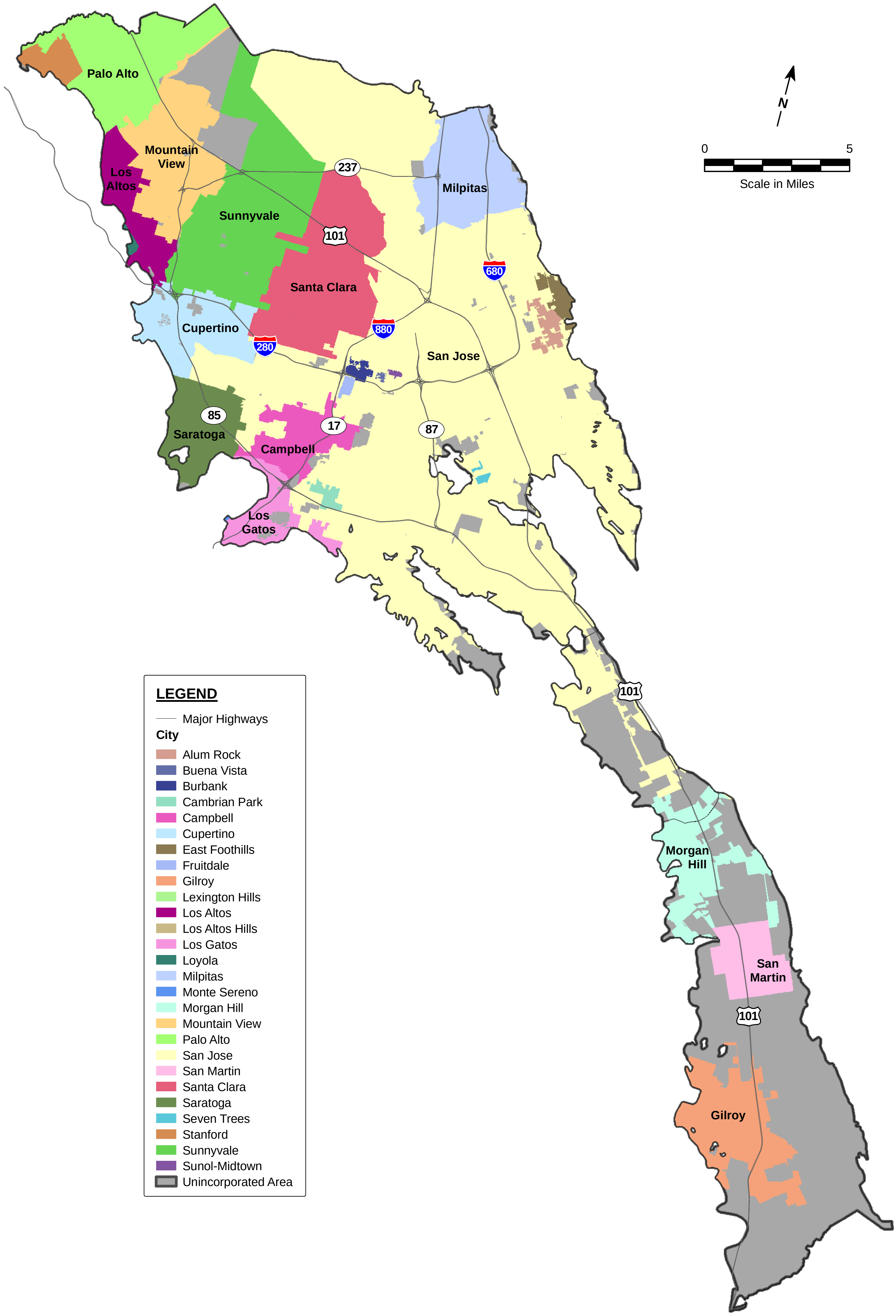
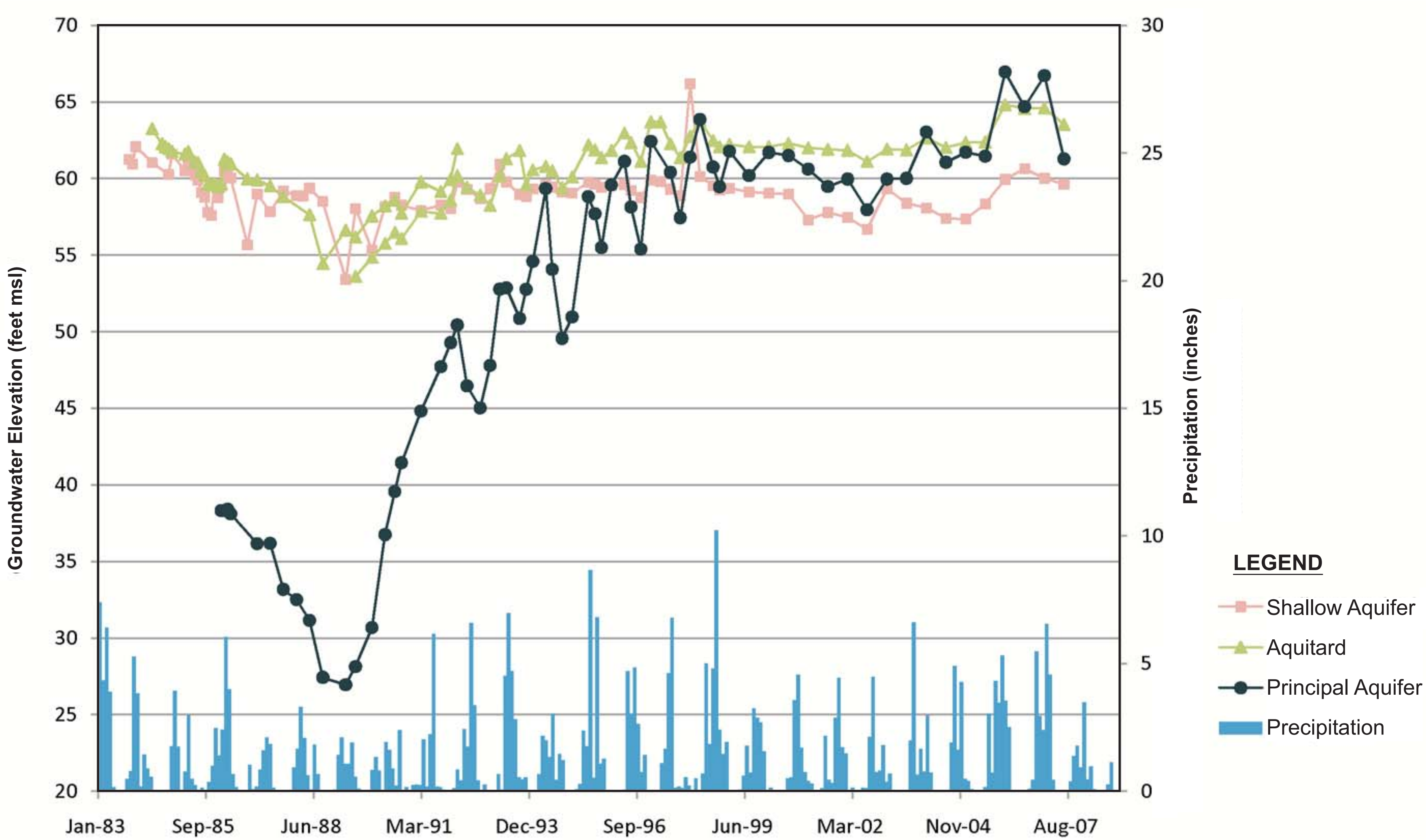
KENNEDY/JENKS CONSULTANTS

Figure 2-1
Study Area
Groundwater
Subbasins



July 2010	**Figure 2-2** **Study Area** **Features**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



Note: Water level data from Solvent Service site located at 1021 Berressa Rd., San Jose.
Monitoring wells used include: Shallow (3A), Aquitard (111B and 111B/C), and Principal (48D)

July 2010

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Figure 3-1
Hydrograph of Vertical Gradient and Precipitation in North San Jose

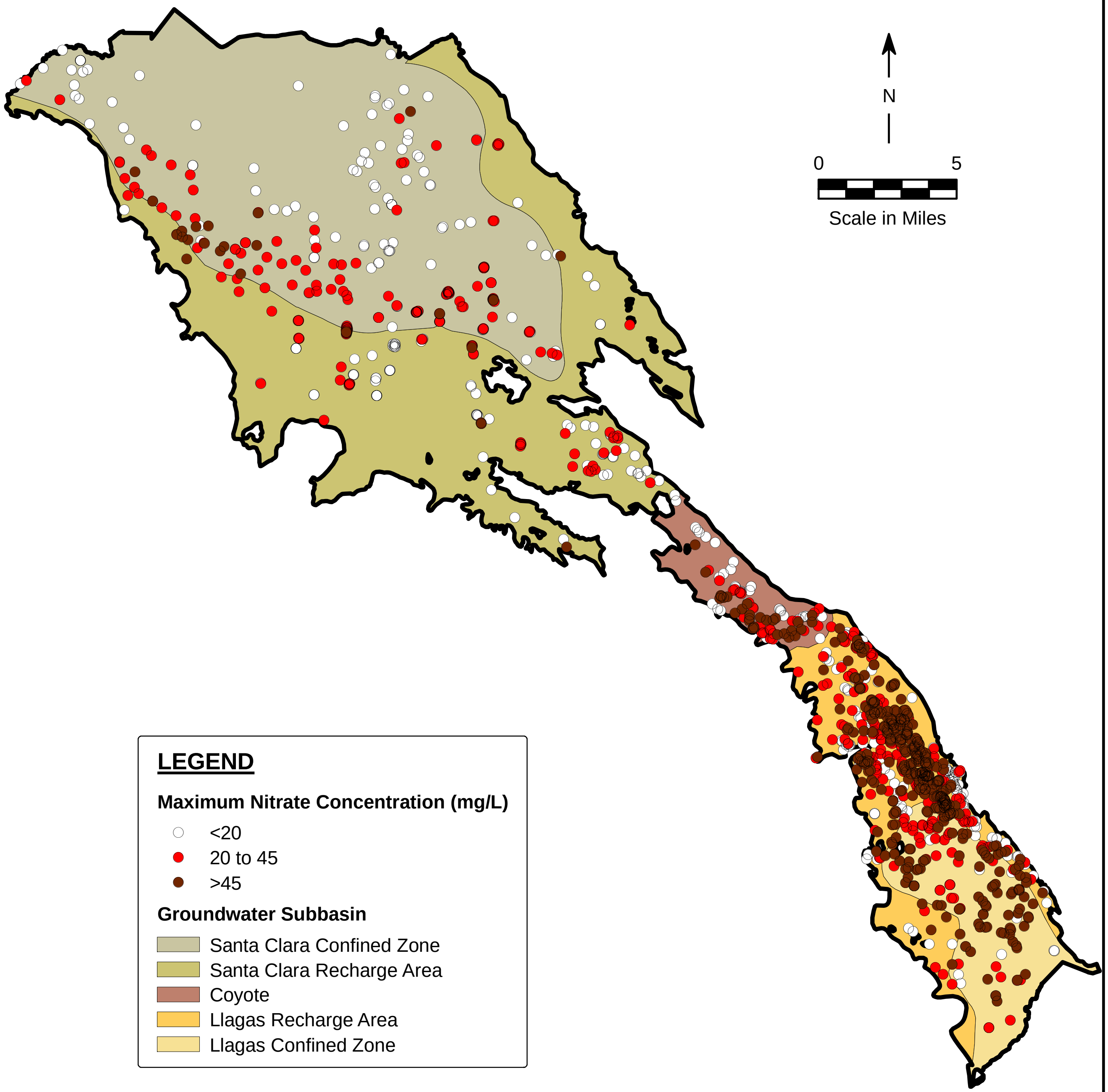

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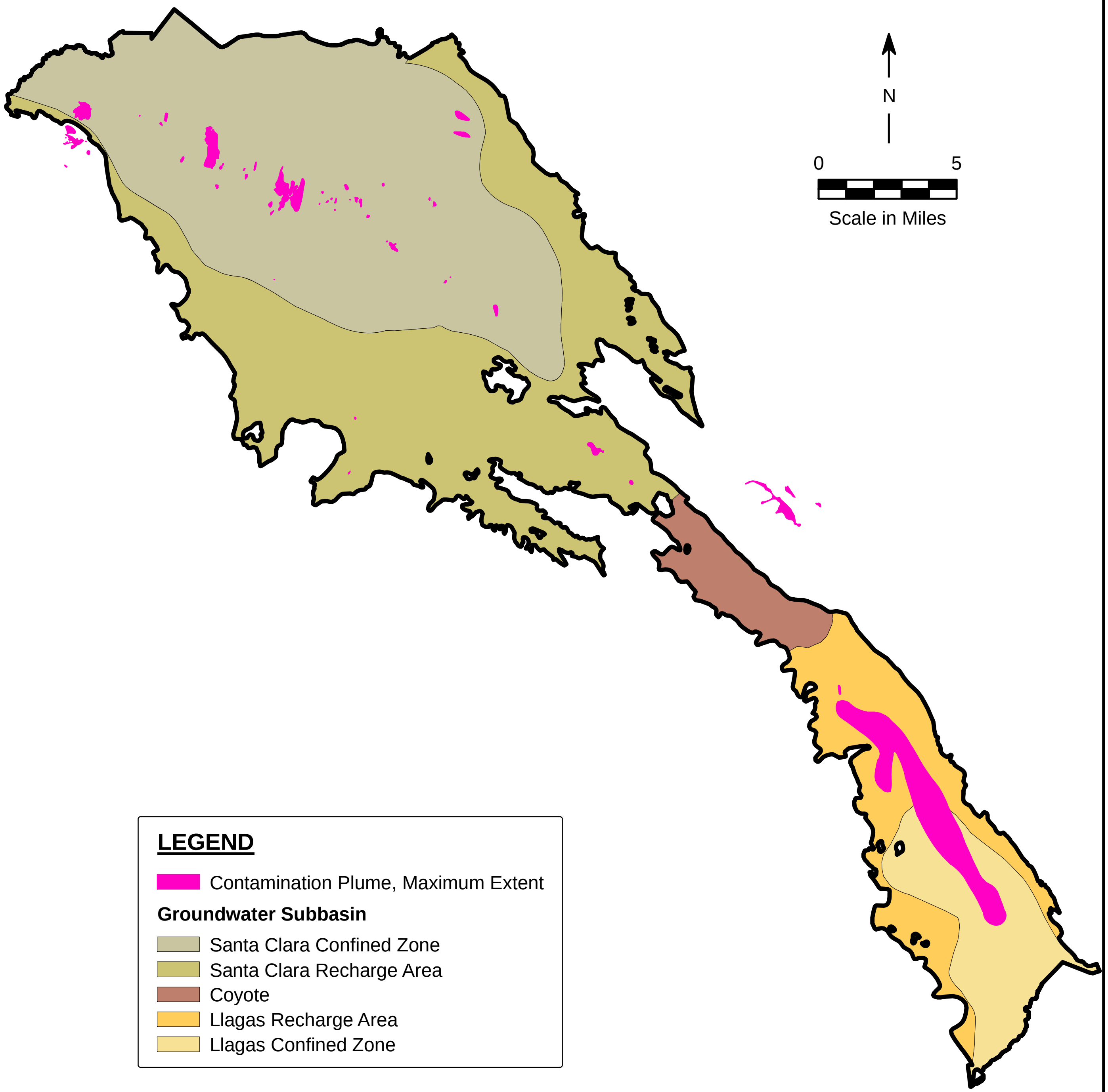
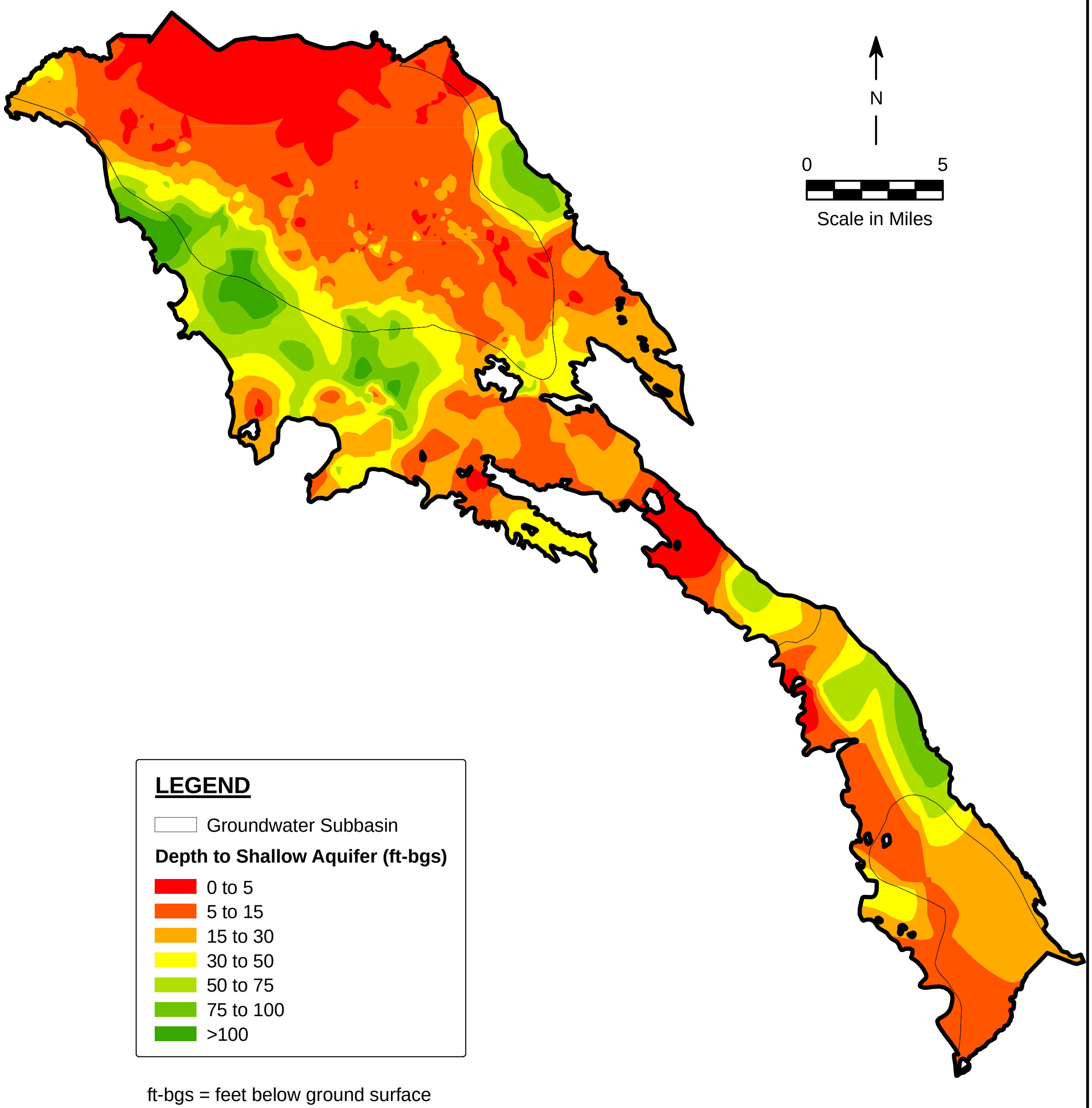
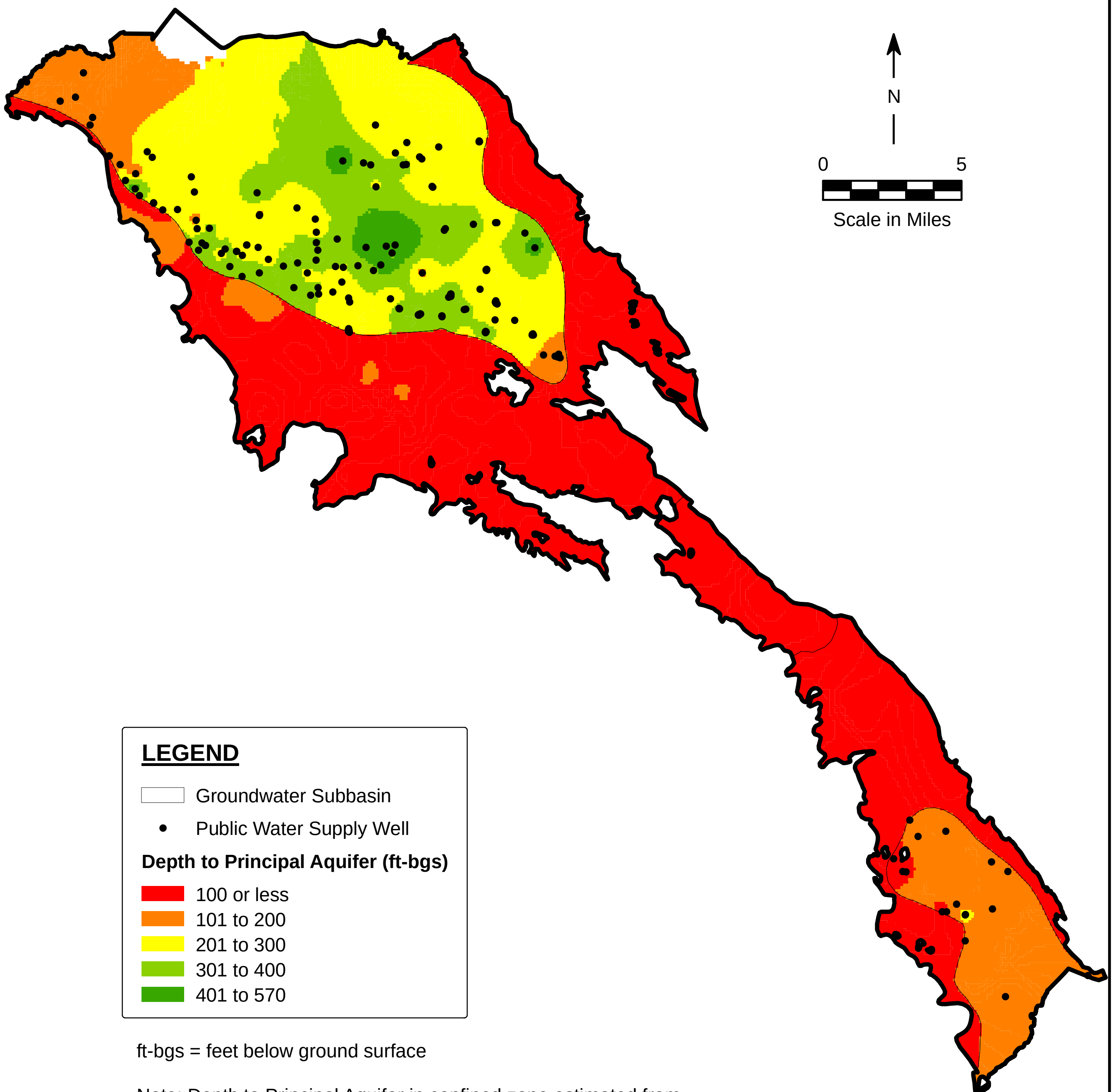
Figure 4-1
Nitrate Distribution
Maximum
Concentration



July 2010	**Figure 4-2 Contamination Plumes Maximum Extent**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



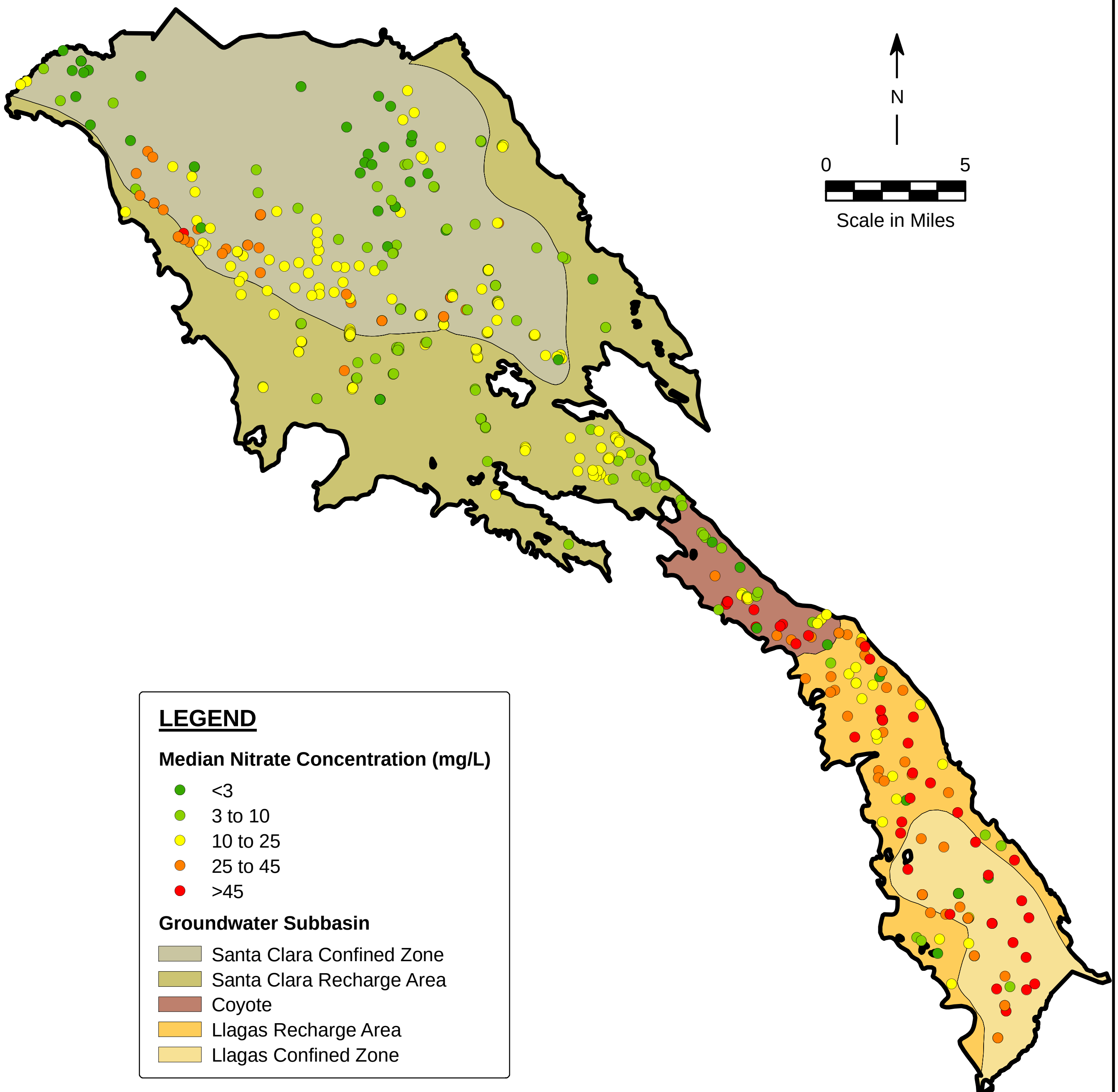
July 2010	**Figure 5-1 Depth to Shallow Aquifer**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



ft-bgs = feet below ground surface

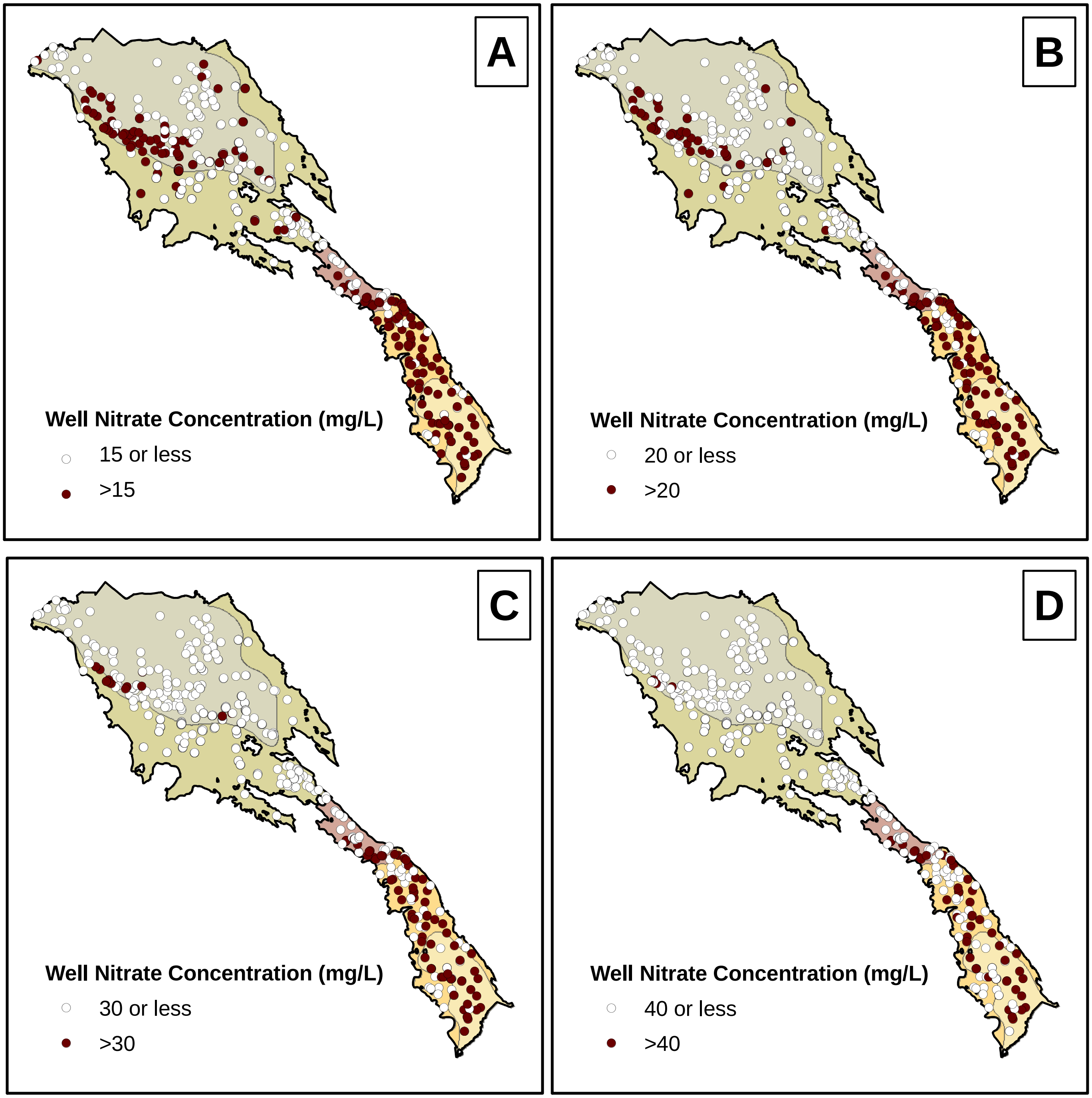
Note: Depth to Principal Aquifer in confined zone estimated from depth to top of shallowest well screen of public water supply wells

July 2010	**Figure 5-2** **Depth to Principal Aquifer**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



Note: 470 wells represent all wells that have both nitrate data and known well construction information. Additional nitrate data are available for other wells.

July 2010	**Figure 5-3 Median Nitrate Concentration for 470 Well Nitrate Dataset**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



LEGEND

- Santa Clara Valley Confined Zone
- Santa Clara Valley Recharge Area
- Coyote
- Llagas Recharge Area
- Llagas Confined Zone

Nitrate concentrations reported as NO_3

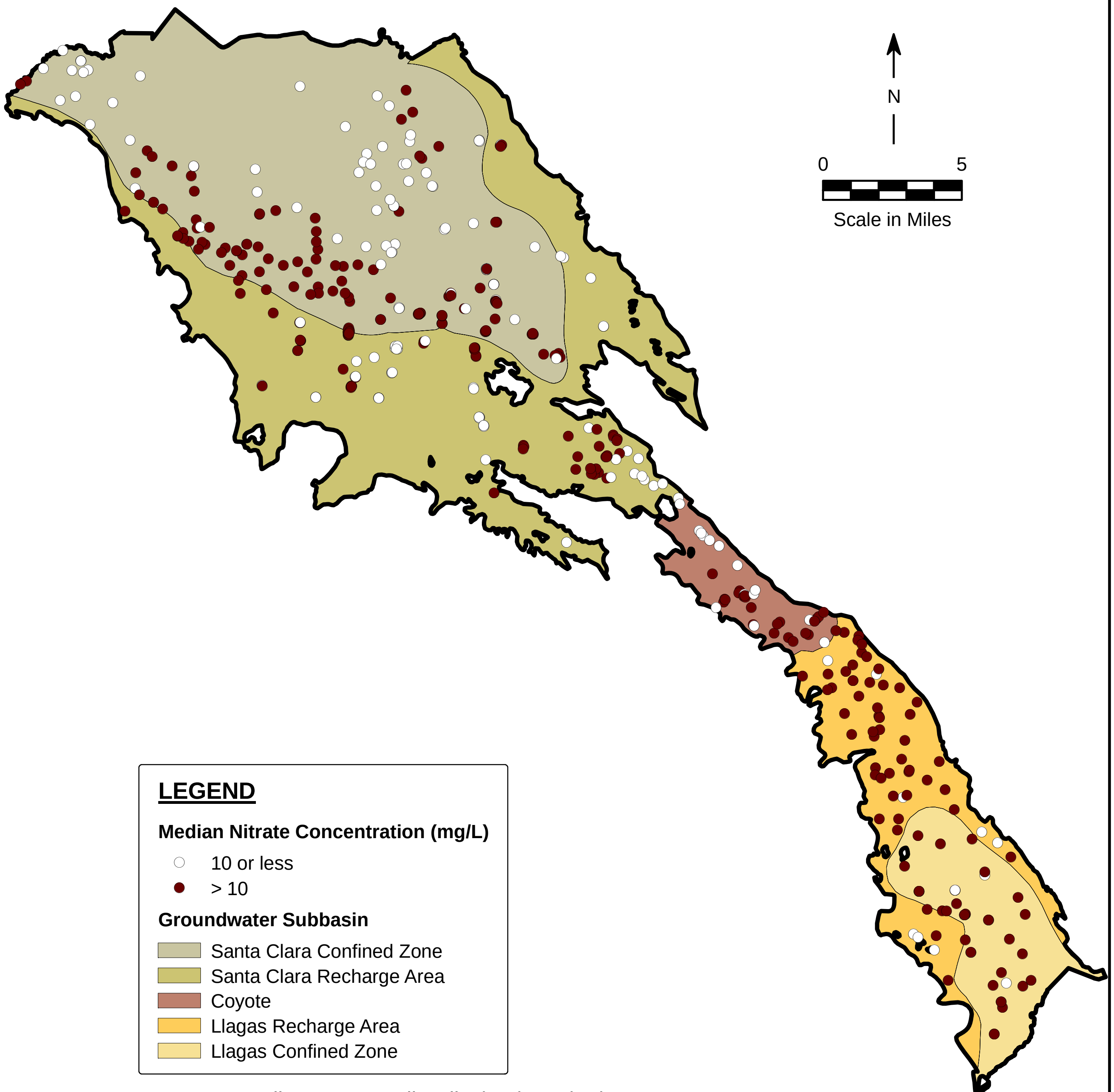
Note: 470 wells represent all wells that have both nitrate data and known well construction information. Additional nitrate data are available for other wells.

0 10

Scale in Miles

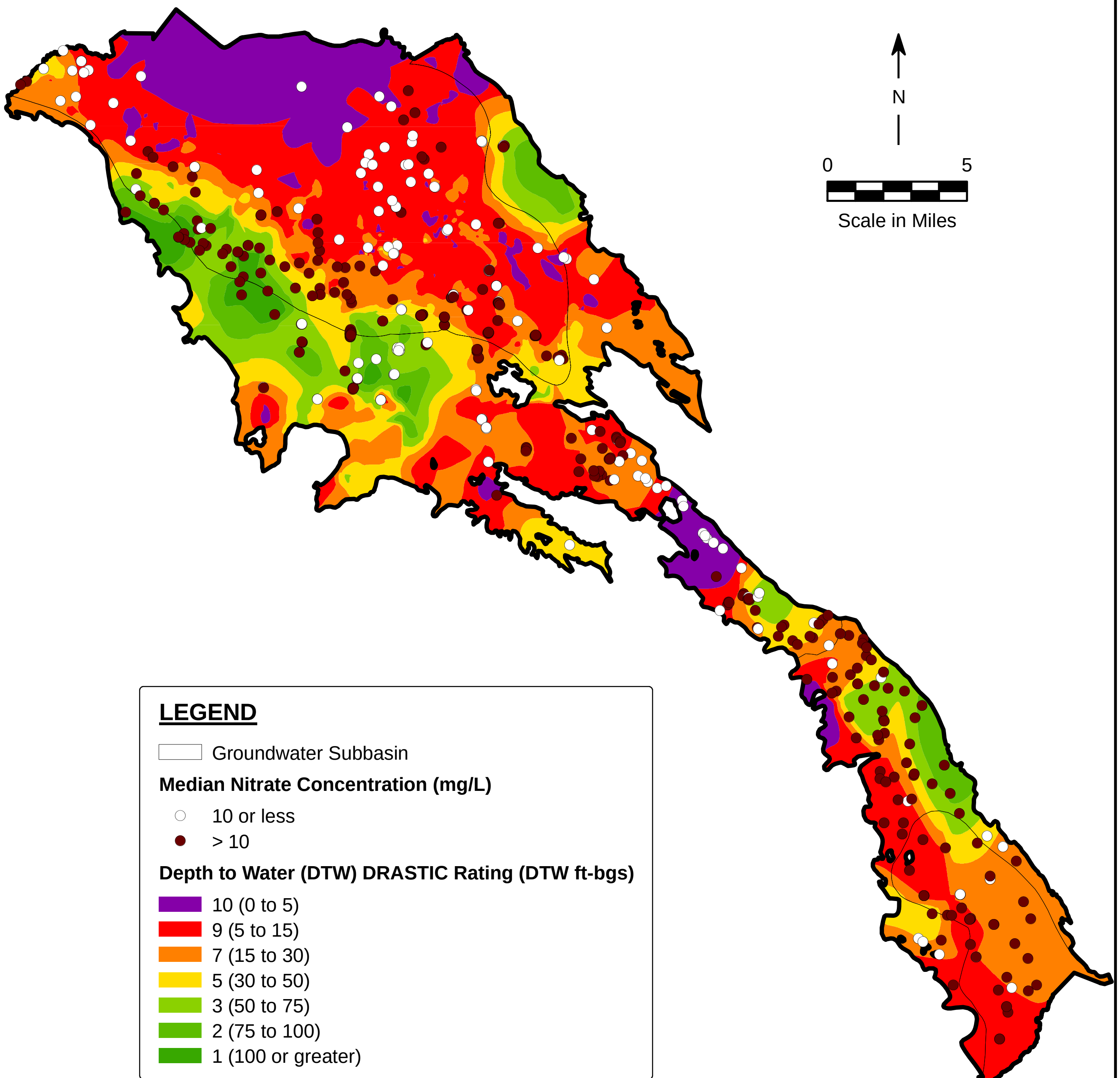
N

July 2010	**Figure 5-4** **Median Nitrate Concentration Threshold Analysis**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



Note: 470 wells represent all wells that have both nitrate data and known well construction information. Additional nitrate data are available for other wells.

July 2010	**Figure 5-5 Median Nitrate Concentration for 470 Well Nitrate Dataset (Binary)**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



ft-bgs = feet below ground surface

July 2010

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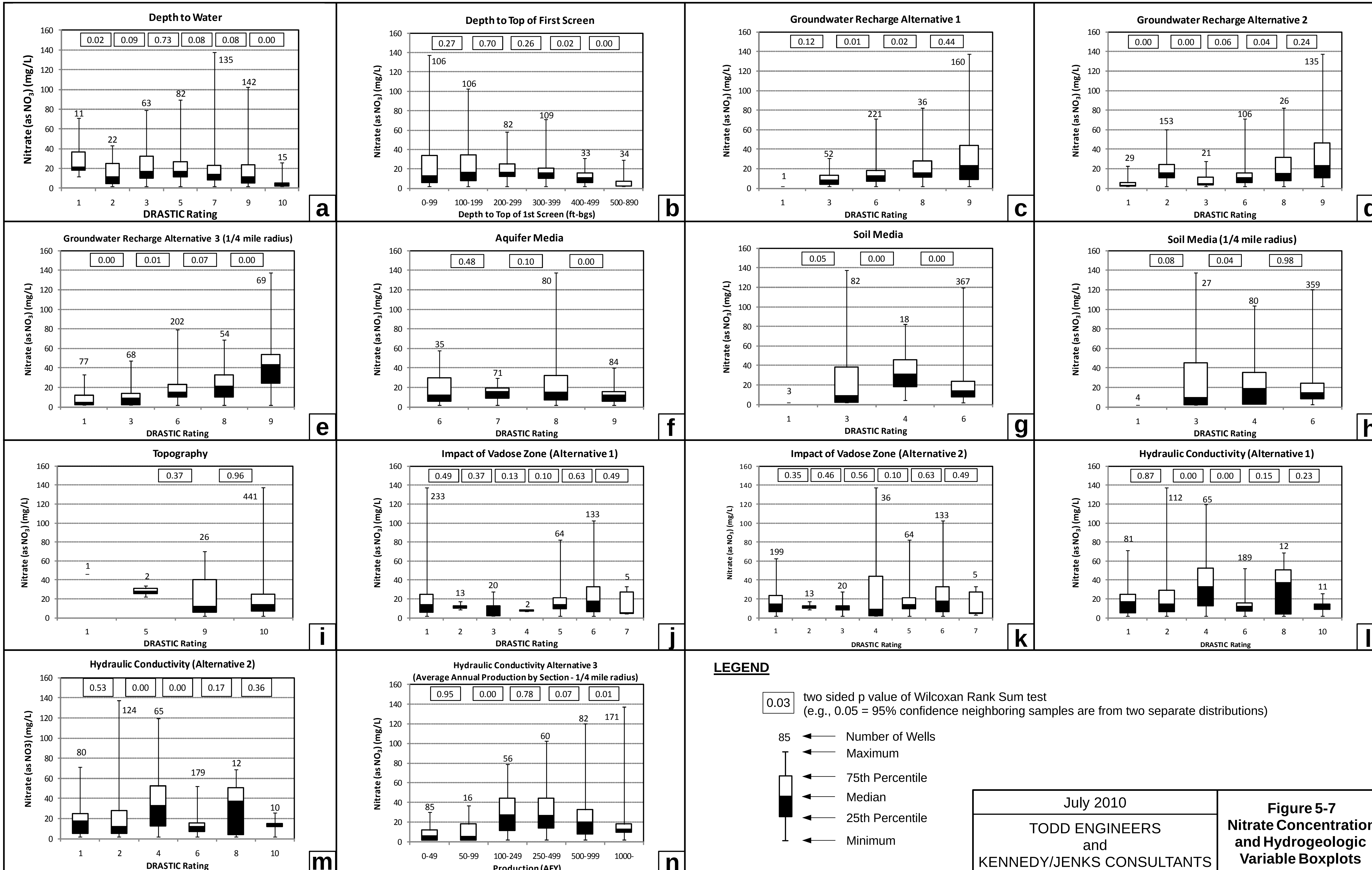
Figure 5-6
Depth to
First Encountered
Water



July 2010

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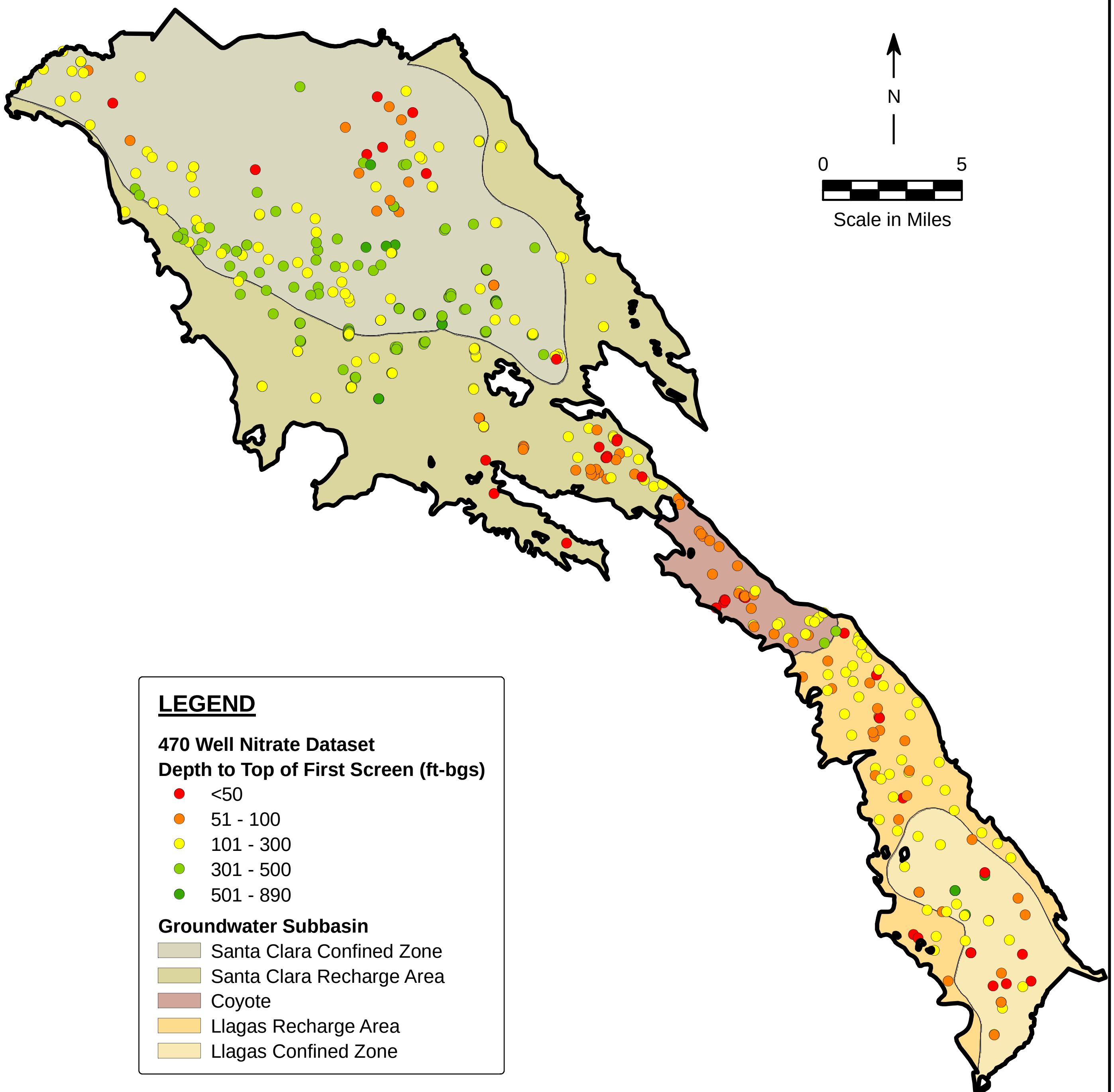
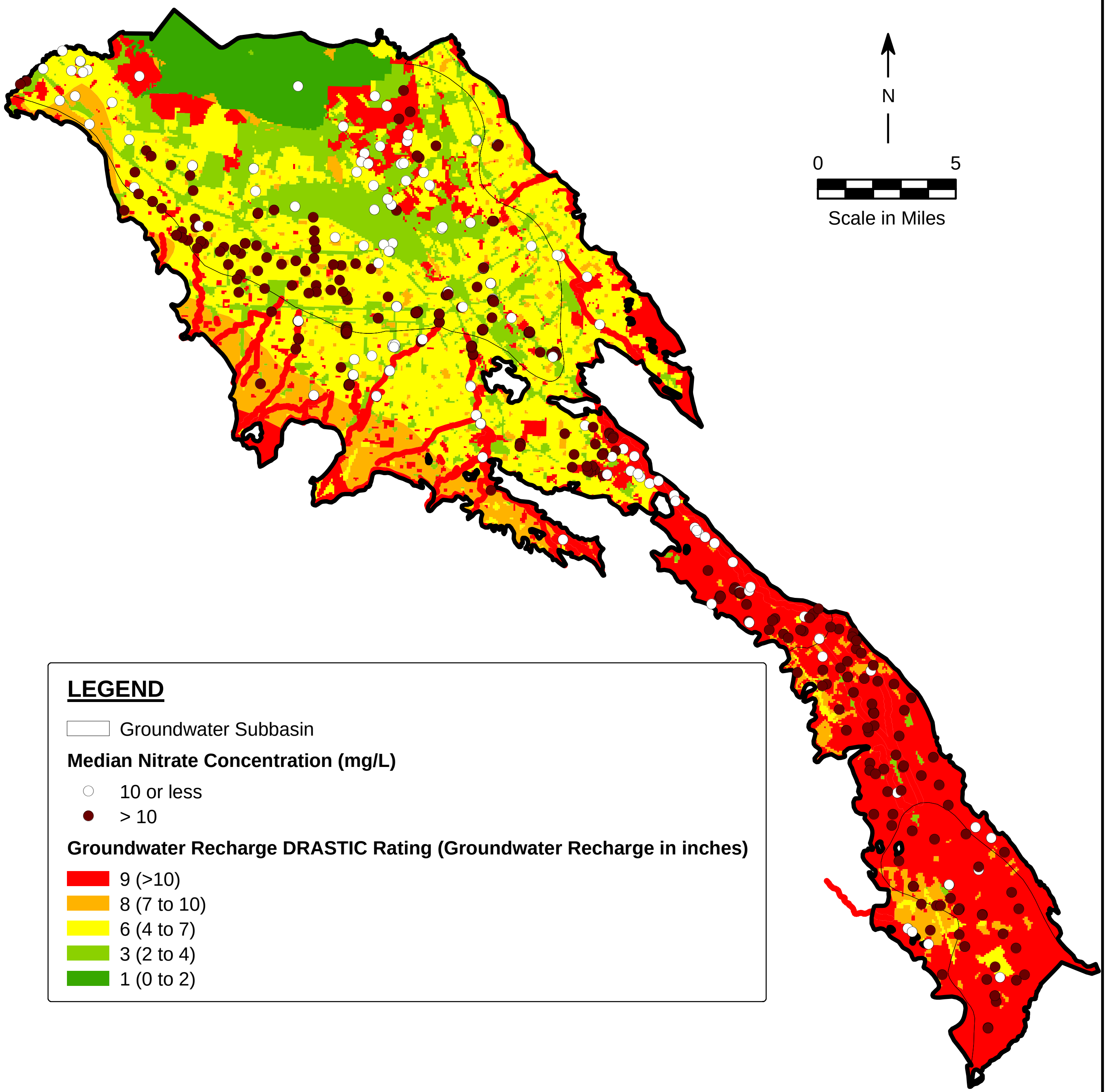
and
KENNEDY/JENKS CONSULTANTS

Figure 5-7
Nitrate Concentration and Hydrogeologic Variable Boxplots



ft-bgs = feet below ground surface
Note: 470 wells represent all wells that have both nitrate data and well construction information. Additional nitrate data are available for other wells.

July 2010	**Figure 5-8 Depth to Top of First Screen for 470 Well Nitrate Dataset**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



July 2010

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Figure 5-9
Groundwater Recharge
(Alternative 1)

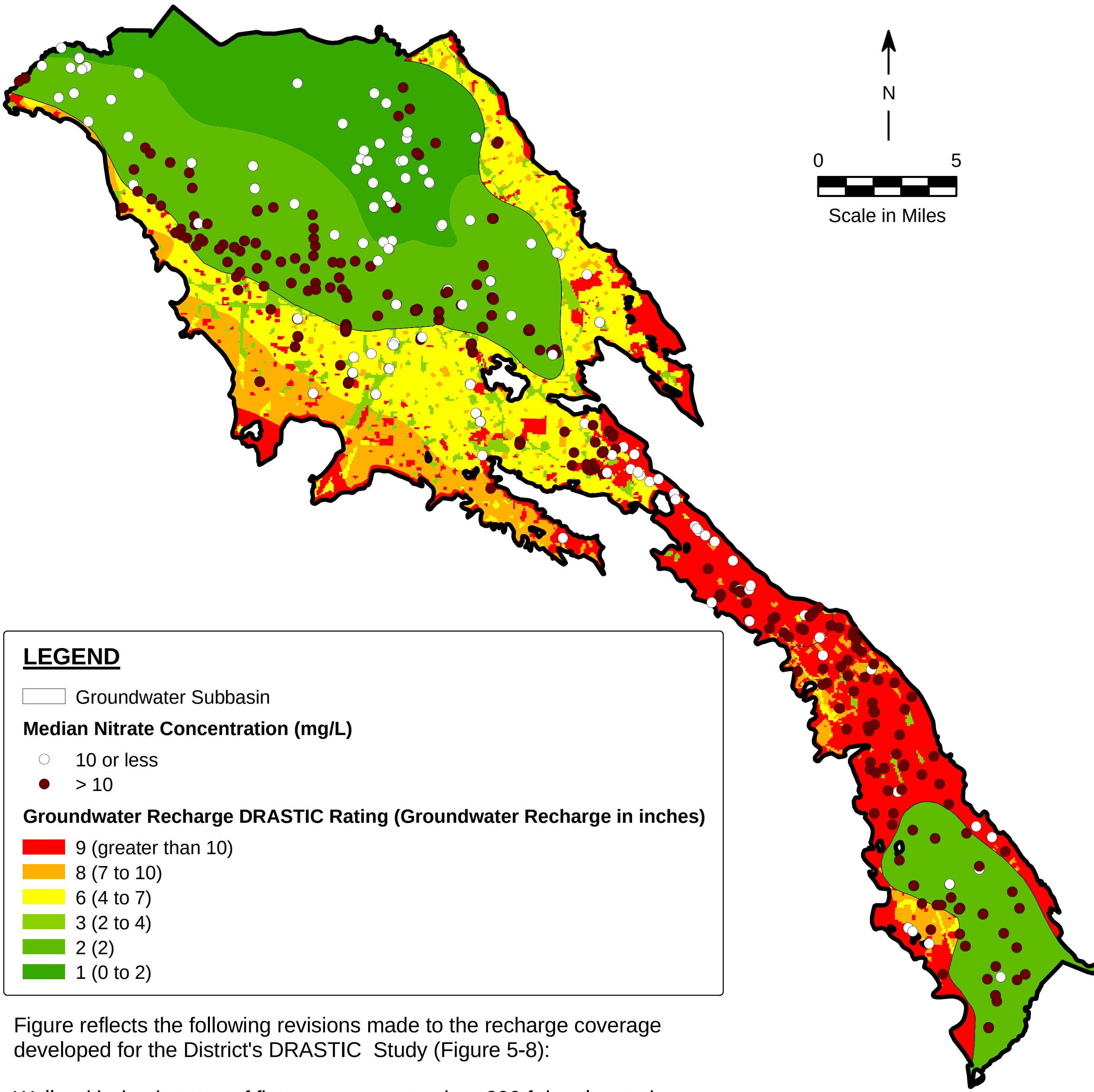
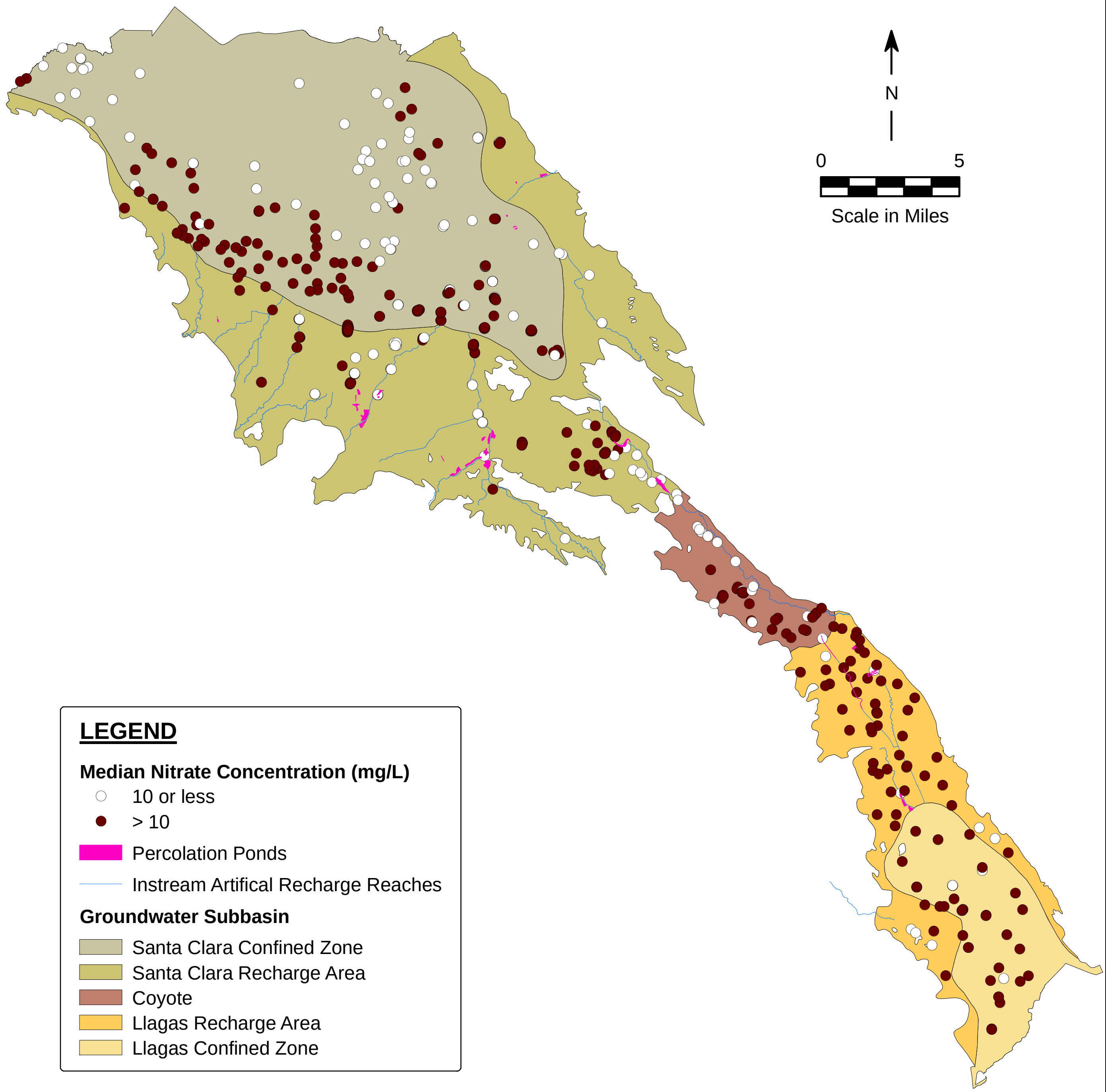


Figure reflects the following revisions made to the recharge coverage developed for the District's DRASTIC Study (Figure 5-8):

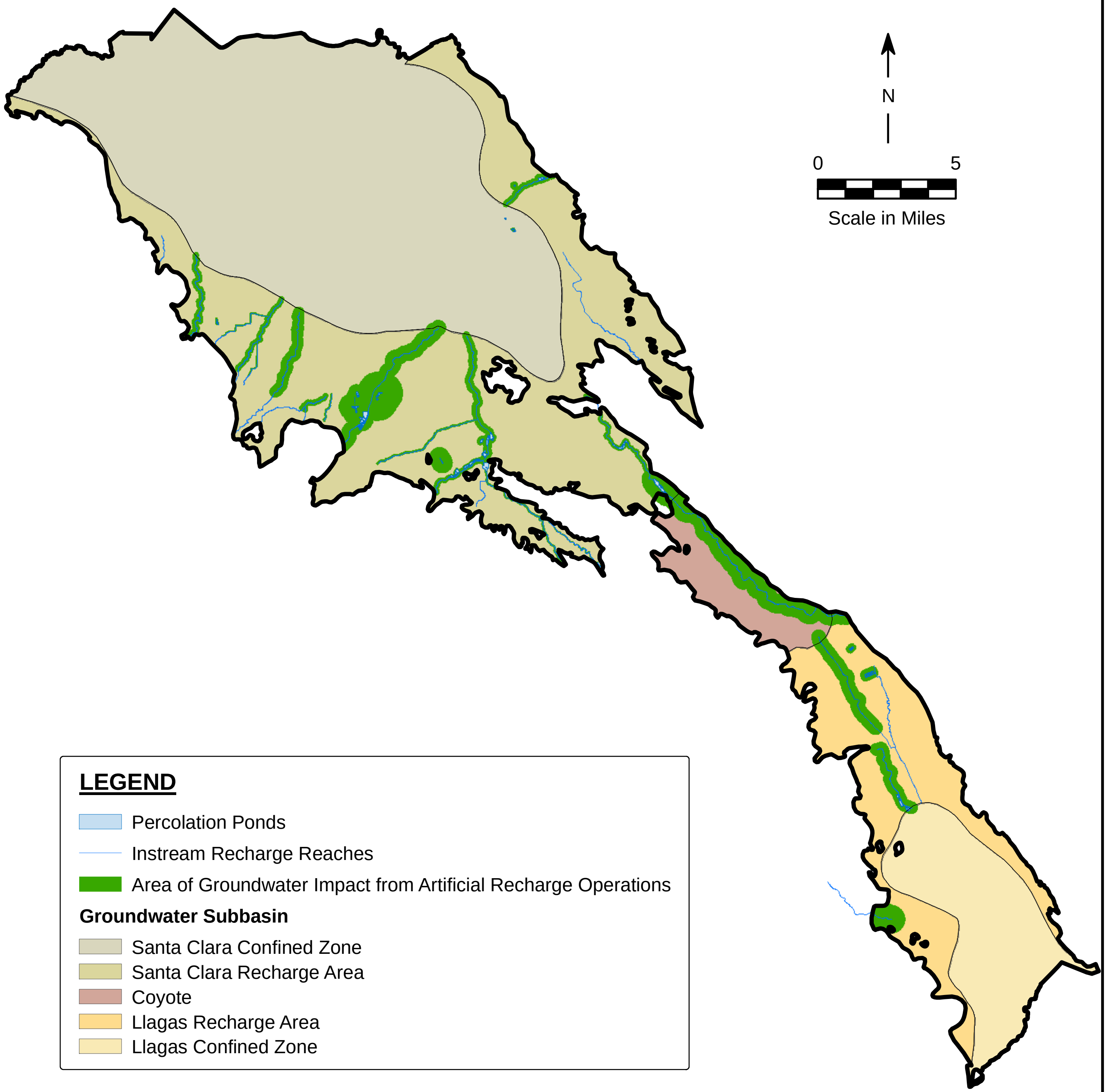
Wells with depth to top of first screen greater than 200 ft-bgs located within model calibrated confined zone of the Santa Clara Subbasin were assigned a DRASTIC recharge rating of 1.

Wells with depth to top of first screen greater than 200 ft-bgs located between originally mapped and model-calibrated confined zone extents in Santa Clara Subbasin and in the confined zone in the Llagas Subbasin were assigned a DRASTIC recharge rating of 2.

July 2010	**Figure 5-10 Groundwater Recharge (Alternative 2)**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



July 2010	**Figure 5-11 Artificial Recharge Facilities**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



July 2010	**Figure 5-12** **Estimated Impact Area of Artificial Recharge Facilities**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	

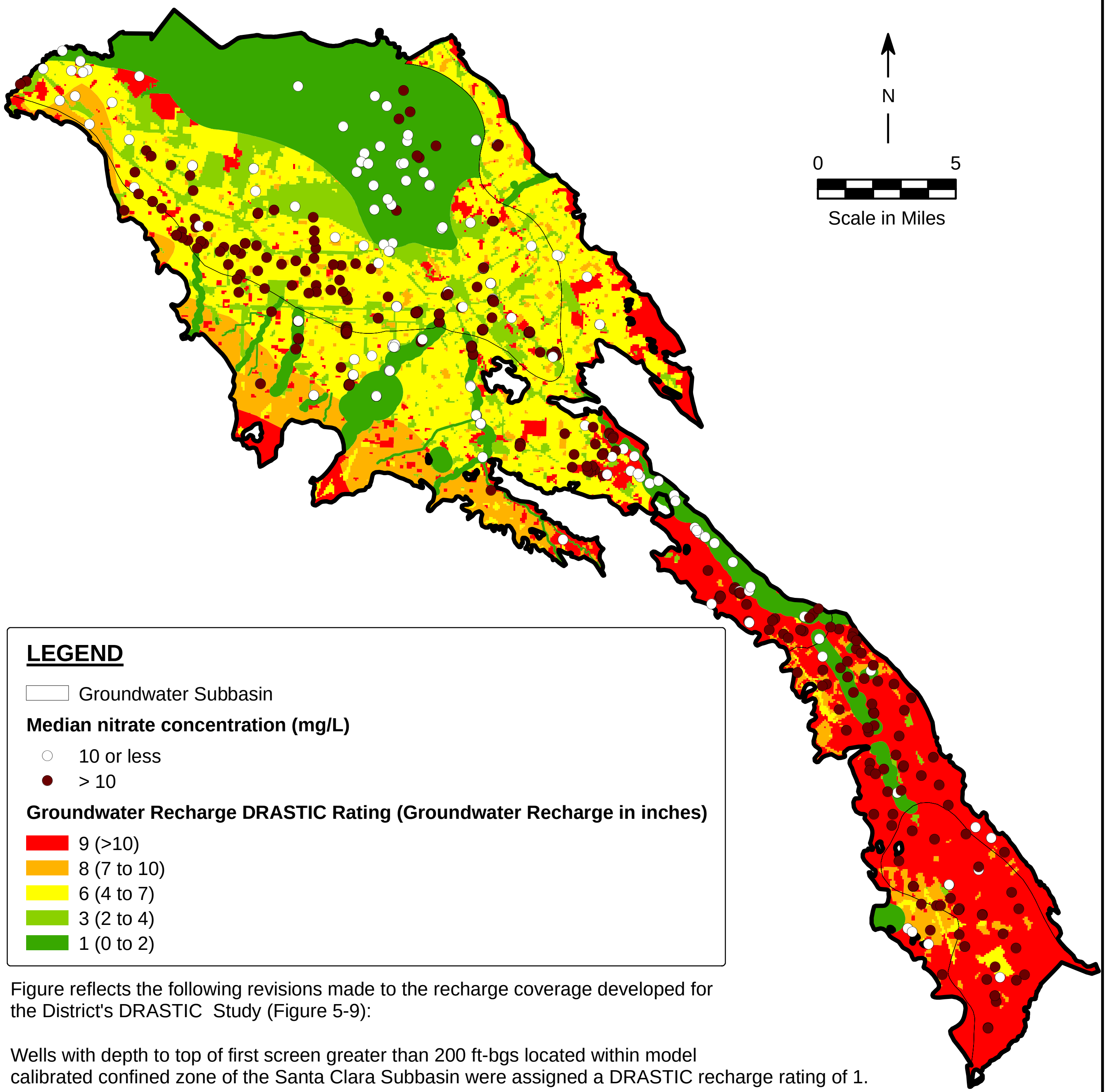


Figure reflects the following revisions made to the recharge coverage developed for the District's DRASTIC Study (Figure 5-9):

Wells with depth to top of first screen greater than 200 ft-bgs located within model calibrated confined zone of the Santa Clara Subbasin were assigned a DRASTIC recharge rating of 1.

Observed dilution of nitrate by artificial recharge of imported water was accounted for by assigning a DRASTIC recharge rating of 1 to calculated impact areas around each artificial recharge facility. Impact areas were determined using two factors. Factor 1 was based on the average volume of recharge applied from 1994 to 2006 (1 to 9). Factor 2 was based on the infiltrating area of the recharge facility, assuming a 40-foot width for linear features. The product of the two factors represents the distance (in feet) from each recharge facility that groundwater is influenced by artifical recharge. It is assumed that artifical recharge water has nitrate concentrations below 10 mg/L and recharge in creeks is distributed evenly along its entire length.

July 2010	Figure 5-13 Groundwater Recharge (Alternative 3)
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	

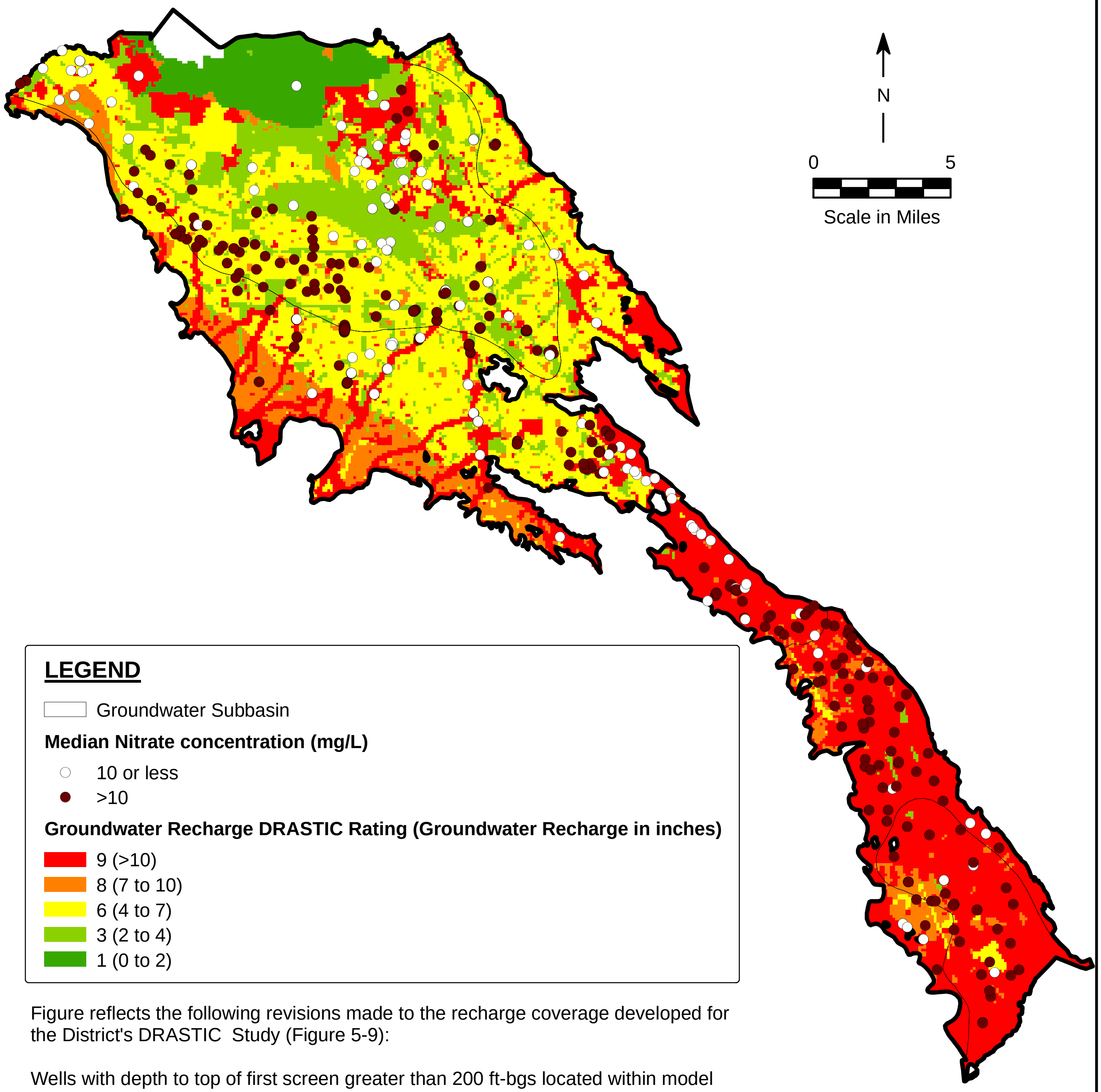


Figure reflects the following revisions made to the recharge coverage developed for the District's DRASTIC Study (Figure 5-9):

Wells with depth to top of first screen greater than 200 ft-bgs located within model calibrated confined zone of the Santa Clara Subbasin were assigned a DRASTIC recharge rating of 1.

For sensitivity mapping, areas within a 500-foot radius of all recharge facilities were assigned a recharge value of 9 to protect groundwater in the vicinity of recharge areas.

July 2010	**Figure 5-14 Groundwater Recharge Shallow Aquifer (Alternative 4)**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	

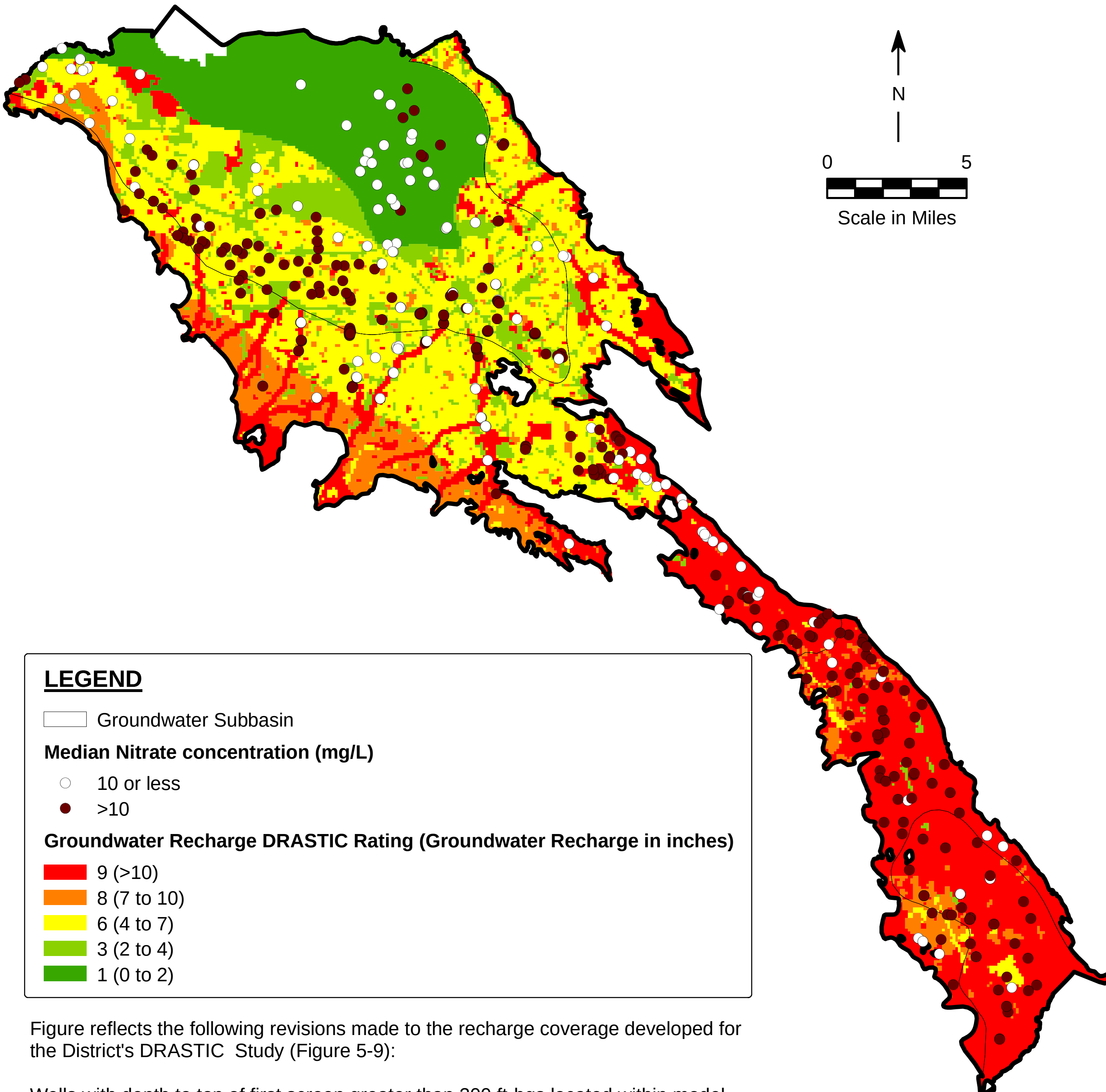
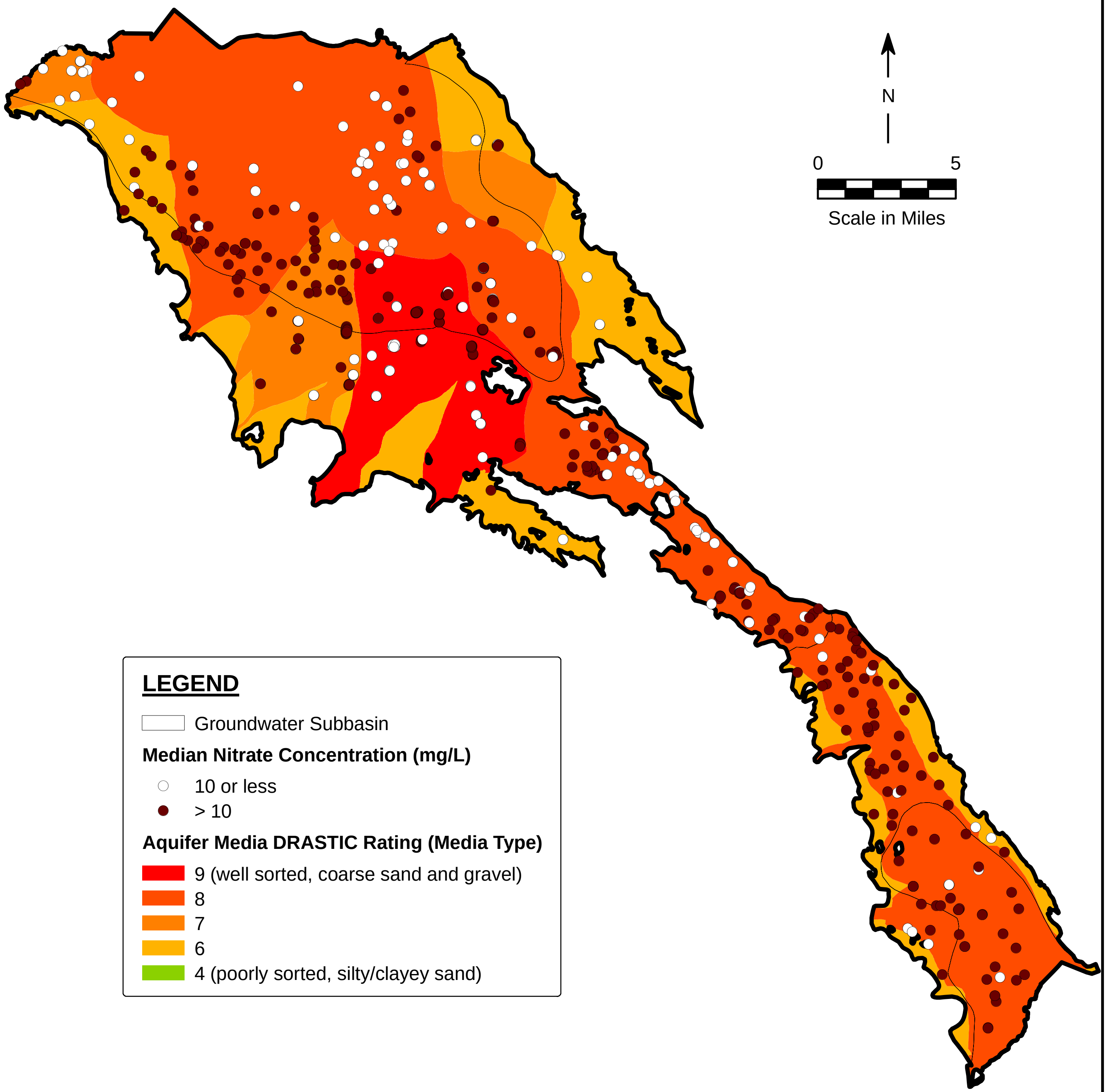


Figure reflects the following revisions made to the recharge coverage developed for the District's DRASTIC Study (Figure 5-9):

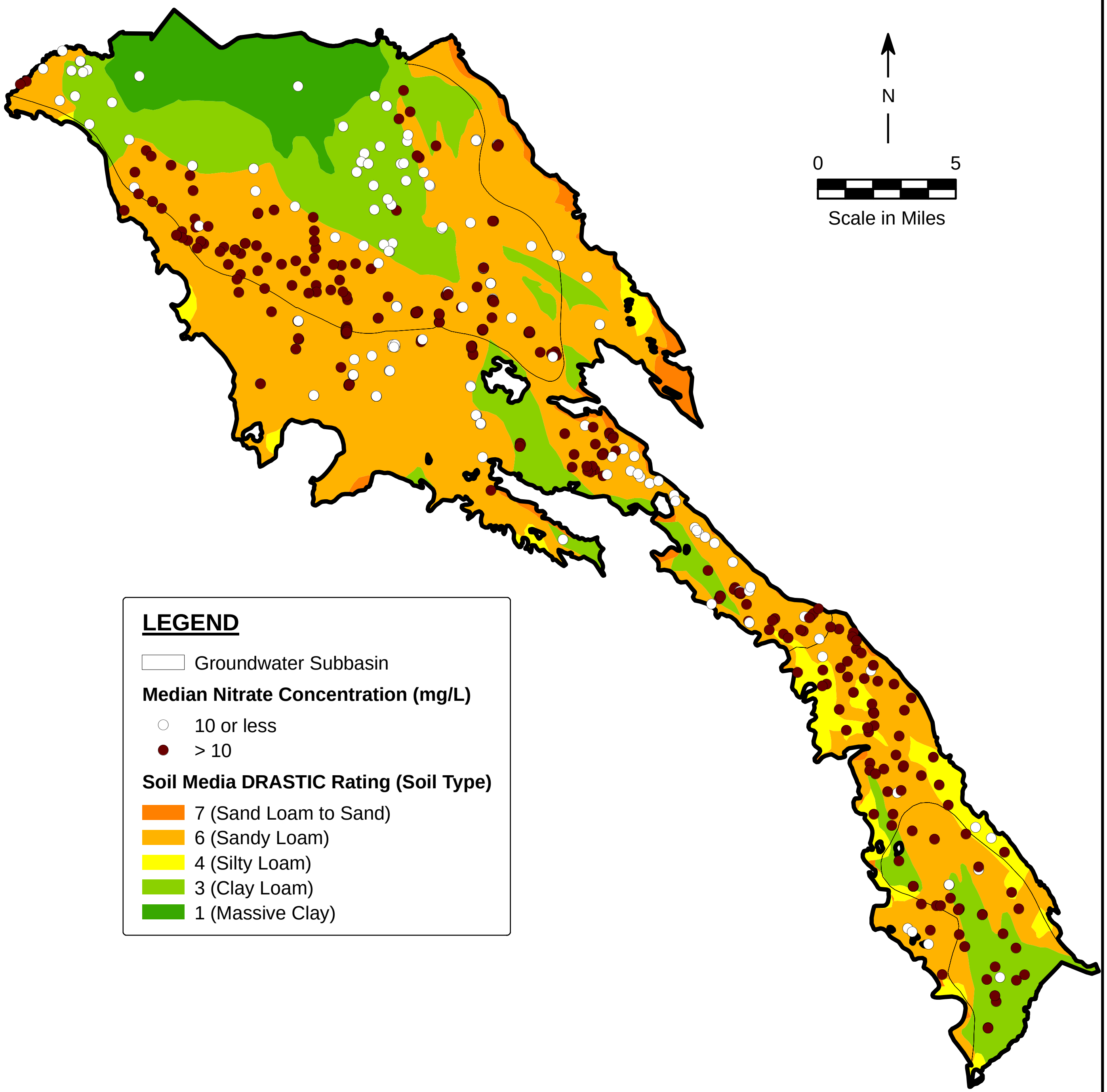
Wells with depth to top of first screen greater than 200 ft-bgs located within model calibrated confined zone of the Santa Clara Subbasin were assigned a DRASTIC recharge rating of 1.

For sensitivity mapping, areas within a 500-foot radius of all recharge facilities were assigned a recharge value of 9 to protect groundwater in the vicinity of recharge areas.

July 2010	**Figure 5-15 Groundwater Recharge Principal Aquifer (Alternative 4)**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



July 2010	Figure 5-16 Aquifer Media
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



July 2010

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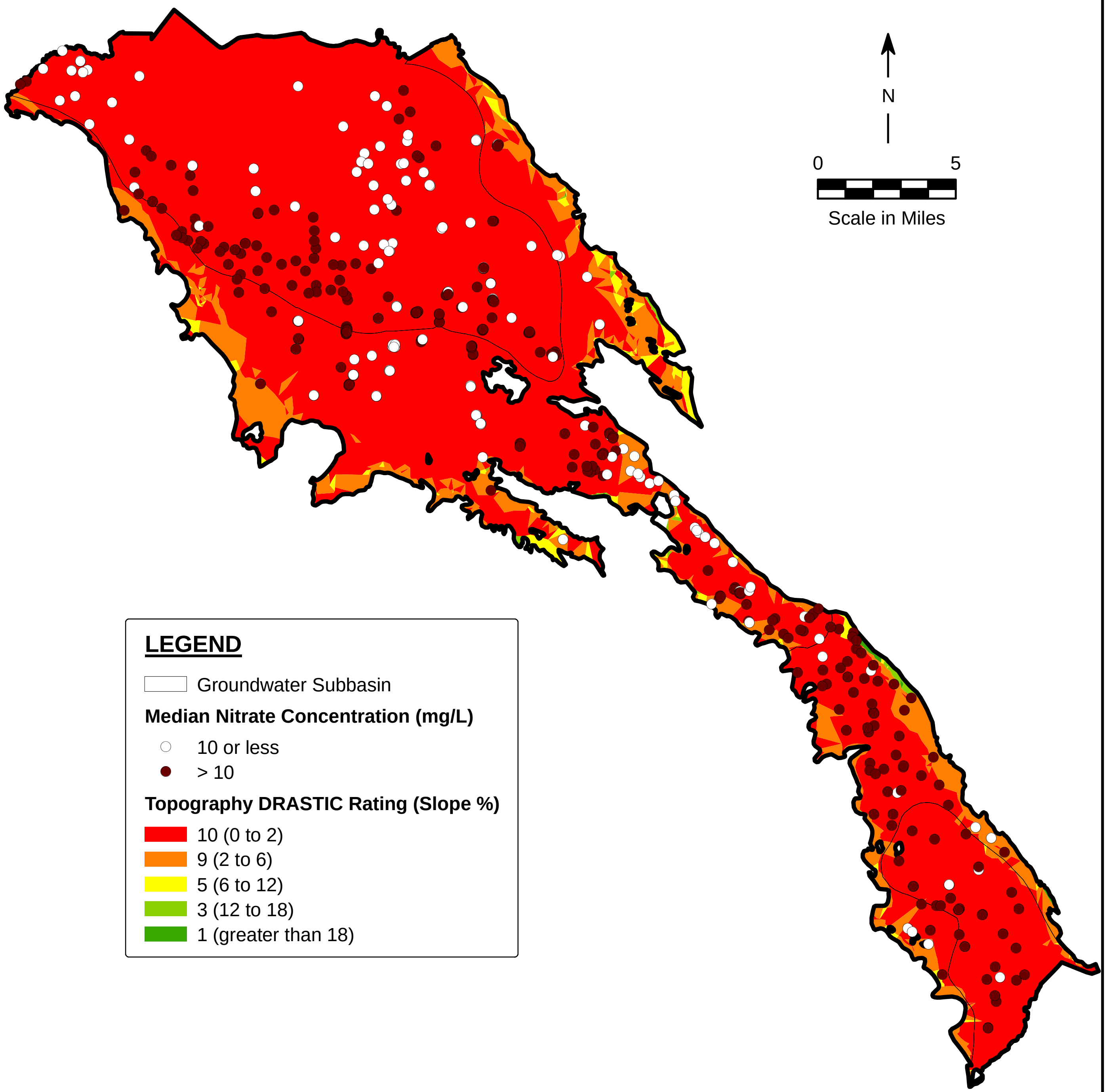
and
KENNEDY/JENKS CONSULTANTS

Figure 5-17
Soil Media



July 2010

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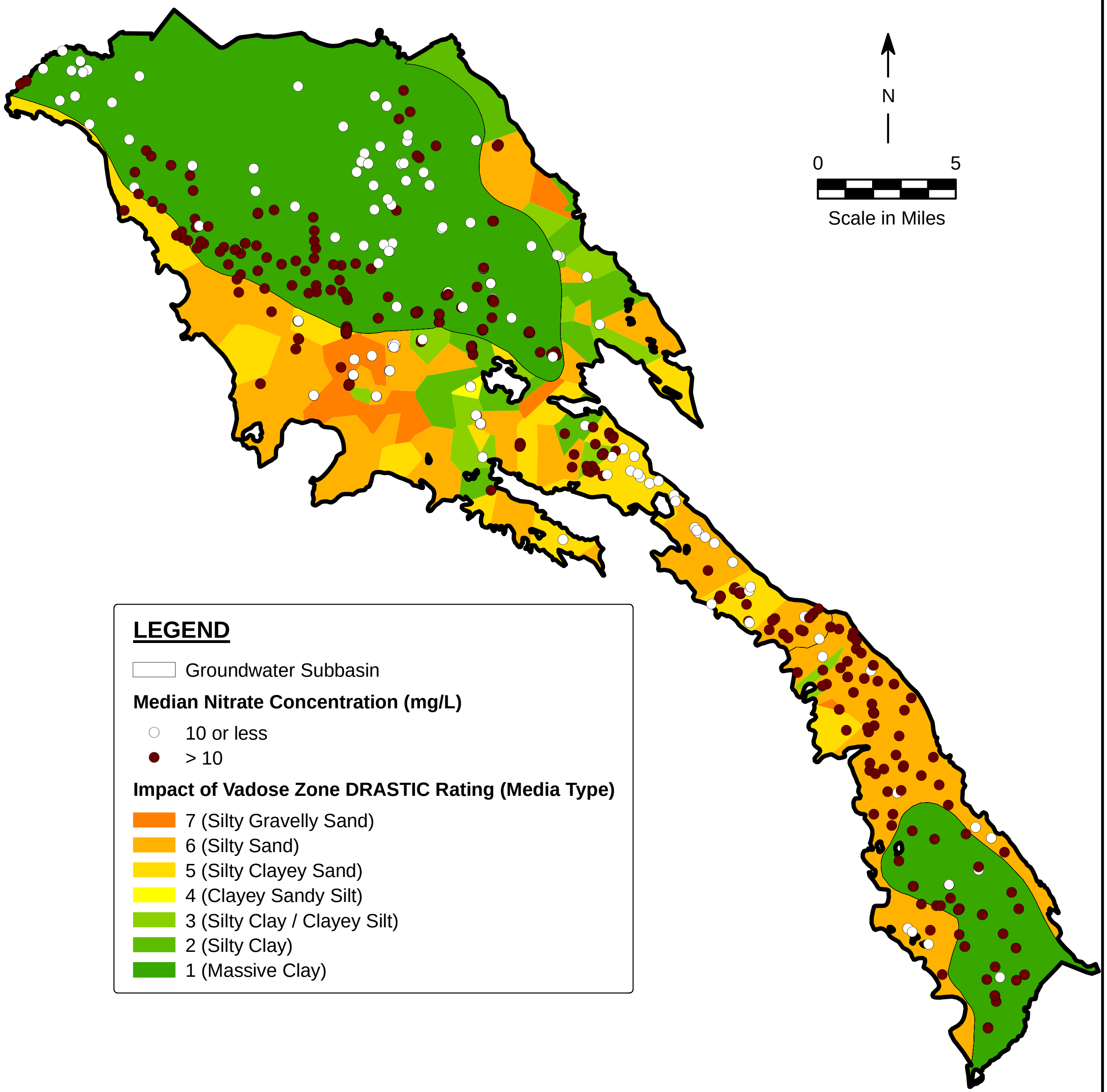
Figure 5-18
Topography
(Slope)



July 2010	**Figure 5-19** **Impact of** **Vadose Zone** **(Alternative 1)**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	

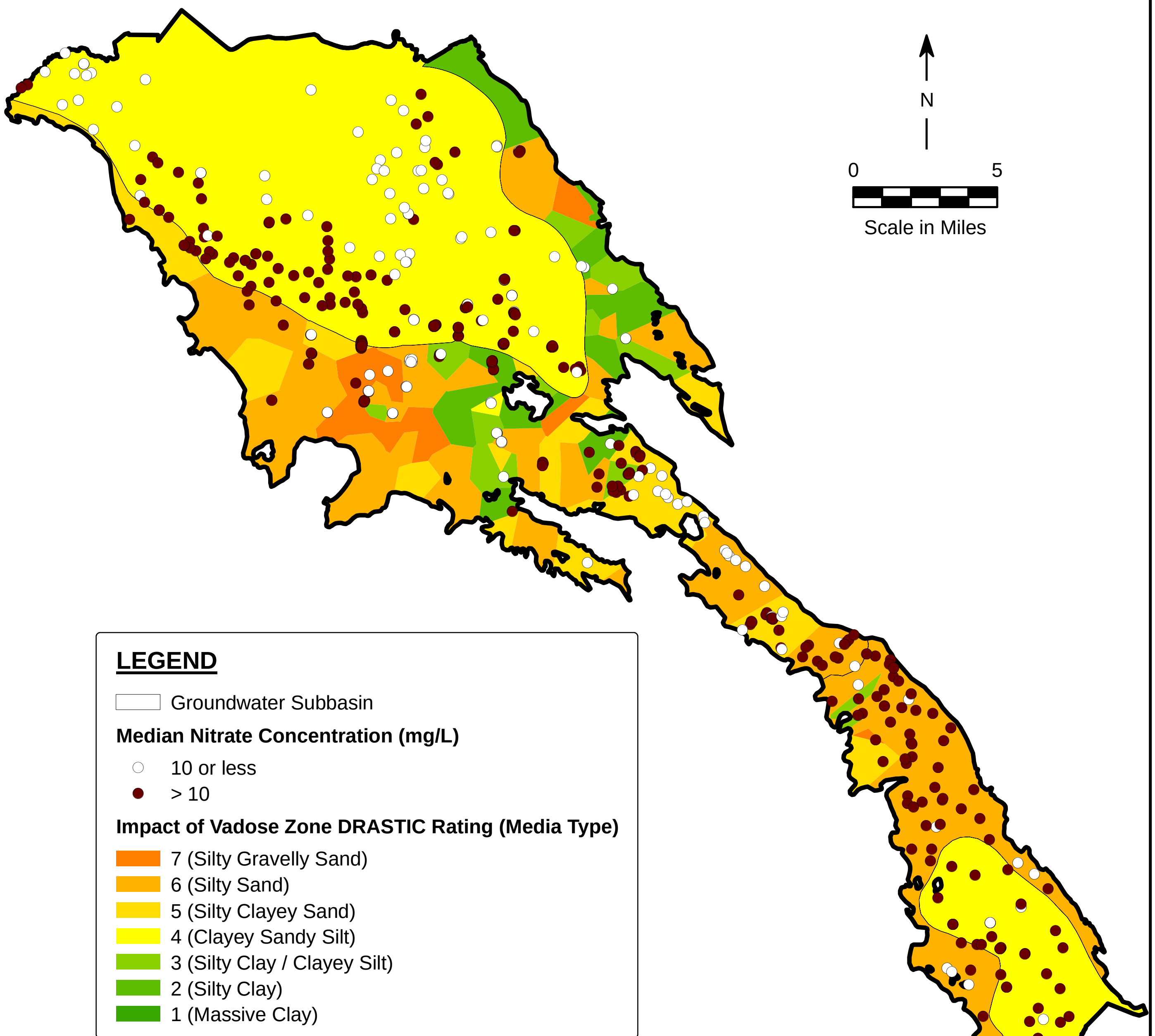
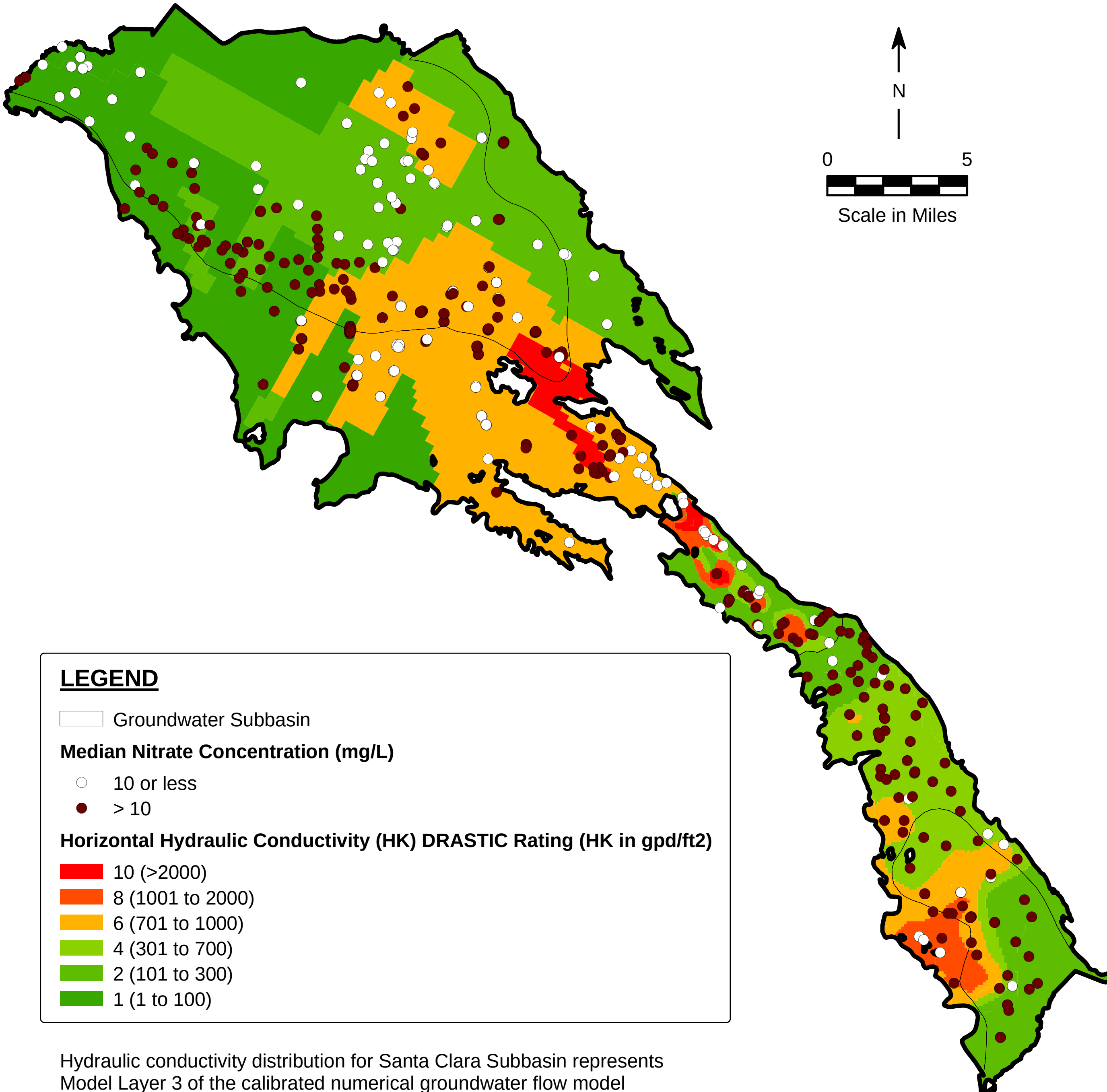


Figure reflects the following revision made to Impact of Vadose Zone coverage developed for the District's DRASTIC Study (Figure 5-16):

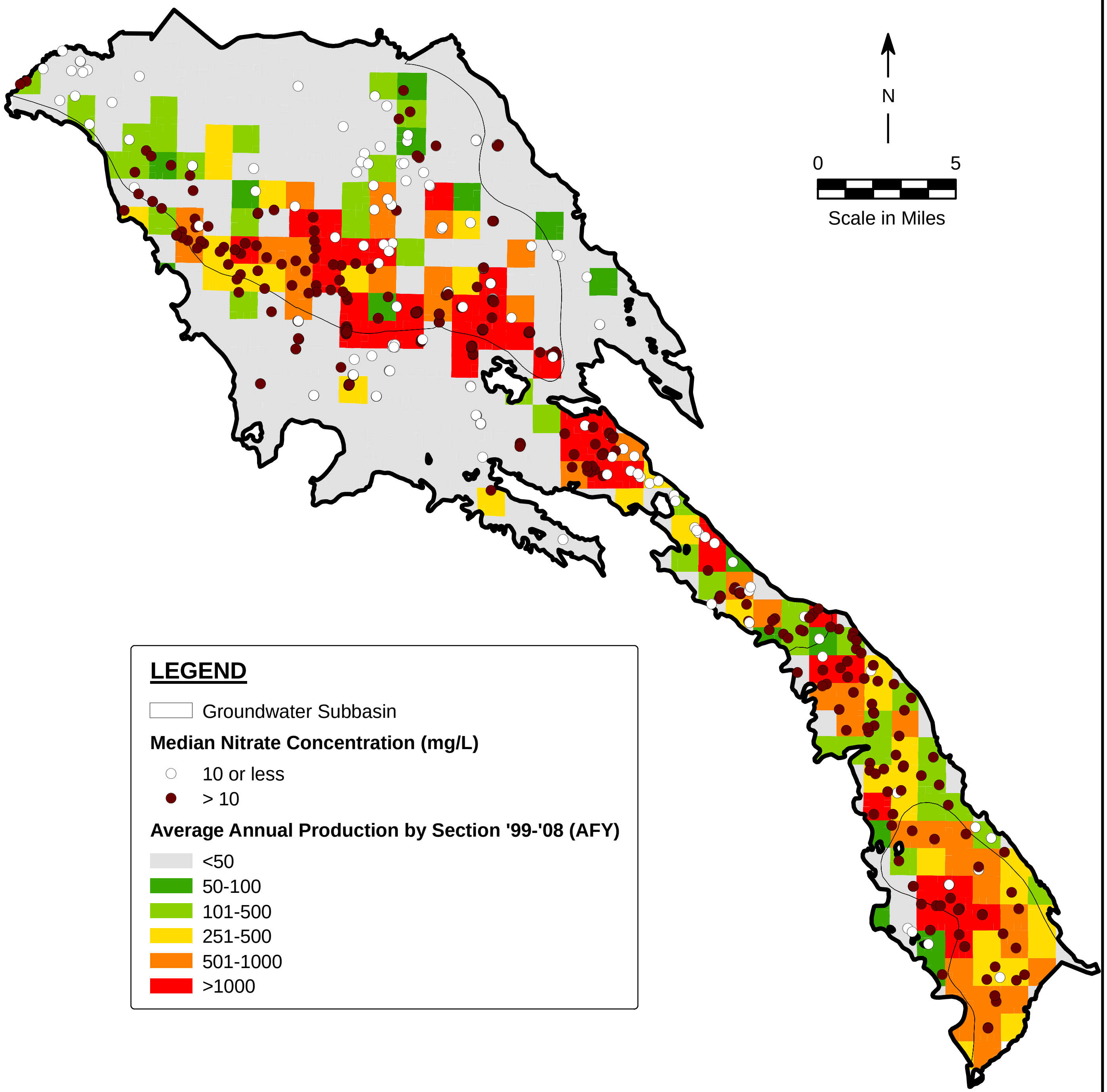
Wells with a depth to top of first screen less than 100 ft-bgs located within the confined zones of the Santa Clara and Llagas subbasins were assigned an Impact of Vadose Zone DRASTIC rating of 4.

July 2010	**Figure 5-20 Impact of Vadose Zone (Alternative 2)**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



Hydraulic conductivity distribution for Santa Clara Subbasin represents Model Layer 3 of the calibrated numerical groundwater flow model (CH2M Hill, 1992). Hydraulic conductiivty distribution from single layer model used for Coyote Subbasin. Average hydraulic conducitivity distribution for major aquifer units used for Llagas Subbasin.

July 2010	**Figure 5-21**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	**Hydraulic Conductivity (Alternative 1)**



July 2010

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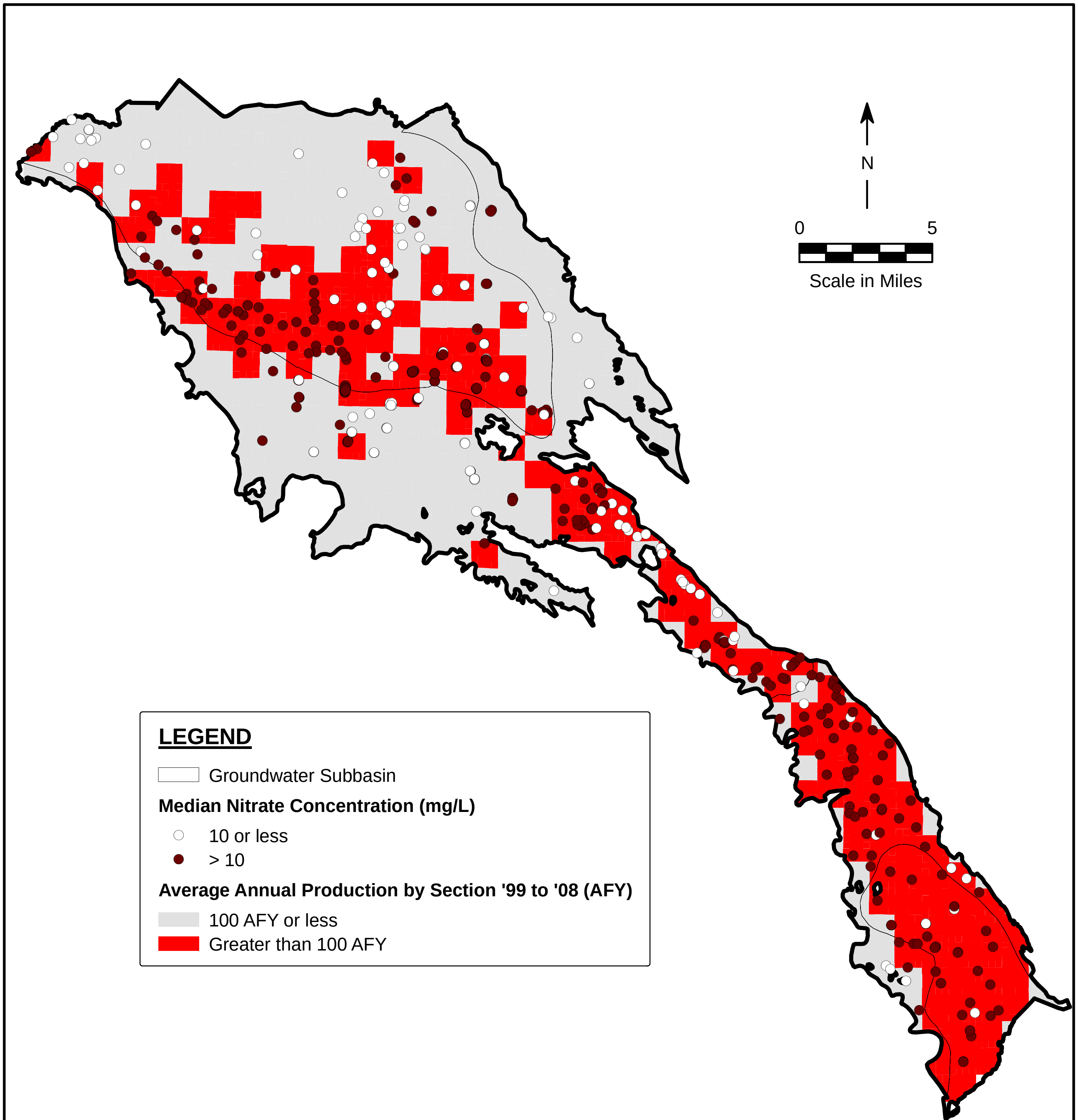
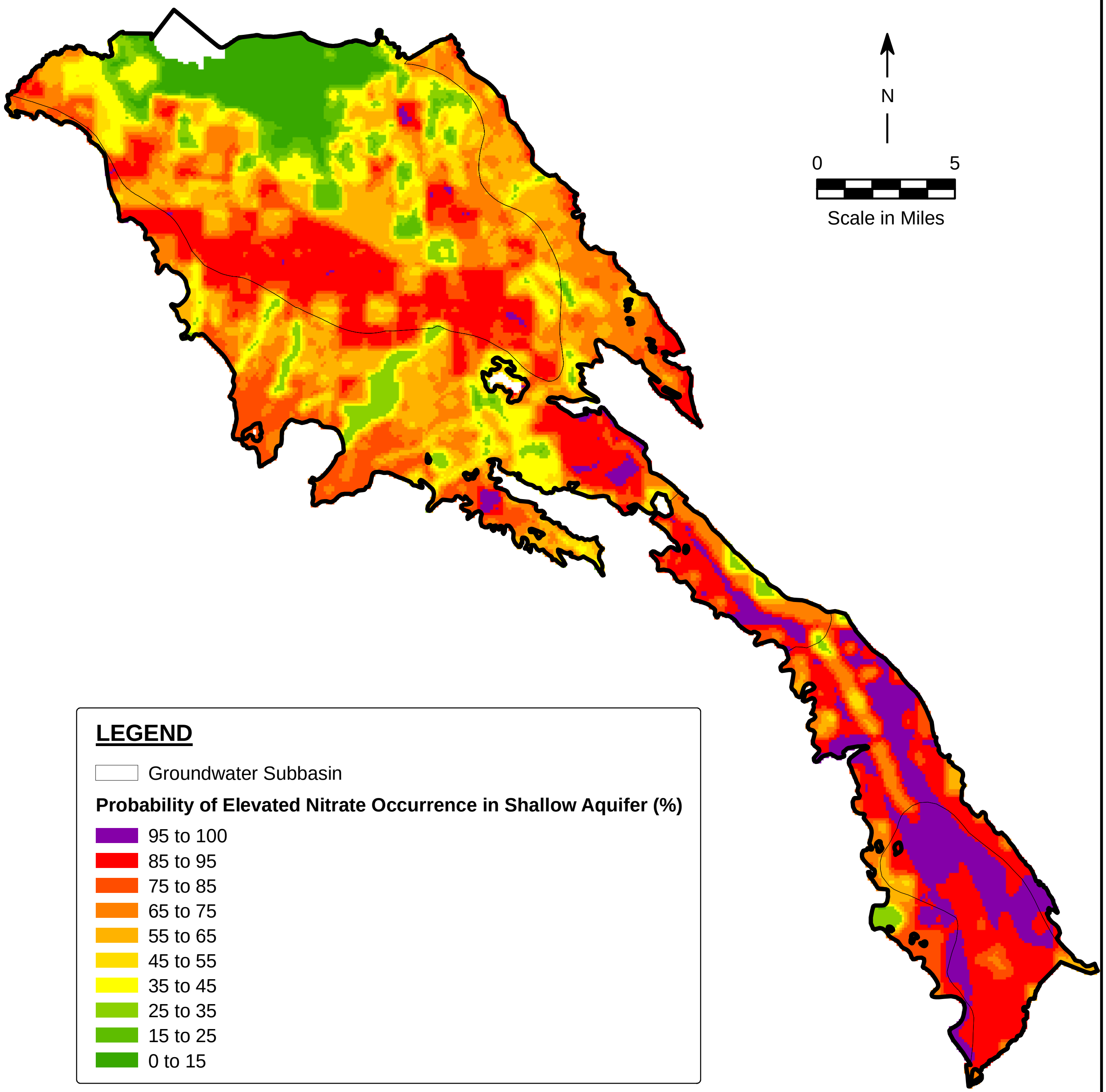
Figure 5-22
Average Annual Production (1999-2008) by Geographic Section



July 2010	**Figure 5-23** **Average Annual Production (1999-2008) by Geographic Section (Binary)**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



July 2010

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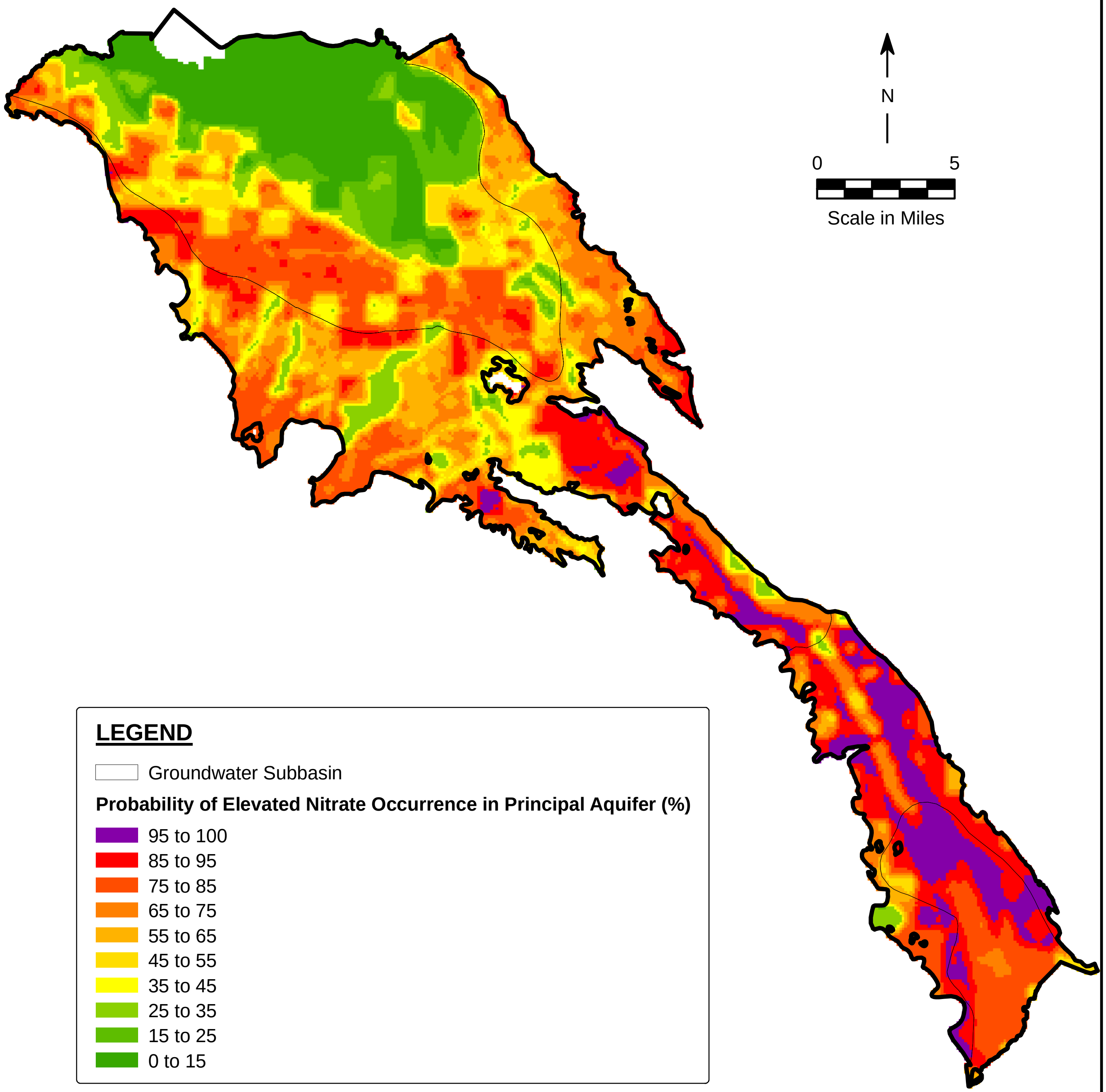
Figure 5-24
Probability
of Elevated Nitrate
Shallow Aquifer



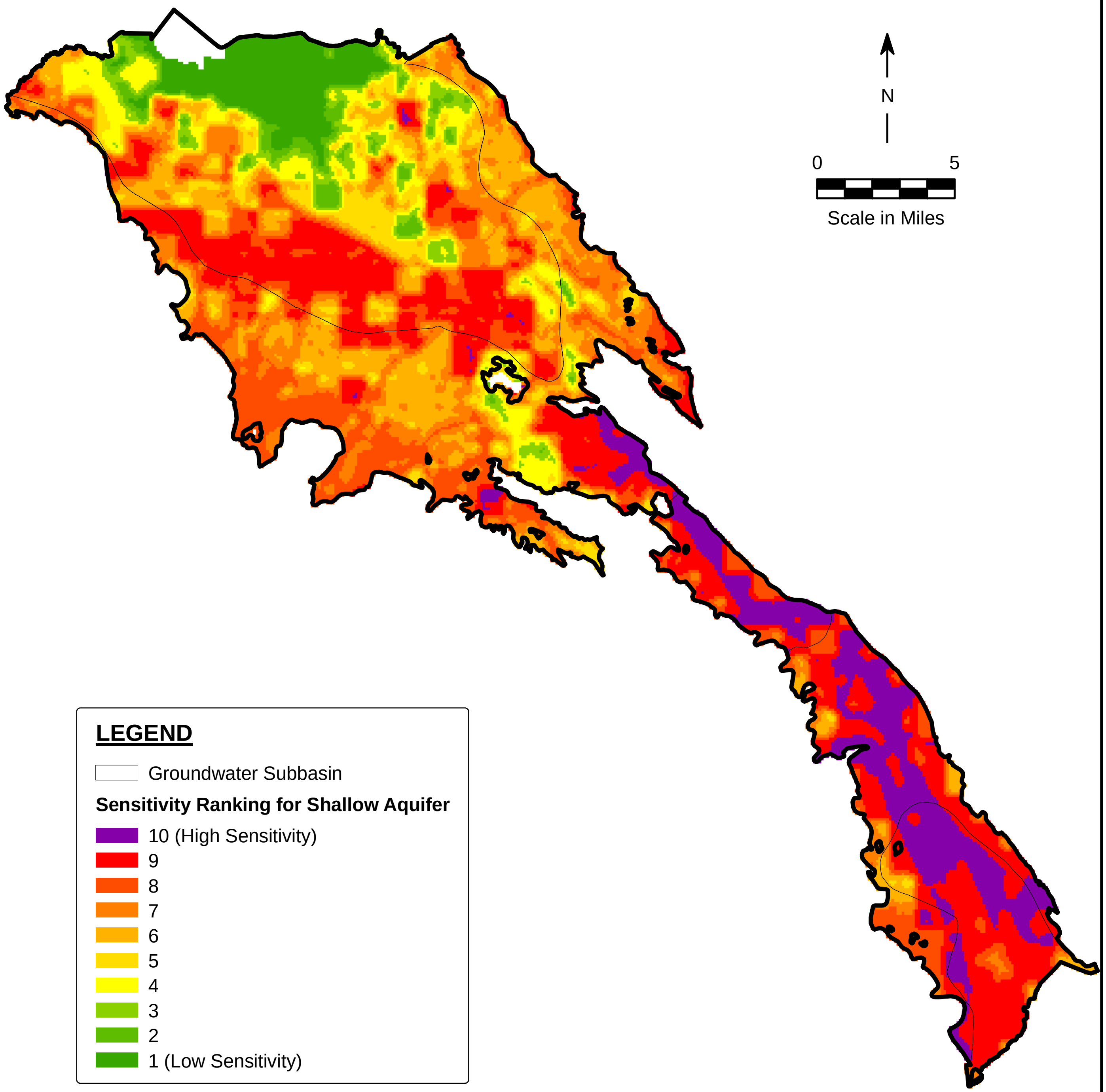
LEGEND

Groundwater Subbasin

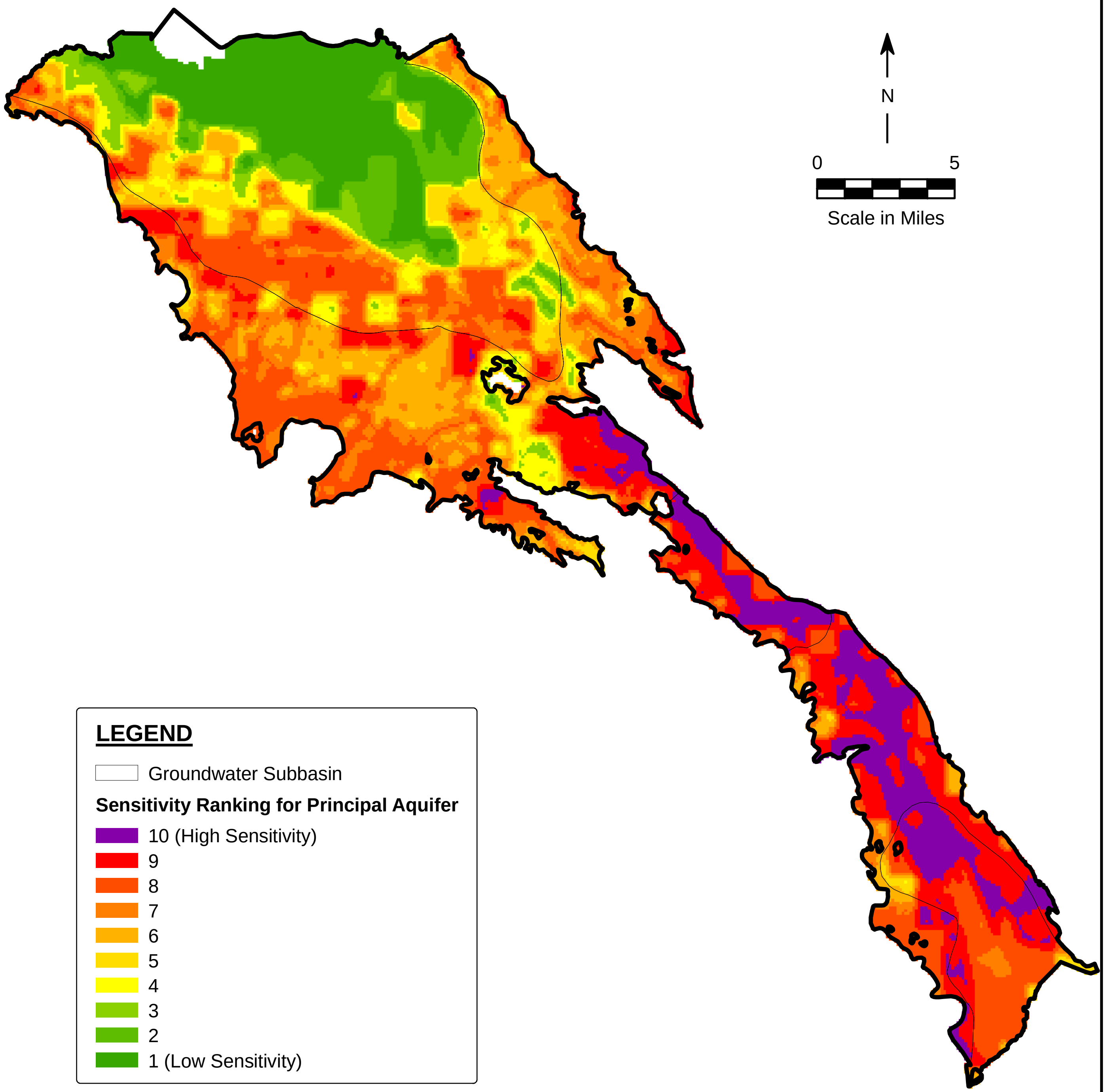
Probability of Elevated Nitrate Occurrence in Principal Aquifer (%)

- 95 to 100
- 85 to 95
- 75 to 85
- 65 to 75
- 55 to 65
- 45 to 55
- 35 to 45
- 25 to 35
- 15 to 25
- 0 to 15

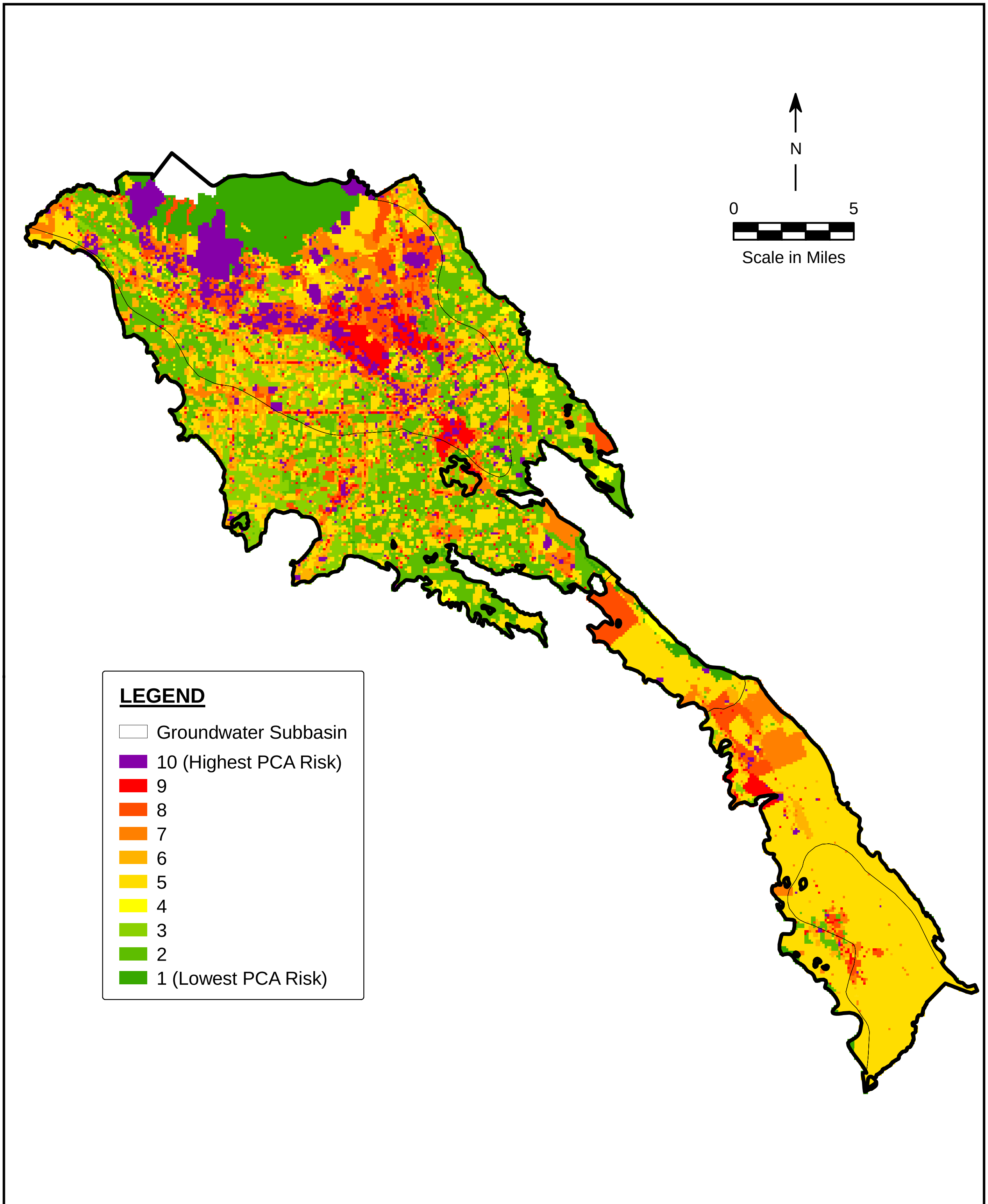
July 2010	**Figure 5-25 Probability of Elevated Nitrate Principal Aquifer**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



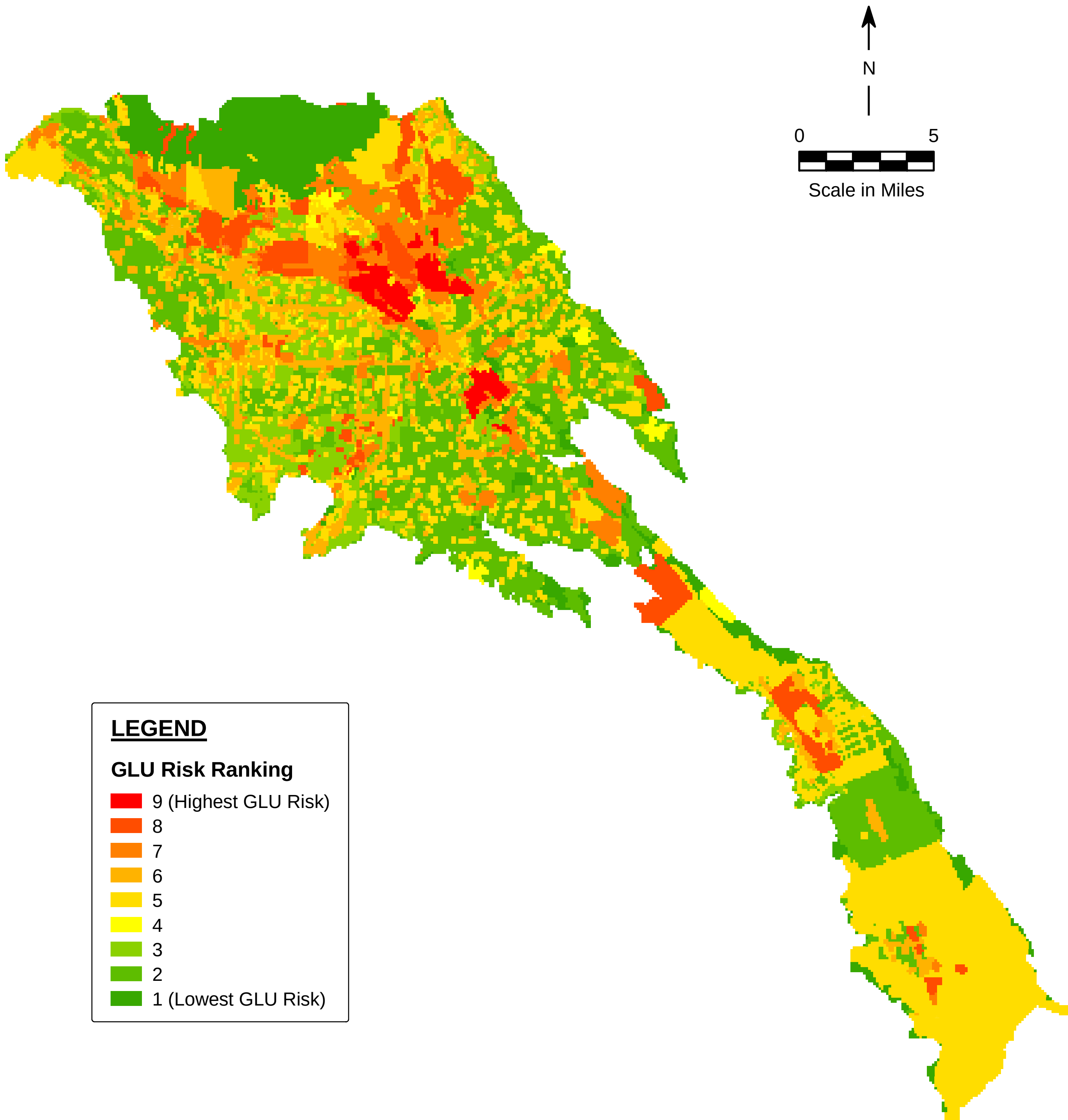
July 2010	**Figure 5-26 Groundwater Sensitivity Shallow Aquifer**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



July 2010	**Figure 5-27 Groundwater Sensitivity Principal Aquifer**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



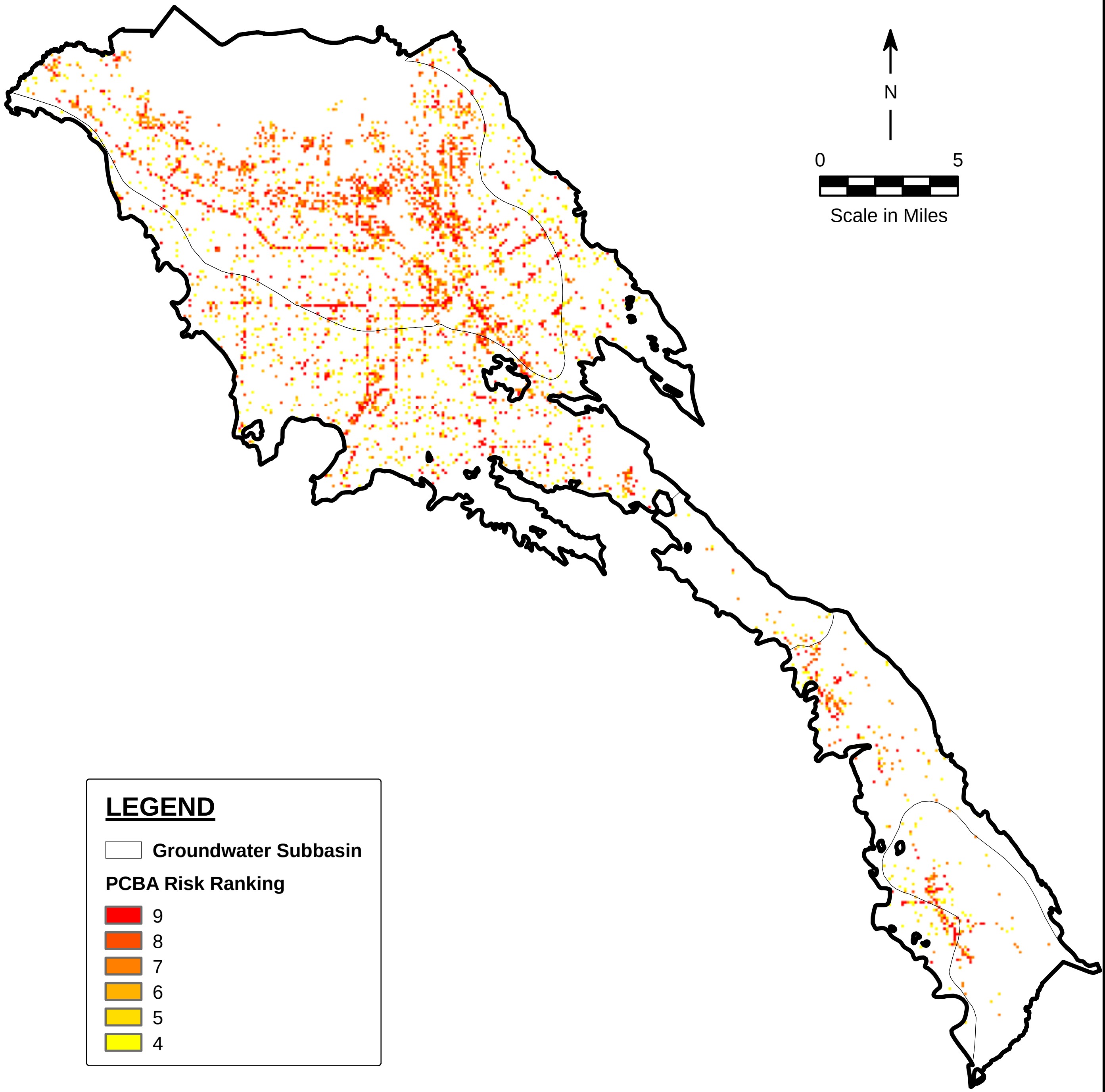
July 2010	**Figure 6-1 Potentially Contaminating Activities Risk**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



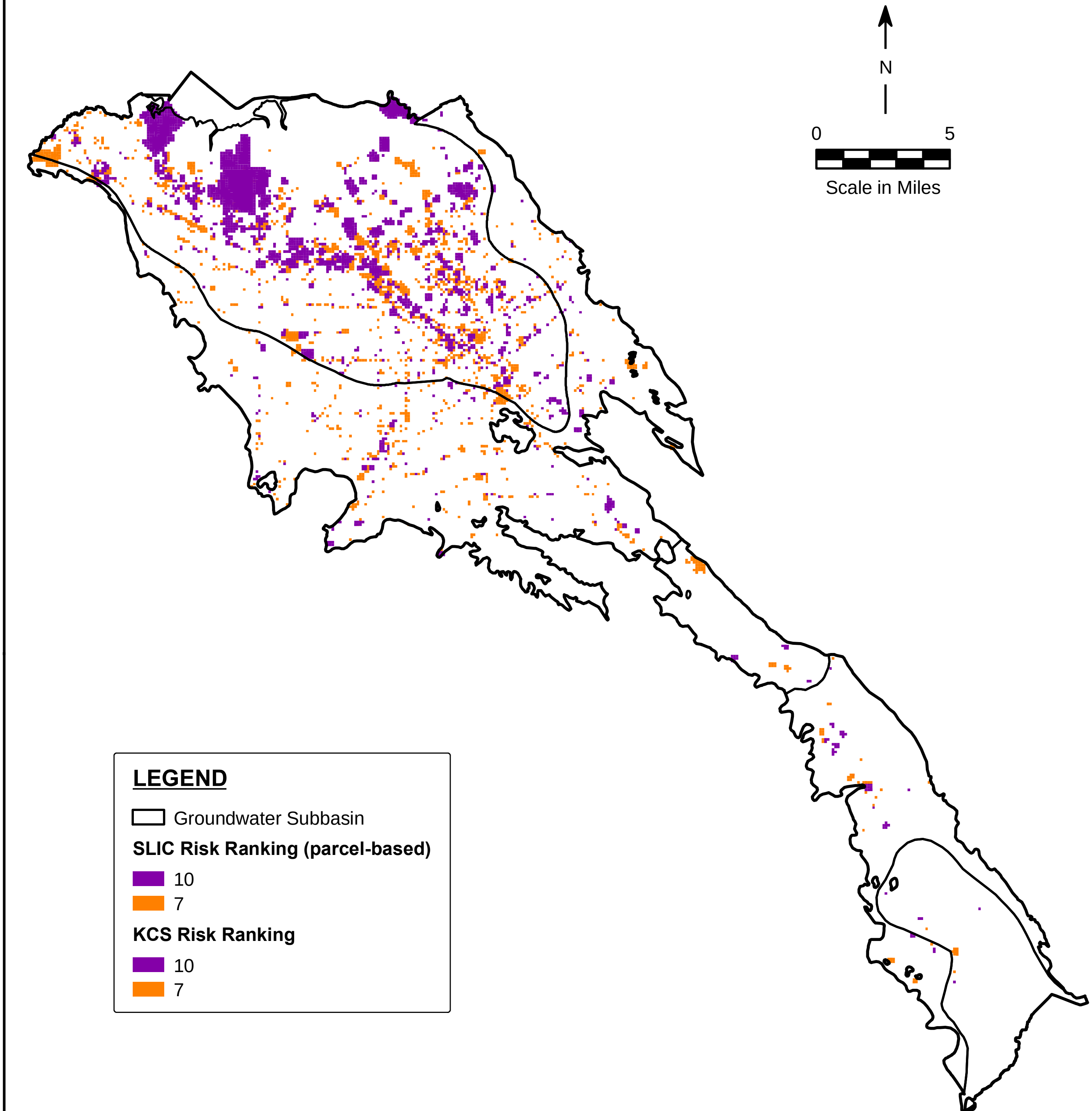
July 2010

TODD ENGINEERS
and
KENNEDY/JENKS CONSULTANTS

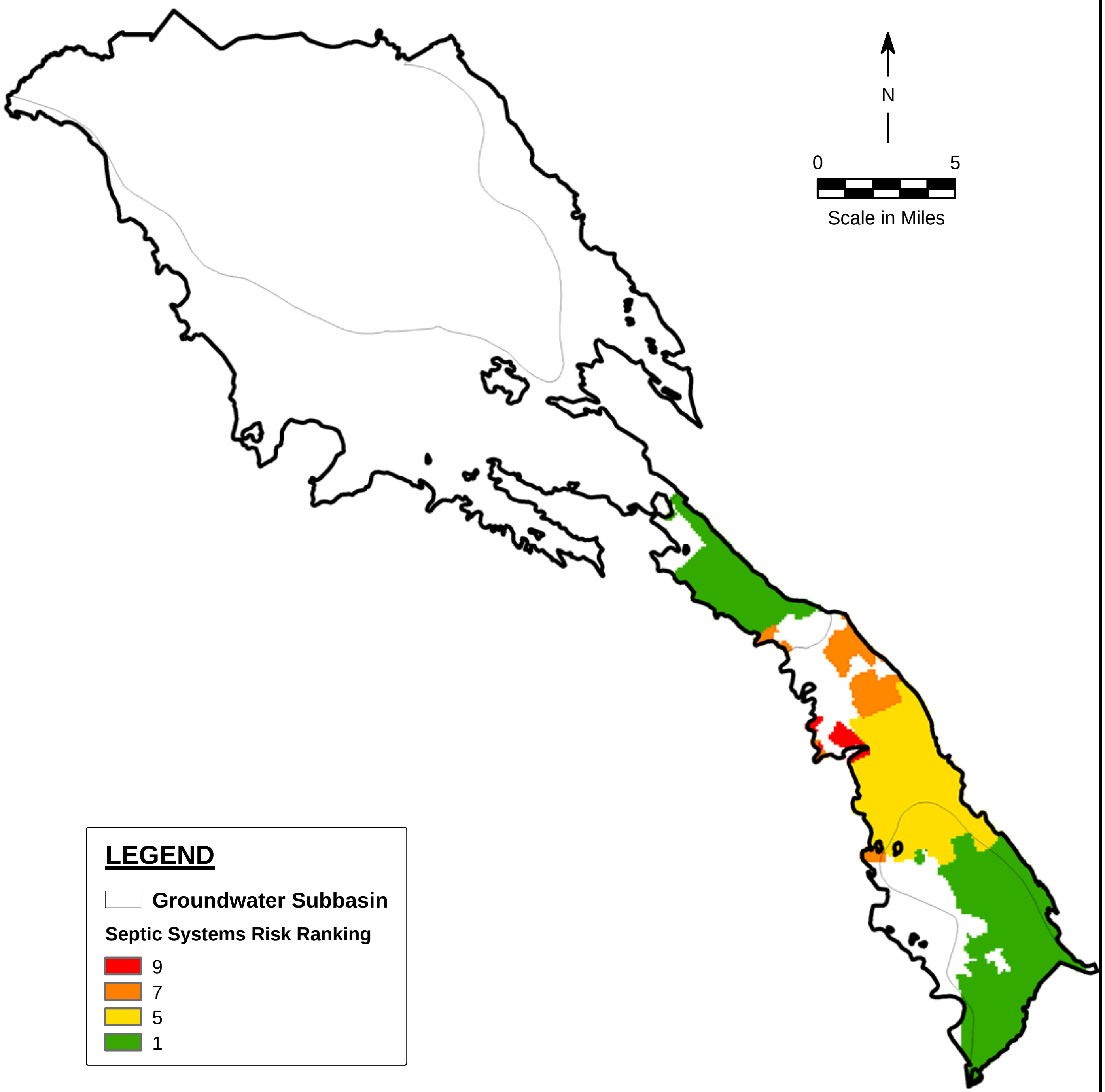
Figure 6-2
General Plan
Land Use Risk



July 2010	Figure 6-3 PCBA Risk
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



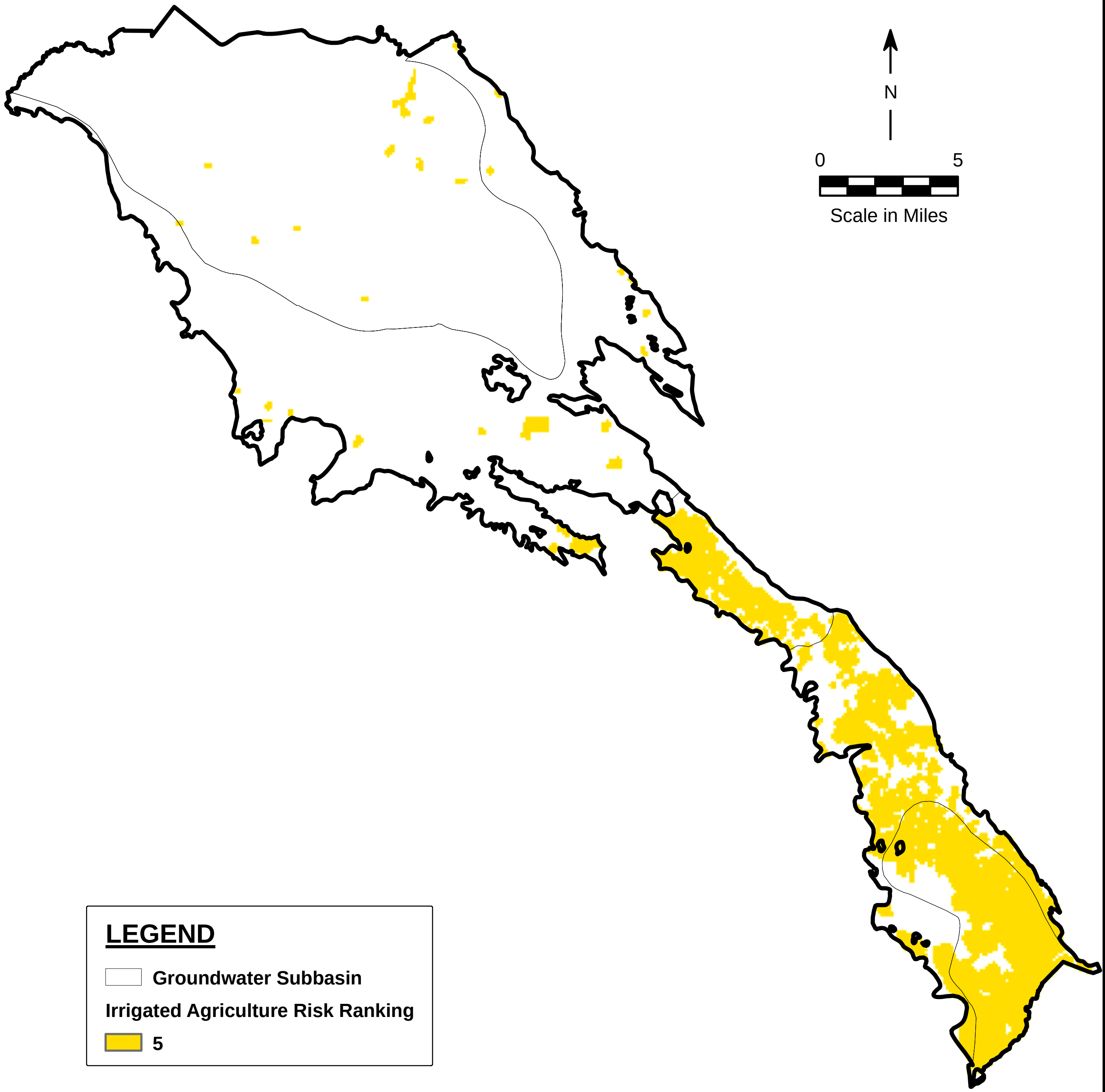
July 2010	Figure 6-4 KCS Risk
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



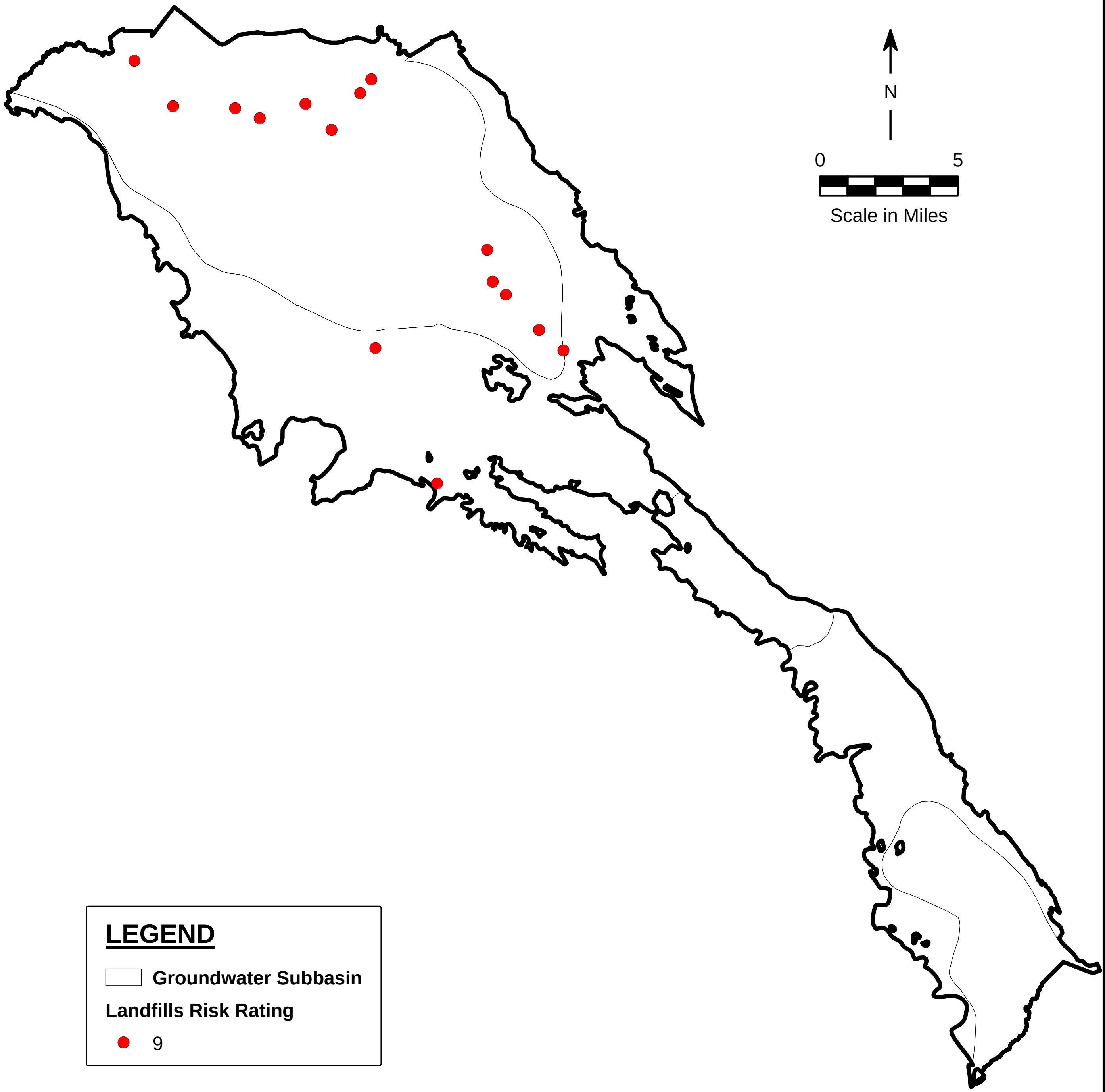
July 2010

TODD ENGINEERS
and
KENNEDY/JENKS CONSULTANTS

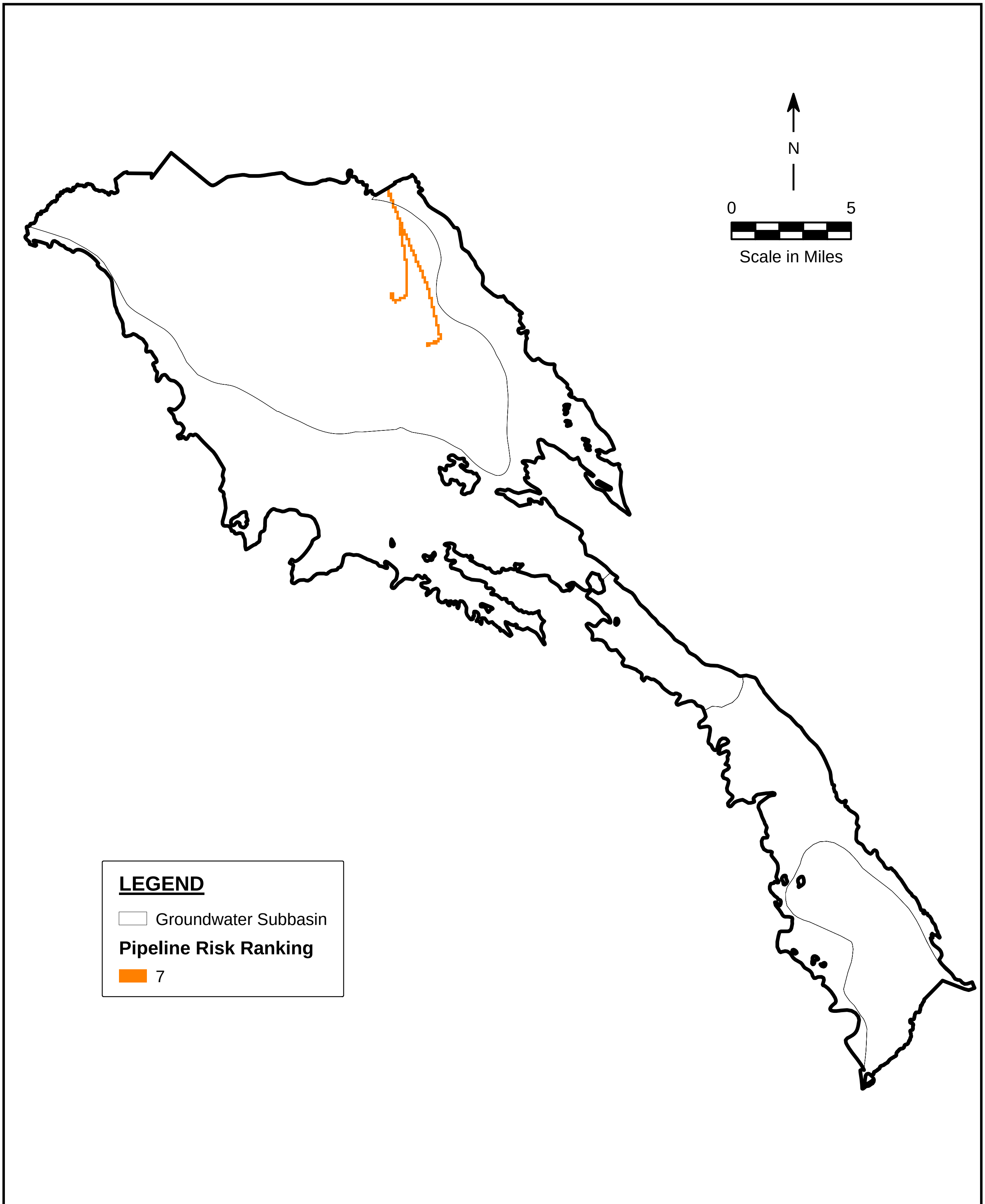
Figure 6-5
Septic System Risk



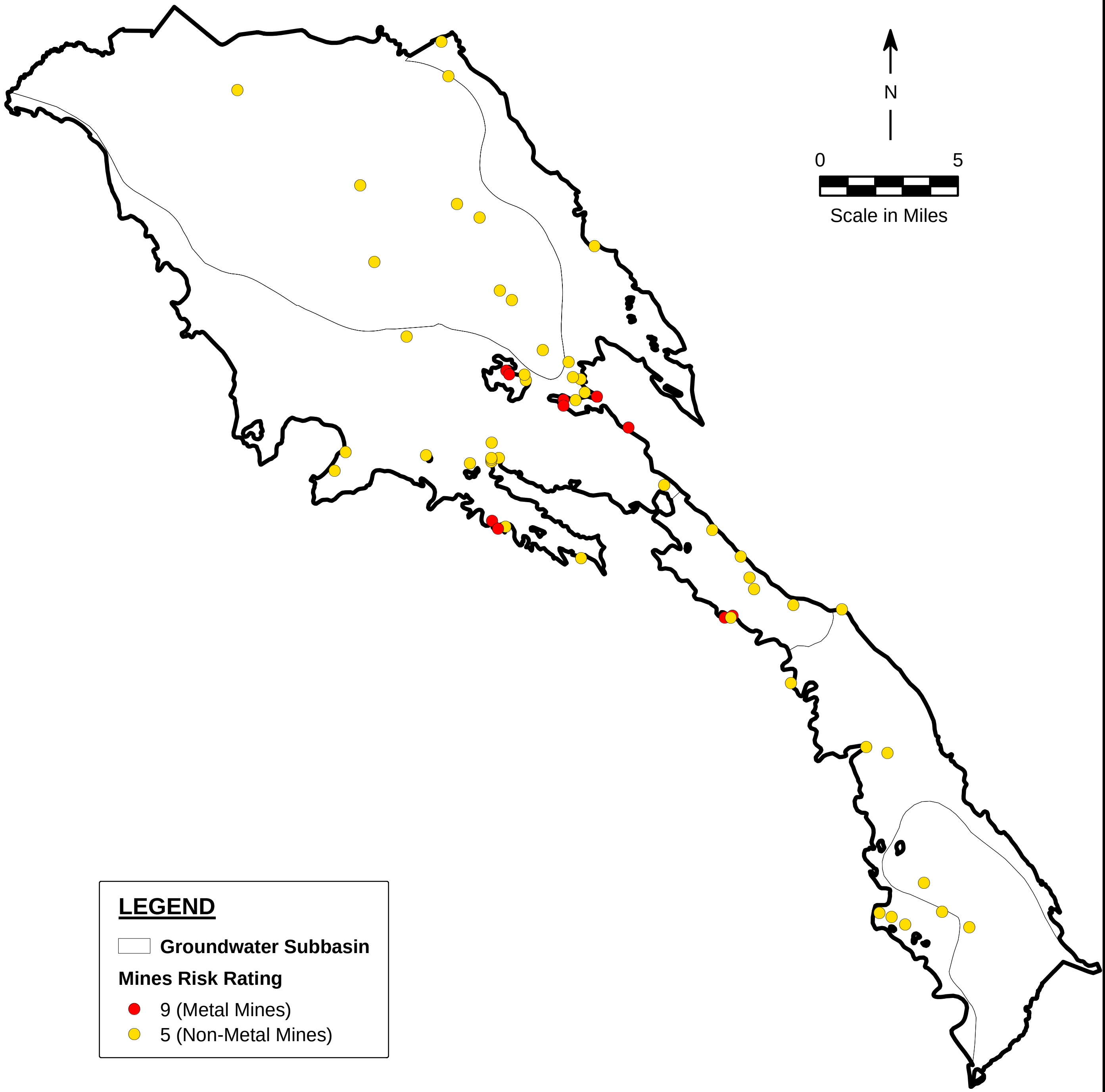
July 2010	**Figure 6-6 Irrigated Agriculture Risk**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



July 2010	Figure 6-7 Landfills Risk
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



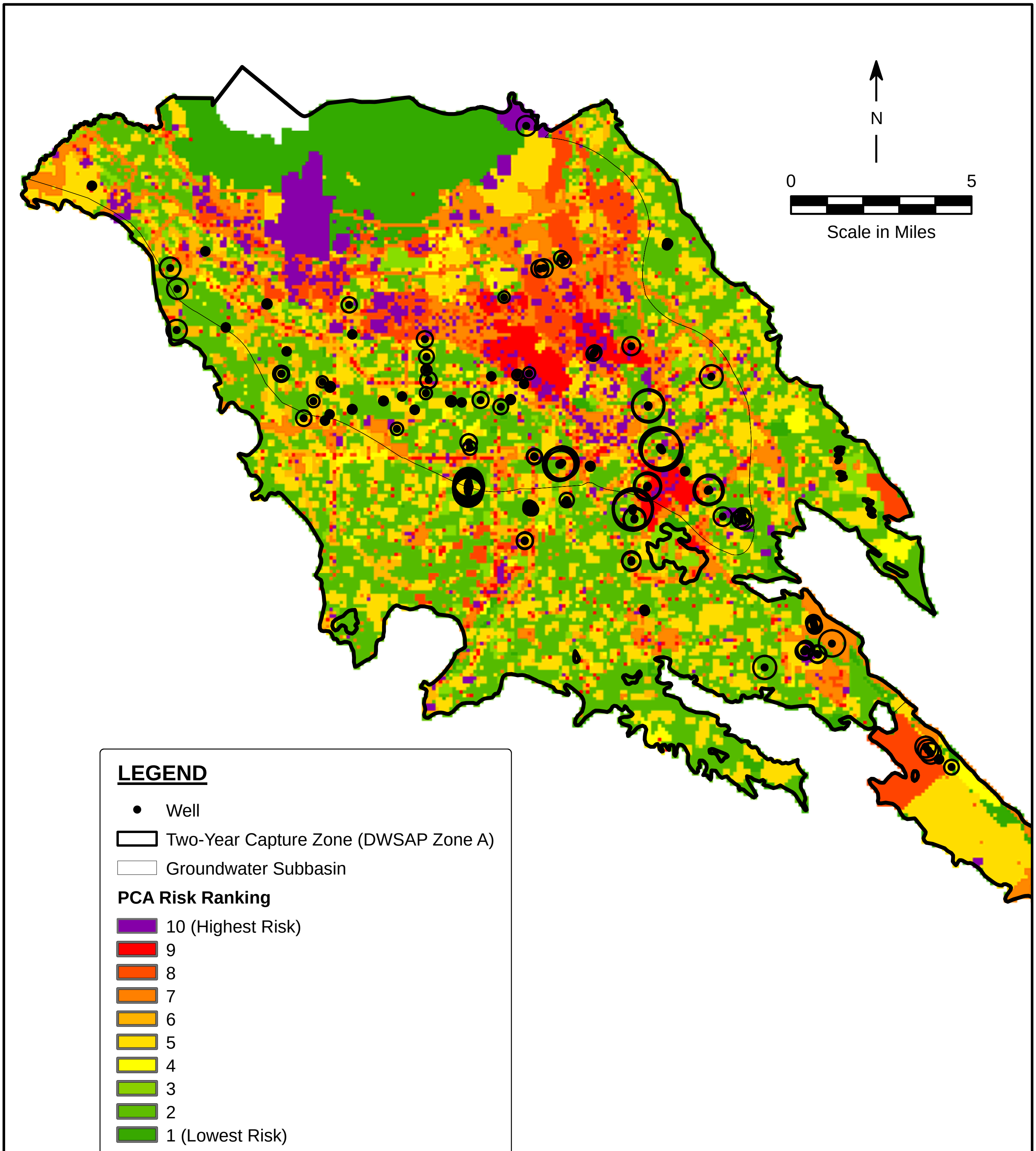
July 2010	**Figure 6-8**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	**Pipelines Risk**



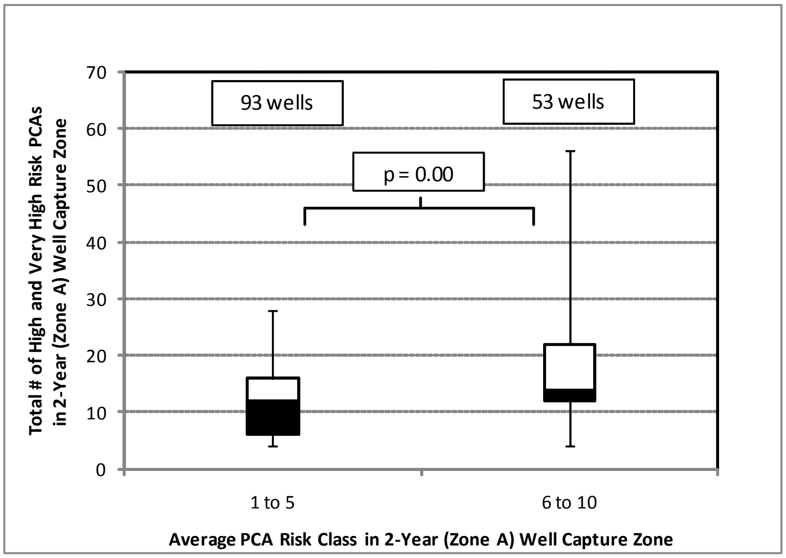
July 2010

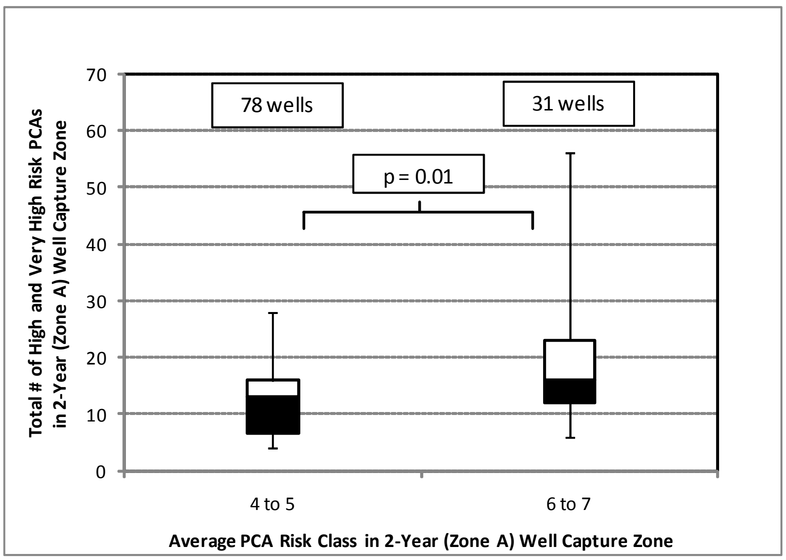
TODD ENGINEERS
and
KENNEDY/JENKS CONSULTANTS

Figure 6-9
Mines Risk



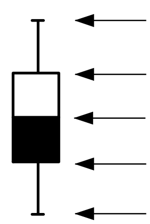
July 2010	**Figure 6-10 Two-Year Capture Zone (DWSAP Zone A) and PCA Risk**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	





LEGEND

p = 0.01 two sided p value of Wilcoxan Rank Sum test (e.g., 0.01 = 99% confidence neighboring samples are from two separate distributions)



Maximum

75th Percentile

Median

25th Percentile

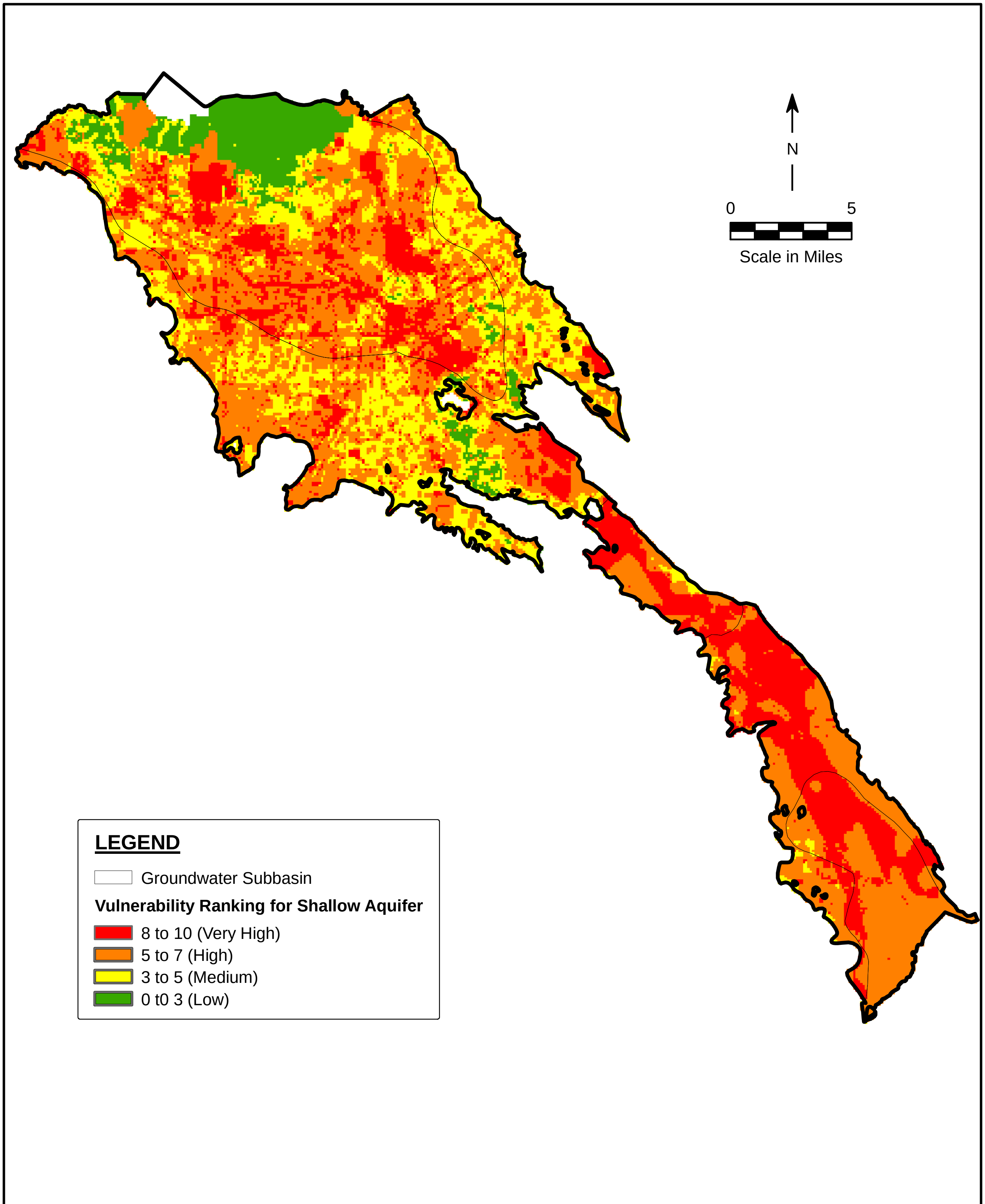
Minimum

July 2010	**Figure 6-11 Comparison of DWSAP and PCA Analysis Methods**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	

PCA Risk Ranking	1	2	3	4	5	6	7	8	9	10
10	6	6	7	7	8	8	9	9	10	10
9	5	6	6	7	7	8	8	9	9	10
8	5	5	6	6	7	7	8	8	9	9
7	4	5	5	6	6	7	7	8	8	9
6	4	4	5	5	6	6	7	7	8	8
5	3	4	4	5	5	6	6	7	7	8
4	3	3	4	4	5	5	6	6	7	7
3	2	3	3	4	4	5	5	6	6	7
2	2	2	3	3	4	4	5	5	6	6
1	1	2	2	3	3	4	4	5	5	6

Sensitivity Ranking

July 2010	**Figure 7.1 Groundwater Vulnerability Matrix**
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	



July 2010

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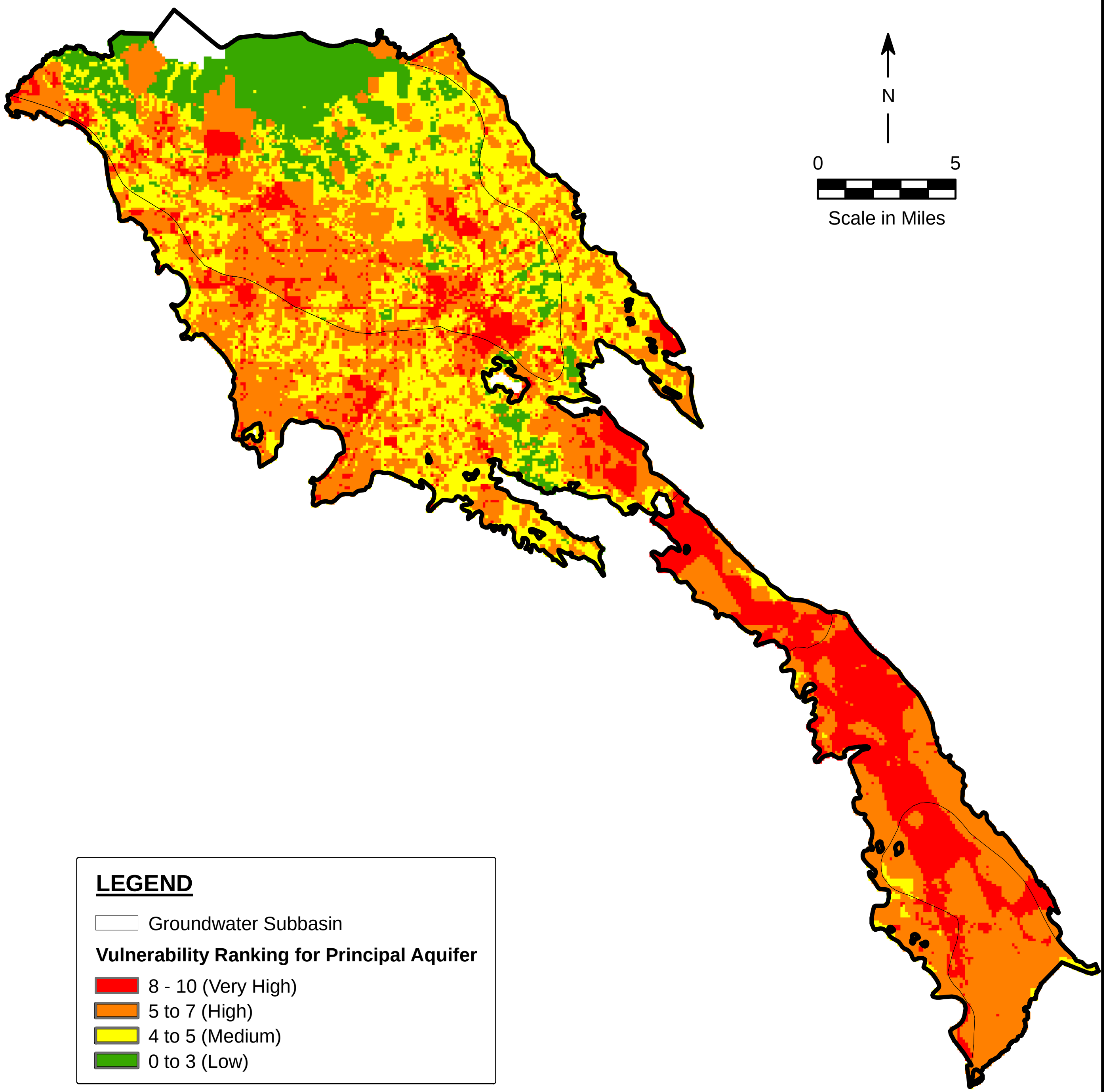
and
KENNEDY/JENKS CONSULTANTS

Figure 7-2
Groundwater Vulnerability Shallow Aquifer



July 2010	Figure 7-3 Groundwater Vulnerability Principal Aquifer
TODD ENGINEERS and KENNEDY/JENKS CONSULTANTS	

Appendix A
Evaluation of Assessment Methodologies

Santa Clara Valley Water District
San Jose, California

Revised Final

Evaluation of Assessment Methodologies for Groundwater Vulnerability Study

Santa Clara County, California

August 2010

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1 Introduction

1.1 Santa Clara Valley Water District

The Santa Clara Valley Water District (District) is the primary water resources agency in Santa Clara County. Since 1929, the District has been responsible for water supply, flood protection, and watershed management across the County's 1,300 square miles. The District's groundwater management objectives are to recharge the groundwater basin, conserve water, increase water supply, and prevent waste and diminution of the District's water supply with the end goal of ensuring that groundwater resources are sustained and protected.

The District manages three groundwater subbasins – the Santa Clara, Coyote, and Llagas – and provides wholesale water to the County's 15 cities (via 13 private and public water retailers) and more than 1.7 million residents. The District operates and maintains a County-wide conservation and distribution system to convey raw water for groundwater recharge and treated water for wholesale to private and public retailers. While nearly half of the District's water supply comes from local sources, such as groundwater, the remaining portion is imported. The District has contracts with the California Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) to receive, treat, and distribute surface water in the Santa Clara Valley. The District also operates ten local reservoirs to store water for treatment at one of its three treatment facilities or to recharge the groundwater in one or more of its eighteen in-stream and off-stream recharge facilities. The District has been a leader in conjunctive use and uses imported water to supplement groundwater and maintain reliability (Reymers and Hemmeter, 2001).

1.2 Study Purpose and Objectives

Protection of the Santa Clara, Coyote, and Llagas subbasins from contamination is an important component of ensuring a reliable water supply for Santa Clara County. The District, in cooperation with other research and governmental agencies, has historically managed numerous investigations and developed comprehensive groundwater monitoring programs. Background studies conducted to develop groundwater flow and solute transport models, combined with focused investigations characterizing the sources and distribution of key contaminants, including petroleum hydrocarbons (LFR, 1999; SCVWD, 1985; Tulloch, 2000), nitrate and pesticides (Carle et al., 2004; Moran et al., 2004; LLNL, 2005), perchlorate (Fostersmith et al., 2005), and perchloroethylene (PCE) (Mohr et al., 2007), have provided the District with a thorough understanding of groundwater flow and contaminant distribution.

The purpose of this Vulnerability Study (Study) is to quantify and produce scientifically-defensible, high-resolution maps depicting the intrinsic sensitivity and vulnerability of groundwater to contaminating land use conditions and practices using existing groundwater quality, hydrogeologic, and land use data. Before further describing the objectives of the Study, it is important to differentiate between the terms *groundwater sensitivity* and *groundwater vulnerability*. For this Study, *groundwater sensitivity* is defined as the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest. Aquifer sensitivity has traditionally been characterized as a function of the intrinsic characteristics of the geologic materials in question and the overlying saturated and unsaturated materials. A more recent definition of sensitivity also acknowledges the influence of associated sources of water as well as key stresses to the aquifer system (Focazio et al., 2002). Groundwater sensitivity considers only the physical factors affecting the flow of water to and through the aquifer system and is not dependent on land use and contaminant characteristics. One the other hand, *groundwater vulnerability* is defined as the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest under a given set of land use management practices, contaminant characteristics, and groundwater sensitivity conditions (USEPA, 1993). Groundwater may be highly sensitive to contamination, but the characterization of contaminant sources (i.e., potentially contaminating activities risk) is needed to determine its vulnerability to contamination.

For this Study, groundwater sensitivity, potentially contaminating activities (PCA) risk, and vulnerability maps and supporting databases are presented in a web-based Geographic Information System (GIS) tool. The GIS tool is designed to assist the District in understanding the potential impacts to groundwater from future proposed land use changes, and prioritizing groundwater management and protection efforts, including monitoring and investigation, in areas where groundwater is considered highly vulnerable to contaminating land use conditions and practices and/or where knowledge gaps exist. The GIS tool is designed to allow the District to update relevant hydrogeologic and land use information as it becomes available in the future. Results of the Study are intended to aid the District in examining alternative ways to mitigate and control the threat of contamination from PCAs, informing land use decisions (including zoning and site screening), and encouraging voluntary changes in behavior as the public is made more aware of the groundwater impacts related to land-based activities.

The Study objectives were completed through a comprehensive literature review, data collection, database and GIS development, spatial analysis, and selection and application of an appropriate groundwater sensitivity, PCA risk, and vulnerability assessment methods that satisfy the Study's primary objectives. The assessment methodologies identify the factors that influence groundwater sensitivity and vulnerability. An additional Study objective was to gain a more thorough understanding of the distribution of and relationship between land use, PCAs, and groundwater contamination. Groundwater sensitivity and vulnerability maps were generated for both the Shallow and Principal aquifers in the Study Area.

1.3 Santa Clara County Groundwater Subbasins

The Santa Clara, Coyote, and Llagas subbasins are located in a northwest-trending structural depression bounded by the Diablo Range to the east and the Santa Cruz Mountains to the west. Principal water bearing formations include young, Pleistocene-Holocene alluvium underlain by older, Plio-Pleistocene Santa Clara Formation. Both units consist of inter-bedded unconsolidated to semi-consolidated deposits of gravel, sand, silt, and clay. Each subbasin has unique hydrogeology, land use, and water quality characteristics, which are described in more detail below.

1.3.1 Santa Clara Subbasin

Hydrogeology

The South Bay Area of Santa Clara Valley Groundwater Basin is identified as Basin No. 2-9.02 by DWR (2004) and includes both the Santa Clara and Coyote subbasins. Located in the northern portion of Santa Clara County, the Santa Clara Subbasin covers 225 square miles and extends from the County's northern boundary to the Coyote Narrows at Metcalf Road to the south. The subbasin is approximately 22 miles long and ranges from about 15 miles in width in the north to about one-half mile at the Coyote Narrows, where the two mountain ranges nearly converge (Fostersmith et al., 2005). In general, coarser-grained sediments occur in the upper alluvial fan areas along the lateral edges of the subbasin, while thick silt/clay units inter-bedded with thin sand/gravel units are found towards the interior of the subbasin. Basin fill deposits range in thickness from about 150 feet near the Coyote Narrows to greater than 1,500 feet in the interior of the subbasin (Iwamura, 1995). The valley is drained to the north by tributaries to San Francisco Bay, including Coyote Creek, the Guadalupe River, and Los Gatos Creek.

The southern area and lateral margins of the Santa Clara Subbasin are unconfined or recharge areas. An extensive regional aquitard occurs within the northern areas of the subbasin with depths to the top of the unit ranging from 75 feet near the recharge areas to 160 feet in the northern interior portion of the subbasin (CH2M Hill, July 1992). The principal water supply aquifers (Principal Aquifer) are mainly located under confining layers. Sources of recharge include deep percolation of precipitation, leakage from uncontrolled streams, subsurface inflow from surrounding hills and the Coyote Subbasin, and recharge operations managed by the District in specific areas that are hydraulically connected to the Principal Aquifer. Shallow groundwater occurs above confining layers in some areas, and the District is currently evaluating potential beneficial uses for this historically under-used resource. Groundwater levels in the shallow, unconfined aquifer (Shallow Aquifer) range from less than 10 feet in the central and southern portions of the subbasin to greater than 100 feet along the lateral edges of the subbasin (Pierno, 1999). Although evidence suggests that an upward vertical gradient currently exists between the confined aquifer and the overlying unconfined aquifer in the northern portion of the subbasin (Moran et al., 2004), groundwater levels in the shallow, unconfined aquifer are dependent upon rainfall and not the pressure from groundwater located at depth (Fostersmith et al., 2005). Groundwater in the Santa Clara Subbasin flows in the general direction of ground surface topography, towards the interior of the subbasin and northerly towards San Francisco Bay.

Land Use and Water Quality

With the high density of urban land uses in the Santa Clara Subbasin (including major industrial manufacturing and processing facilities), point-source contamination is prevalent but generally contained in the shallow unconfined aquifers (Judd, 2001; SCVWD, December 2005). There are currently over 2,000 environmental sites located within the Santa Clara Subbasin regulated by the San Francisco Bay and Central Coast Regional Water Quality Control Board (SWRCB, 2008). Sites represent historic or existing sources of contamination to soil or soil and groundwater undergoing active investigation, monitoring, and/or soil and groundwater remediation. Active sites include leaking underground storage tank (LUST) and Spills, Leaks, Investigations, and Cleanup (SLIC) sites. In addition, there are several existing federal Superfund sites in the Santa Clara Subbasin (DTSC, 2008).

The Principal Aquifer in the Santa Clara Subbasin yields good to excellent quality water. Public water supply wells generally meet drinking water standards without water treatment (Fostersmith et al., 2005). Table A-1 summarizes the water quality data collected from 396 wells in 2002 and 473 wells in 2003 by the District and local water suppliers. The table shows the number of occurrences when water quality standards were exceeded for key inorganic constituents and when concentrations were above detection levels for key organic contaminants. As shown in the table, primary maximum contaminant levels (MCLs) for key inorganic constituents were not exceeded in the Santa Clara Subbasin. Secondary MCLs were exceeded more than 10 times for manganese, iron, and boron. VOC concentrations were detected 35 times in the Principal Aquifer and once in the Shallow Aquifer. All VOC concentrations were below primary MCLs. Water quality samples from 70 wells in 2002 and 65 wells in 2003 were also analyzed for synthetic organic carbon compounds (SOCs). Only one well in the Principal Aquifer of the Santa Clara Subbasin had detectable SOC concentrations in 2002. SOCs were not detected in any wells in 2003. It is noted that the wells monitored are primarily water supply wells and the water quality summarized in Table A-1 does not reflect the large number of shallow environmental site wells with contaminant detections.

1.3.2 Coyote Subbasin

Hydrogeology

The Coyote Subbasin is identified by DWR (2004) as part of the South Bay Area (Basin No. 2-9.02) of the Santa Clara Valley Groundwater Basin. The Coyote Subbasin extends from the Coyote Narrows in the north, where it borders by the Santa Clara Subbasin, to about Cochrane Road in the south where it borders the Llagas Subbasin. The surface area of Coyote Subbasin is approximately 15 square miles, or about 10,000 acres. Coyote Valley is drained to the north by two tributaries to San Francisco Bay – Coyote Creek and Fisher Creek. Coyote Creek flows most of the length of the Coyote Subbasin along its eastern side. Coyote Creek is downstream of and benefits from controlled releases from the Anderson and Coyote reservoirs, which are situated east of the subbasin in the Diablo Range. Coyote Creek is a losing stream throughout the year, whereby surface water percolates through the stream bed and recharges local groundwater. Fisher Creek flows north along the western portion of the Coyote Subbasin. Fisher Creek is a variably gaining and losing stream. During conditions of high groundwater, Fisher Creek receives groundwater discharge from much of the Coyote Valley floor. Fisher Creek joins Coyote Creek near Coyote Narrows, where it exits the Coyote Subbasin (Fostersmith et al., 2005).

Table A-1: 2002 and 2003 Water Quality Monitoring Results for Santa Clara Valley, Coyote, and Llagas Subbasins

Groundwater Subbasin	Constituent mg/L	Sample Occurrences above MCL or Detection Limit								
		TDS 500[d]	Mn 0.05[b]	Fe 0.3[b]	Cl 600[e]	B 0.2[c]	Al 1[a]	NO_3 45[a]	VOCs > Detect	ClO_4- > Detect
Santa Clara Valley	Shallow Aquifer	4	6	1		15			1	
	Principal Aquifer	2	19	11	5	20			35	
Coyote		0						9		
Llagas	Shallow Aquifer	1	1			2		14	2	
	Principal Aquifer		3	5		4	1	35	4	~800

Source: Santa Clara Valley Groundwater Conditions Report 2002/2003, SCVWD, January 2005.
Note: The majority of wells in the District monitoring program are screened in the Principal Aquifer

TDS = Total Dissolved Solids
Mn = Manganese
Fe = Iron
Cl = Chloride
B = Boron
Al = Aluminum
NO_3 = Nitrate
VOCs = Volatile Organic Carbons
ClO_4 = Perchlorate
[a] primary maximum contaminant level (MCL)
[b] secondary MCL
[c] secondary MCL, recommended
[d] secondary MCL, short-term
[e] agriculture MCL
>detect = above detection limit but below primary MCL

The Principal Aquifer in the Coyote Subbasin is comprised of alluvial deposits of unconsolidated and semi-consolidated sediments. Unlike portions of the Santa Clara and Llagas subbasins, no significant laterally extensive clay layers exist in the Coyote Subbasin, and groundwater occurs under unconfined conditions throughout the subbasin. The alluvial deposits in the Coyote Subbasin range in thickness from about 500 feet in the south to 150 feet in the north near the Coyote Narrows (Iwamura, 1995). The direction of groundwater flow through Coyote Subbasin is north to northwest towards the Coyote Narrows, where groundwater exits the basin and enters the Santa Clara Subbasin (Fostersmith et al., 2005). To the south, the Coyote Subbasin extends to about Cochrane Road, where it meets the Llagas Subbasin at a boundary defined by a groundwater divide. Depth to groundwater ranges from about 75 feet in the south to less than 5 feet in the north near the Coyote Narrows and is commonly less than 20 feet throughout the subbasin (Pierno, 1999).

Land Use and Water Quality

Currently, the Coyote Subbasin is predominantly rural and is thus generally not impacted by most commercial and industrial sources of pollution. Of the historical regulated environmental sites in the subbasin, none are currently active. However, there are ongoing investigations and remediation at a closed rocket manufacturing plant located in the hills immediately north of Anderson Reservoir. Groundwater quality in the Coyote Subbasin is good and is in compliance with primary drinking water standards with the exception of nitrate (see Table A-1). With no significant separation between the land surface and groundwater, aquifers in the Coyote Subbasin are considered vulnerable to point and non-point source contamination, including agricultural drainage and sewer collection systems (i.e., septic tanks). Elevated nitrate levels occur in the southern half of the Coyote Subbasin, where nitrate sources associated with agriculture and septic systems are concentrated.

As the Coyote Subbasin becomes more urbanized in the future, new potential contamination sources (e.g., urban runoff, gas stations, dry cleaners, leaking sewer lines, etc.) are expected to pose a threat to groundwater quality. To address these concerns, the District has recommended steps above and beyond those required by state and federal law including the following: 1) avoiding high-risk land uses such as underground chemical storage; 2) establishing wellhead protection zones and locating the most hazardous PCAs far away from and downgradient of drinking water supply wells; 3) implementing best management practices with respect to collection, conveyance, and treatment of urban storm water runoff; 4) enforcing rigorous commercial and industrial pre-treatment programs to minimize discharges to the sanitary sewer system; and 5) constructing deep excavations and facilities to standards that prevent hydraulic connection between surface water and groundwater (SCVWD, April 2005). The District also requires advance treatment of any recycled water used for irrigation in Coyote Valley.

1.3.3 Llagas Subbasin

Hydrogeology

The Llagas Subbasin is an inland valley that is drained to the south by tributaries of the Pajaro River, including the Uvas and Llagas creeks. The Llagas Subbasin extends from the groundwater divide at about Cochrane Road, near Morgan Hill, in the north to the Pajaro River (the Santa Clara-San Benito County line) in the south. The Llagas Subbasin is approximately 15 miles long, three miles wide along its northern boundary, and six miles wide along the Pajaro River. DWR (2004) identifies the Llagas Subbasin as part of the Gilroy-Hollister Groundwater Basin (Basin 3-3).

The thickness of alluvial fill and the underlying Santa Clara Formation varies from about 500 feet at the northern groundwater divide to about 1,800 feet at its south end. Principal sources of recharge to the Llagas Subbasin include deep infiltrating precipitation, natural and artificial recharge through Uvas and Llagas creeks, recharge ponds, and irrigation return flows. The northern and central part of the subbasin is unconfined to semi-confined. Confining layers become more frequent and laterally extensive in the southern portion of the subbasin, where confined conditions exist. Groundwater flows generally from north to south in the Llagas Subbasin. The vertical groundwater gradient is currently downward in the subbasin (SCVWD, December 2005).

Land Use and Water Quality

Residential and commercial development in the subbasin is focused in the City of Morgan Hill in the north and the City of Gilroy in the south. The central portion of the subbasin is comprised predominantly of agricultural development and large (greater than 10 acre) residential parcels, which rely on private wells for water supply and onsite septic systems. Groundwater in the Llagas Subbasin has been impacted by elevated nitrate concentrations related to fertilizer use and septic tank discharges. More than half of the private domestic wells in the Llagas Subbasin exceed the primary MCL of 45 milligrams per liter (mg/L) for nitrate, although public water supply wells, drawing from deeper aquifer units, have generally not been impacted by nitrate contamination. Table A-1 shows that the primary MCL for nitrate was exceeded a total of 35 times in wells monitored by the District in 2002 and 2003.

The largest SLIC case in the Llagas Subbasin is the Olin/Standard Fusee site, a former safety flare manufacturer located in Morgan Hill that has been linked to a perchlorate plume that extends across much of the Llagas Subbasin. As shown in Table A-1, of the 1,300 water supply wells in the Llagas Subbasin sampled in 2003, perchlorate (ClO_4-) was detected in nearly 800 wells, with all but 10 of the wells having perchlorate below 10 micrograms per liter (μg/L). Perchlorate has also been detected in five public water supply wells at concentrations between 4 and 8 μg/L (Fostersmith et al., 2005). The MCL for perchlorate is 6 μg/L.

2 Groundwater Vulnerability Assessment Methods

Numerous tools have been developed to assist governmental, academic, and private organizations in assessing the sensitivity and vulnerability of groundwater to contamination. The United States Environmental Protection Agency (USEPA) (1993), National Research Council (NRC) (1993), and United States Geological Survey (USGS) (Focazio et al., 2002) have each published documents that provide an overview of the types of assessment methods available and include useful information on their potential uses, data requirements, computational procedures, and levels of uncertainty. Based on specific objectives and available resources, assessment approaches may concentrate on individual wells (e.g., source water assessments for wellhead protection) or entire aquifer systems and may target the sensitivity of groundwater to contamination in general or to a specific contaminant. An example of an assessment approach concentrating on individual wellhead protection is the method developed by DPH (1999) for the Drinking Water Source Assessment and Protection (DWSAP) Program. Although components of the DWSAP methodology were used in this Study, the regional scope and groundwater management objectives of this Study warranted a scientifically-defensible assessment that characterized the sensitivity and vulnerability of the groundwater system as a whole in Santa Clara County. Review of available references and case studies reveals that groundwater assessment methods can be grouped into the following three categories:

- Subjective Rating Methods
- Statistical Methods
- Process-Based Methods

Selecting an appropriate assessment method for a given Study may depend on several key factors, including any of the following:

- Size and characteristics of the assessment area
- Availability and accuracy of water quality data and information associated with potential explanatory variables
- Physical properties of the targeted contaminant(s) of concern
- Objectives of the Study findings (e.g., policy/management decisions or scientific/academic objectives)
- Impact of uncertainty on use of assessment results

2.1 Subjective Rating Methods

Subjective rating methods focus on policy/management end-uses and produce maps generally delineating between two and five degrees of relative groundwater vulnerability (e.g., low, medium, and high). Subjective rating methods include simplified index methods that rely on a pre-defined list of hydrogeologic parameters and PCAs suspected to be indicators of groundwater vulnerability and assigned ranking systems to calculate the vulnerability of groundwater to contamination in general. More complex hybrid methods are also included in subjective rating methods. Hybrid methods are based on a user-defined list of factors believed to influence groundwater vulnerability. Unlike the index methods, weighting systems used in hybrid methods are usually selected based on project-specific categorizations that may be subjective (subjective hybrid methods) or based on correlations with actual water quality (objective hybrid methods). For this report, any hybrid method used to conduct more reliable groundwater sensitivity and vulnerability assessments than traditional index methods are grouped and discussed together.

2.1.1 Index Methods

Index methods assign numerical ratings or scores directly to physical hydrogeologic attributes and PCAs to generate a range of subjective rankings of groundwater sensitivity and vulnerability. Theoretically, areas with higher scores should have more frequent occurrences of contamination events. Hydrogeologic setting classification methods (or overlay methods) (USEPA, 1993) are not distinguished from index methods in this report, because they both produce maps of subjective ratings. Groundwater vulnerability maps generated from index methods are generated by overlaying and summing the ratings for each physical hydrogeologic attribute and PCA across the study area. In some instances, the ratings are multiplied by a factor accounting for the relative significance of each attribute. Groundwater sensitivity maps generated from index methods are intended to be used as screening tool for water managers and land use planners providing a basis to compare areas with respect to groundwater sensitivity. Index methods rely on data that are commonly available or estimated, and produce maps that are easily interpreted and incorporated into the decision-making process. The numerical ratings or scores used in index methods are neither based on nor calibrated to actual water quality data. In some cases, index method-based maps are compared qualitatively (e.g., in areas where groundwater contamination has occurred).

Several index methods have been developed to assess the sensitivity of groundwater to contamination. The most commonly used index method is the DRASTIC method, which was developed by the USEPA (Aller et al., 1987). DRASTIC is an acronym standing for the seven hydrogeologic variables considered in the method: **D**epth to Water, Net **R**echarge, **A**quifer Media, **S**oil Media, **T**opography, **I**mpact of Vadose Zone, and Aquifer Hydraulic **C**onductivity. The DRASTIC system has been used to produce groundwater sensitivity maps in many parts of the United States (Hearne et al., 1992; Kalinski et al., 1993; Pierno, 1999) and throughout the world (Johansson et al., 1999; Lobo-Ferreira et al., 1997). To calculate a DRASTIC score, each of the seven variables is divided into a numerical range (see Table A-2) to allow for relative comparisons.

The relative significance of each of the seven hydrogeologic variables in DRASTIC is then multiplied by a weighting factor (Table A-3). As shown in Table A-3, the most significant variables – Depth to Water and Impact of Vadose Zone – are assigned weighting factors of 5, and the least significant weighting factor (Topography) is assigned a weighting factor of 1. The weighting factors are constant and may not be changed in the traditional DRASTIC approach. To calculate a final DRASTIC index score, the weighted values for each variable are added according to the equation below:

$$\textit{DRASTIC Index score} = aD + bR + cA + dS + eT + fI + gC$$

where, upper-cased letters = rating assigned to the respective variable
lower-cased letters = weighting factor assigned to variable

Table A-2: DRASTIC Variable Rating System

Depth to Water	
Feet bgs	**Rating**
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
100+	1

Aquifer Media	
Type	**Rating**
Massive Shale	1-3 (2)
Metamorphic/Igneous	2-5 (3)
Weathered Metamorphic/Igneous	3-5 (4)
Glacial Till	4-6 (5)
Bedded Sandstone, Limestone and Shale Sequences	5-9 (6)
Massive Sandstone or Limestone	4-9 (6)
Sand and Gravel	4-9 (8)
Basalt	2-10 (9)
Karst Limestone	9-10 (10)

Topography	
Percent slope	**Rating**
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Hydraulic Conductivity	
gpd/ft	**Rating**
1-100	1
100-300	2
300-700	4
700-1,000	6
1,000-2,000	8
2,000+	10

Net Recharge	
in/yr	**Rating**
0-2	1
2-4	3
4-7	6
7-10	8
10+	9

Soil Media	
Type	**Rating**
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or Aggregated Clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Non-shrinking / Non-aggregated Clay	1

Impact of Vadose Zone	
Type	**Rating**
Confining Layer	1 (1)
Silt/Clay	2-6 (3)
Shale	2-5 (3)
Limestone	2-7 (6)
Sandstone	4-8 (6)
Bedded Limestone, Sandstone, Shale	4-8 (6)
Sand and Gravel with Significant Clay	4-8 (6)
Metamorphic/Igneous	2-8 (4)
Sand and Gravel	6-9 (8)
Basalt	2-10 (9)
Karst Limestone	8-10 (10)

Source: USEPA, DRASTIC, May 1987.
Ratings for Aquifer Media and Impact of Vadose Zone are provided as a range; any value within the range can be used; values shown in parentheses are typical values.
bgs = below ground surface
gpd/ft = gallons per day per foot
in/yr = inches per year

Table A-3: DRASTIC Weighting Factor System

Hydrogeologic Variable	Weighting Factor
Depth to Water (D)	5 (a)
Net Recharge (R)	4 (b)
Aquifer Media (A)	3 (c)
Soil Media (S)	2 (d)
Topography (T)	1 (e)
Impact of Vadose Zone (I)	5 (f)
Aquifer Hydraulic Conductivity (C)	3 (g)

The DRASTIC system was developed as a relatively inexpensive, straight-forward tool for planners, managers, and administrators to evaluate the relative sensitivity of areas 100 acres or greater to groundwater contamination. The DRASTIC system assumes a pollutant that is introduced at the ground surface, is carried to groundwater by areal recharge from precipitation, and has a similar mobility to that of recharge water. No consideration is given to unique chemical and physical properties of a contaminant that may influence the fate and transport of the contaminant with respect to groundwater recharge. The only modification to the DRASTIC scoring system occurs when calculating a DRASTIC score for pesticides, for which modified weighting factors for Soil Media (5), Topography (3), Impact of Vadose Zone (4), and Aquifer Hydraulic Conductivity (2) are assigned. The DRASTIC system assumes that groundwater quality is influenced only by the seven hydrogeologic variables mentioned. The DRASTIC system is intended to provide a relative rather than absolute assessment of groundwater sensitivity to surface contamination (Aller et al., 1987).

When using the DRASTIC method for assessing the sensitivity of deeper, confined aquifers, the following must be considered when applying variable rating values:

- <u>Depth to Water</u>: When evaluating a confined aquifer, depth to water should be re-defined as the depth to the top of the aquifer. A semi-confined aquifer must be defined as either an unconfined or confined aquifer for purposes of rating depth to water. DRASTIC does not provide a way to assign depth to water to a semi-confined aquifer.
- <u>Net Recharge</u>. Calculation of net recharge to an unconfined aquifer is relatively straightforward in that it is typically calculated as a percentage of precipitation over the Study Area. Additional sources of recharge may include irrigation return flows and recharge from managed aquifer recharge projects. When evaluating a confined aquifer, consideration must be given to the location of the recharge zone (which may be many miles away) and the influence of the confining layer, vertical gradients, and groundwater pumping on the rate of recharge/leakage to the confined aquifer.

- Impact of Vadose Zone. When evaluating a confined aquifer, all of the sediments above the confined aquifer should be considered. In this case, the vadose zone is not a true vadose zone as it includes both unsaturated and saturated sediments. Typically, sediments comprising the confining layer are selected to evaluate the impact of the vadose zone on a confined aquifer, as the confining layer is most likely to impact significantly contamination potential of the confined aquifer.

The seven variables in the DRASTIC Index system were not selected based on rigorous quantitative analysis but rather a subjective understanding of the many processes governing contaminant fate and transport (USEPA, 1993). It is recognized that the hydrogeologic variables in the DRASTIC system are interacting and in some ways redundant. For example, the Soil Media type affects not only contaminant fate and transport (addressed in the Impact on Vadose Zone variable) but also groundwater recharge (addressed in the Net Recharge variable). Although not prescribed in the DRASTIC method, some studies have evaluated and in some cases attempted to verify factor values and weights to occurrences of groundwater contamination. Three example studies are provided below.

- Kalinski et al. (1994) studied the relationship between the frequency of community groundwater supply systems impacted by volatile organic compounds (VOCs) and DRASTIC scores in Nebraska. Overall, 681 water supply systems were partitioned into seven categories of relative groundwater sensitivity (Categories 1 to 7) based on a state-wide DRASTIC map. The frequency of community water supply contamination ranged from 12 percent for water supply systems assigned to DRASTIC Category 1 up to 33 percent for water supply systems assigned to DRASTIC Category 7. A linear regression analysis found a strong positive correlation ($r^2 = 0.93$[1]) between the frequency of VOC contamination for each group of water supply systems and the DRASTIC Category. Overall, the Study supports the use of the DRASTIC method or similar hydrogeologic sensitivity evaluation tool for land use planning and indicates that vadose zone time-of-travel is the likely link between DRASTIC scores and probability of VOC contamination. Although recognized as having a significant effect on contamination, land use and well construction practices that could result in VOC contamination were assumed to be similar from region to region in the study area. In addition, because well screen depths were not considered, production zones were assumed to be hydraulically connected to the surficial aquifer system.
- As part of their study, Richards et al. (1996) compared the relationship between county-wide DRASTIC scores and nitrate and two herbicide concentrations measured in 35,000 private rural wells in Indiana, Illinois, Kentucky, Ohio, and West Virginia. Regression relationships for each of the three constituents were calculated for five concentration measures (county-level mean, median, 75th percentile, 95th percentile, and percentage of wells above non-detect) and for each

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[1] r^2 = coefficient of determination used to quantify model goodness-of-fit. r^2 values range from 0 to 1, where a value of 1 represents a perfect correlation between actual and modeled data, and a value of 0 indicates no correlation between actual and model data.

state individually, and for all five states as a whole. Of the 90 total regression analyses performed for each individual state, in only seven instances did r^2 values exceed 20 percent (four of seven instances were based on seven or fewer data points). None of the regression relationship for the five-state area evaluated as a whole achieved an r^2 above 20 percent. Based on these results, the authors conclude that DRASTIC scores cannot be used to estimate either typical or extreme contaminant concentrations in well water at the county level, and the DRASTIC system should not be used to predict actual pollution in wells.

- Koterba et al. (1993) analyzed water quality results from 100 water supply wells in the Delmarva Peninsula of Delaware, Maryland, and Virginia and compared the frequency of detectable concentrations of 36 pesticides, four metabolites, and other constituents to final DRASTIC scores and the ratings of each of the seven variables that comprise the final DRASTIC score. The study found that most detections occurred in samples collected from wells screened shallower than 10 meters below the water table, consistent with the suspected history of pesticide use in the region. Using statistical (Mann Whitney) tests, the study found no significant differences in final DRASTIC scores for any of the seven variables that comprise the final DRASTIC scores between samples with and without detectable pesticide or nitrate concentrations in shallow groundwater. Thus, the authors conclude that the DRASTIC score cannot be used to differentiate between sites with and without agriculturally affected waters nor between sites with and without pesticide residues in shallow groundwater, and contaminant distribution is better characterized by land use (and associated pesticide use), soil groups, and the depth of the sample interval of the surficial aquifer. Although the study demonstrates that the DRASTIC method is not particularly useful when applied in the Delmarva Peninsula, the authors state that the DRASTIC method could be useful elsewhere.

The California Drinking Water Source Assessment and Protection (DWSAP) Program utilizes an index method that is intended to predicted groundwater vulnerability based on intrinsic hydrogeology parameters and PCAs for individual wells (DPH, January 1999). As such, the methodology also takes into account the characteristics of the well including well construction and capture zones over time, referred to as protection zones. The size of the protection zones vary based on aquifer parameters, pumping rate of the well, and method of analysis used to estimate the capture zones. The Physical Barrier Effectiveness (PBE) of each well is an estimate of the ability of the natural geologic materials, hydraulic conditions, and construction features of a well to limit the movement of contaminants to the well. A PCA inventory is conducted to allow assessment of spatial relationships between protection zones and PCAs. Hydrogeologic parameters, PCAs, and well construction factors are assigned numbers, which are combined to determine the overall vulnerability ranking. A vulnerability ranking is performed to determine which PCAs pose the greatest threat of contamination to the wells.

2.1.2 Hybrid Methods

Groundwater vulnerability assessment methods that combine statistical, process-based, and other objective components along with subjective categorization and indexing of vulnerability are categorized as *subjective hybrid methods* (Focazio et al., 2002). Subjective hybrid methods are suitable for groundwater assessment studies covering broad regional areas where error characteristics in water quality datasets compiled from diverse sources limit multivariate analysis but more reliable results than that provided by index methods are sought (Nolan et al., 1997). In many instances, hypothesis testing is used to select, eliminate, or calibrate ratings and weights for variables addressed in index methods to predict the probability of contamination. Such methods may be categorized as *objective hybrid methods*. Three example studies are summarized below.

- Rupert (2001) compared the effectiveness of using modified DRASTIC methods in predicting nitrite and nitrate contamination in the Snake River Basin (Idaho and Wyoming). The first modified DRASTIC method used only three of the seven DRASTIC variables believed to be the most important with respect to groundwater sensitivity – Depth to Water, Net Recharge, and Soil Media – to produce a groundwater sensitivity map in Idaho. Land use data were used as a surrogate for Net Recharge, and variable rating values were modified from the original DRASTIC system based on best professional judgment. Land uses included urban, irrigated and dryland agriculture, rangeland, and forest. The final map showed relative sensitivity ratings (low, medium, high, and very high). For the second modified DRASTIC method, the variable rating values for the same three variables were calibrated based on nonparametric, statistical correlations between the three variables and groundwater nitrite and nitrate data. The calibration data set included nitrite and nitrate data collected from 1991 to 1994 for 726 wells by the Idaho Statewide Groundwater Monitoring Program (ISGWMP). The final calibrated DRASTIC map showed relative sensitivity ratings correlating to low, medium, high, and very high probability of contamination. An independent set of groundwater nitrite and nitrate data retrieved from the USGS National Water information System (NWIS) database from 1980 to 1991 were used to compare the effectiveness of the two methods in predicting the probability of nitrate contamination in groundwater. The study found no statistical differences in groundwater nitrite and nitrate concentrations between the low and medium, low and very high, and high and very high sensitivity categories generated from the uncalibrated DRASTIC rating system. Whereas, clear statistical differences were confirmed between all probability categories using the calibrated DRASTIC method except between low and medium probability. The study proved that calibration of the groundwater sensitivity maps with groundwater quality is an effective way to determine which characteristics are related to groundwater contamination for the compound of interest.

- Johansson et al. (1999) combined the DRASTIC method with contaminant source characterization to identify areas of high groundwater vulnerability in Managua, Nicaragua. The characterization of contaminant sources included a screening step, for which contaminant sources were identified and grouped according to activity levels related to handling and storage of chemicals and disposal of wastes. Contaminant sources were then assigned a high, medium, or low contaminant load potential based on five characteristics of the contaminant source –

contaminant class, relative concentration, mode of deposition, duration of load, and potential for remediation. The authors state that the method is useful for planning purposes as different potentially contaminating activities can be tested by superimposing their potential contaminant loads on a traditional DRASTIC map to retrieve a contamination liability. In addition to characterizing contaminant load, a groundwater protection value map was generated that identified areas with a high value for water supply. Although not conducted for this study, the authors cite the potential utility in overlaying the protection value map over the DRASTIC map to guide land use regulations for present and planned activities. Such regulations could place constraints on certain activities or require detailed hydrogeologic investigations, monitoring programs, and engineering design standards in high risk areas (i.e., where groundwater vulnerability and protection values are both high). Groundwater liability categories were not compared to actual water quality data for this study.

- Nolan et al. (1997) produced a map of the United States depicting the risk of nitrate contamination in groundwater using four variables – nitrogen loading, population density, soil hydrologic group, and woodland-to-cropland ratio. Each of the variables was segregated into nitrogen loading and aquifer vulnerability factors to create risk groups for mapping. Four risk groups were created on the basis of thresholds obtained by examining scatter-plots fitted with a locally weighted scatter-plot smoothing (LOWESS) technique that reduces the influence of outliers in datasets. A scoring system was developed using scatter-plots and box-plots of nitrate concentrations for each of the four factors and determining where nitrate concentrations increased above background levels. Results showed significant differences between the four risk groups and better separation than a previous study that did not consider the influence of population density or woodland-to-cropland ratio on nitrate contamination.

2.2 Statistical Methods

Water quality is a multivariate concept that is not defined by any single constituent. Therefore, multivariate statistical techniques may be well suited to identify the relationships between water quality data and other physical data. As discussed in the previous section, statistical methods have been used in hybrid-based approaches to validate otherwise subjective variable ranking systems. Statistical methods can also be used independently to evaluate, determine, and quantify the association between measures of vulnerability and various types of information that are thought to be related to vulnerability. Examples of statistical methods include single and multiple regression for univariate and multivariate variables, analysis of variance, discriminant and cluster analyses, geostatistical analyses, and time series (NRC, 1993). Statistical methods are based on the concept of uncertainty, which is described in terms of probability distributions for the variables of interest. By correlating physical parameters to water quality data, potential explanatory variables can be checked for significance and adjusted, and variables that do not help explain variations in groundwater quality can be eliminated from consideration. An additional critical component of statistical methods is the use of a developmental water quality dataset to identify and weight explanatory variables and the use of a validation water quality dataset to confirm the predictive capability of the final sensitivity or vulnerability equations.

One of the most common statistical methods used in groundwater vulnerability assessments is logistic regression. The form of a logistic regression model is shown below:

$$P = \frac{e^{(b_o + bX)}}{1 + e^{(b_o + bX)}}$$

where P is the probability of an event (e.g., probability of groundwater at a certain location exceeding a critical contaminant concentration), X is a vector of n explanatory variables, b_o is a scalar intercept parameter, and b is a vector of slope coefficient values, such that $bX = b_1X_1 + b_2X_2 + \ldots\ldots b_nX_n$. Potential explanatory variables can be either continuous (e.g., well screen depth, net recharge) or binary (e.g., presence of absence of a certain land use or activity within a prescribed radius). A transformation, called the logit transformation, is then performed to yield a linear function:

$$\ln \frac{P}{1 - P} = b_o + bX$$

Values of b_o and b are calculated using an iterative procedure contained in traditional statistical packages that tests each variable for significance and produces a best-fit regression model. Logistic regression is a promising method for assessing groundwater vulnerability as it can be used to treat large numbers of censored values (i.e., concentrations below laboratory detection levels) to identify the level of influence of potential variables on the probability of an event. Four example studies are summarized below.

- Tesoriero and Voss (1997) used logistic regression analysis to relate the occurrence of elevated nitrate concentrations in the Puget Sound Basin (Washington) to natural and anthropogenic variables. The response variable was used in the logistic regression to differentiate nitrate concentrations above and below 3 mg/L, a threshold concentration selected to identify areas affected by anthropogenic activities. The study found that elevated nitrate concentrations correlated with well depth, surficial geology, and land use percentage. Net recharge, soil hydrologic group, and population density were shown to have no influence on elevated nitrate concentrations. For surficial geology type, logistic regression was performed on the presence or absence of coarse-grained and fine-grained glacial deposits. For land use percentage, logistic regression was performed on the percentage of urban, forest, and agriculture land for eight different radii ranging from 0.8 to 13 kilometers (km). An optimal significance for land use was demonstrated for a radius of 3.2 km. Coefficients for well depth and surface geology type were used to develop a multivariate groundwater sensitivity model for groundwater withdrawn from 15- and 70-meter deep wells. The sensitivity model was used to map the probability of a well having elevated nitrate concentrations, if a nitrate source was present. Percentages of urban and agricultural lands within 3.2 km correlated with elevated nitrate concentrations and were included along with well depth and surficial geology type in the multivariate vulnerability model. The vulnerability model was able to predict events better than the groundwater sensitivity model for the water quality dataset from which it was developed ($r^2 = 0.98$ for the vulnerability model versus $r^2 = 0.76$ for the sensitivity model using 1,967 data points) as well as a verification water quality dataset ($r^2 = 0.79$ for the vulnerability model versus $r^2 = 0.66$ for the sensitivity model using 1,729 data points).

- Eckhardt and Stackelberg (1995) and Eckhardt et al. (1988) used logistic regression to demonstrate the influence of land use (as a surrogate for potential contamination sources) and population density on boron, nitrate, VOC, and pesticide concentrations in the shallow sand and gravel aquifers underlying Nassau and Suffolk counties (Long Island, New York). Based on water quality data collected from 90 monitoring wells screened within 50 feet of the water table in five selected areas in Nassau and Suffolk counties, the study found that elevated contaminant concentrations were related to a combination of variables, including mean area-weighted population density and percentage of high and/or medium-density residential, agricultural, and commercial land use within a radius of 0.5 miles (representing the highest resolution obtainable from available data). Nitrate contamination also correlated to the thickness of the vadose zone. Three measures of model goodness-of-fit (chi-square statistic, rank correlation between predicted probabilities and observed responses, and Akaike Information Criterion) were used to assess the predictive ability of the selected logistic regression equations. Final regression equations included between one and four variables depending on the contaminant. The equations developed from the 90 monitoring well dataset were compared to similar equations developed from an independent water quality dataset collected from 240 wells less than 50 feet deep throughout Nassau and Suffolk counties (wells within one mile of each other were excluded to minimize spatial correlation). Both sets of equations identified the same significant land use variables for specific contaminants with slight differences in slope and intercept coefficients reflected differences in the frequency of contamination in the two well networks. The authors caution that in comparing equations developed from two water quality datasets, difficulties may arise due to 1) datasets representing different sampling periods, 2) variability in laboratory procedures and field methods between water collection agencies, and 3) incomplete information on wells. Overall, the study confirmed the effectiveness of the logistic regression method in developing contamination probability maps appropriate for planning purposes.

- Ayotte et al. (2004) used logistic regression to examine methyl tert-butyl ether (MTBE) occurrence in 86 private and public fractured bedrock wells in Rockingham County, New Hampshire and its relationship to well construction, pH, and other urban land use factors. Model predictive performance was not evaluated in this study, as the objective of the study was not to map contamination probability but rather to identify factors related to MTBE occurrence. For the study, wells within 500 meters of each other or those without a complete set of independent variable values were excluded to minimize spatial correlation. As expected, MTBE concentrations in private and public water supply wells were found to correlate strongly with population density and pH (a surrogate for the age of groundwater recharge in this area). Surprisingly however, MTBE concentrations correlated positively with well depth for public water supply wells. Results suggest that deeper fractured bedrock public water supply wells may be more vulnerable to MTBE due to their lower yield (which may result in less contaminant dilution and a greater contribution of groundwater from shallow aquifers leaking through near-surface fractures or along the well casing) and larger contributing areas (which may increase the likelihood of intercepting subsurface MTBE contamination compared to shallower wells screened in unconsolidated sediments). The results of the study challenge the perception that deep fractured bedrock wells are less vulnerable to surface contaminant sources in this area.

- Squillace and Moran (2000) used logistic regression to evaluate the occurrence of MTBE in 1,042 wells in the Northeast and Mid-Atlantic Regions of the United States in relation to a number of actors describing the land use and hydrogeologic conditions in the vicinity of the wells. The study found that three factors – MTBE use in gasoline (grouped into high- and low-MTBE use categories), density of aboveground and underground storage tanks within one-square kilometer of the well (continuous variable), and a soil erodability factor (used as a surrogate for infiltration capacity and grouped into high- and low soil erodability categories) – most effectively explained the frequency of MTBE detection above 0.5 μg/L. The low concentration of 0.5 μg/L was selected to balance the number of events as best as possible so that final regression equations were not limited to one variable. The final multivariate model did not predict favorably the MTBE frequency for a validation dataset consisting of 2,787 wells located throughout the United States (nor did the model predict favorably when half of the developmental data set was used for calibration and the remaining dataset was reserved for calibration). Nonetheless, a major study finding was that a larger calibration dataset on MTBE concentrations and ancillary information (including well characteristics, pumping rate, and hydrogeologic characteristics of the aquifer) were likely needed to reduce the model input and parameter errors.

Additional studies using logistic regression (Squillace et al., 1999), multiple linear regression (Druliner, 1988), and hypothesis testing (Vowinkel and Battaglin, 1988) have successfully correlated the vulnerability of groundwater to various land use practices.

2.3 Process-Based Methods

Process-based methods typically use mathematical models to approximate contaminant behavior in the subsurface environment using first-order (deterministic) equations or physically-based techniques used to describe underlying processes. Processed-based methods differ from other assessment methods in that they attempt to predict contaminant transport in both space and time. In addition, process-based methods are able to handle objectively multiple interacting physical processes simultaneously. Using process-based methods, the intrinsic sensitivity of groundwater may be determined by focusing on the source and movement of groundwater (e.g., using numerical groundwater flow modeling and age-dating of water), while groundwater vulnerability may be estimated by focusing on the source and movement of the contaminant (e.g., using solute transport modeling, geochemical modeling, or source-characterization techniques) (NRC, 1993). Process-based methods may be used to highlight the most important factor controlling groundwater vulnerability thereby assisting water managers design targeted management practices. Although they may account for all of the important hydrologic processes controlling groundwater vulnerability, process-based methods are not commonly used in vulnerability assessments over large study areas due to the difficulty in obtaining reliable data for model input parameters. However, results from process-simulating models can be used to verify subjective and statistical methods. Two example studies using a process-based method are summarized below.

- Moran et al. (2004) used ultra low concentrations of VOCs and age-dating/fingerprinting techniques (including tritium-helium and oxygen-deuterium analyses) to help define the groundwater flow field and indicate the degree of vertical connection between near-surface sources of contamination and deeper groundwater in San Mateo County and Santa Clara County. The presence of tritium and VOCs was used to differentiate between pre- and post-industrial age groundwater. In Santa Clara County, the most vulnerable areas included the recharge area of the Santa Clara Subbasin, the recharge area in the Llagas Subbasin, and confined areas of the Llagas Subbasin where young groundwater exists in the Shallow Aquifer. The Llagas and Coyote subbasins were characterized as having a relatively high vulnerability to contamination. The study also found that widespread vertical contamination is not evident in the confined zone of the Santa Clara Subbasin, where groundwater is generally greater than 50 years old. Deep groundwater protection in the confined zone may be a consequence of an upward vertical gradient in this area, although the study concluded that additional investigation was necessary to confirm this condition. The few VOC detections in the confined zone are believed to be the result of contamination short-circuiting the regional groundwater flow regime as a result of abandoned wells, compromised well casings, or natural conduits such as faults or buried erosional features. Additionally, results of the study indicate that topographic barriers may inhibit horizontal flow from the southeastern portion of the recharge area to the central portion of the Santa Clara Subbasin.

- The USGS has published production well-based vulnerability assessment study findings for four areas across the country (USGS 2008, 2009a, 2009b, 2010). The studies used computer models to estimate travel times of water particles entering water supply wells and, in two cases, to simulate contaminant concentrations. Those studies identified three important factors affecting well vulnerability including: 1) groundwater age, i.e. younger groundwater is more vulnerable to anthropogenic contamination; 2) aquifer geochemistry, i.e. redox conditions affect fate and transport of some contaminants; and 3) direct pathways, i.e. wells and other hydrogeologic conditions provide conduits for the rapid transport of contaminated shallow groundwater to depth. Additionally, based on a focused study of a public water supply well in Modesto, CA, the USGS acknowledges the strong correlation between groundwater production and downward vertical transport of contaminant to underlying aquifers (USGS, 2010).

2.4 Errors and Uncertainties

Any groundwater vulnerability assessment will be subject to uncertainty for many reasons. The NRC (1993) has grouped sources of error into six classes:

1. Errors in obtaining data
2. Errors due to natural spatial and temporal variability
3. Errors in digitization and storage of data
4. Data processing errors
5. Modeling and conceptual errors
6. Output and visualization errors

All forms of uncertainty are critical in the design and use of a groundwater vulnerability assessment. Consideration should be given to the effects of uncertainty on how decision will be made, what decisions are made, and how the results of the assessment are presented. In all cases, uncertainty and errors should be discussed to help determine what policy/planning decisions are possible, the benefits of making correct decisions, and consequences of making incorrect decisions. Overall, the eventual use of a specific assessment method should more or less reflect the technical limitations of the method (NRC, 1993).

2.5 Summary of Assessment Methodologies

Table A-4 provides a summary of the groundwater vulnerability assessment methods (index and hybrid methods are differentiated in the table). Advantages and disadvantages of the assessment method categories are summarized below.

<u>Index Methods</u>

Advantages: For a regional-scale assessment, subjective index methods are conceptually appropriate in that they address explicitly the multivariate nature of groundwater sensitivity. Index methods rely on readily available information and can be used implemented and refined using GIS tools.

Table A-4: Summary of Groundwater Vulnerability Assessment Methods

Assessment Criteria	Index	Hybrid	Statistical	Process-Based
Size of Study Area	Regional	Regional	Site or Regional	Site or Regional
Data Requirements	Low	Low/Moderate	Moderate/High	High
Level of Uncertainty	High	High/Moderate	Moderate/Low	Moderate/Low
Targeted Contaminant	General Only	General or Specific	General or Specific	General or Specific
Use of Occurrence Data	No	Variable*	Yes	Yes
Ease of Refinement	Easy	Easy	Moderate	Difficult

*In subjective hybrid methods, user-defined vulnerability categories are not verified with occurrence data
*In objective hybrid methods, user-defined vulnerability categories are verified with occurrence data

Disadvantages: Subjective methods rely largely on data availability and expert judgment with less emphasis on processes controlling groundwater contamination. One set of variable weights suitable for one region may not be appropriate for another region. Although index methods are designed to address the multivariate nature of water quality, subjective sensitivity and vulnerability categories and weights are typically not verified using actual water quality data resulting in an unreliable assessment. Because the distribution and characterization of PCAs are typically not evaluated when using an index method, the ability to assess groundwater vulnerability to specific contaminants is not possible.

Hybrid Methods

Advantages: Hybrid methods allow for the evaluation of contaminant source characteristics that influence not only the intrinsic sensitivity of groundwater to contamination but also its vulnerability to specific contaminants based on land use conditions and activities. Hybrid methods are suitable for groundwater assessment studies covering broad regional areas. Hybrid methods are also suitable in areas where error characteristics in water quality datasets compiled from diverse sources limit statistical methods. Hypothesis testing can be used to improve the reliability of hybrid method in comparison to subjective rating systems used in index methods. Similar to index methods, the implementation and refinement of hybrid methods are relatively simple compared to statistical methods using GIS tools.

Disadvantages: Although occurrence data can be used to verify user-defined vulnerability categories, results of hybrid methods are not correlated directly to probability. As a consequence, resolution of results may be coarser compared to results obtained from statistical methods.

Statistical Methods

Advantages: The complexity and local nature of water quality make it difficult to establish a set of variables important in all cases. The important parameters may differ in different parts of the country and within a county, watershed, or groundwater basin. The variety of statistical methods available for treating various types of data makes statistical approaches inherently flexible. Typically, no assumptions are made about the list of candidate variables to be included in a statistical model, nor do the results attempt to identify cause-effect relationships. Statistical methods can more easily deal with differences in scale than other methods that are based on the description of physical relationships. Overall, the integrity and confidence in vulnerability assessment can be bolstered using developmental and validation datasets to confirm variable selection and weighting in a statistical method such as logistic regression.

Disadvantages: Since groundwater quality data are essential for calibrating and verifying correlations drawn from statistical methods, high quality data is needed to ensure model input and parameters errors in the resulting vulnerability assessment are minimized to acceptable levels. Because statistical methods rely strictly on correlation to explain physical-based processes, a disciplined approach combined with knowledge of fundamental groundwater processes is necessary to prevent mistreatment of statistical methods. Although final vulnerability equations can be easily incorporated in GIS, statistical relationships between variables should be re-evaluated when additional data become available.

Process-Based Methods

Advantages: Process-based methods use first order equations to model contaminant fate and transport processes. Uncertainty can be minimized if data requirements for inputs are met. Process-based methods can be used to address multiple interacting physical processes and identify the most important factor in groundwater sensitivity or vulnerability. Similar to objective hybrid methods and statistical methods, occurrence data in process-based methods can be used to calibrate and verify model outputs, thereby reducing uncertainty to acceptable levels.

Disadvantages: Sophisticated process-based methods do not necessarily provide more reliable outputs. Since data for many of the required input parameters for sophisticated models are not always available, their values often must be estimated by indirect means using surrogate parameters or extrapolated from data collected at other locations. Errors and uncertainties associated with such estimates or extrapolations may be large and may negate the advantages gained from using a rigorous method that simulates physical processes. The effort and cost of gathering data needed to estimate (or later refine) many of the parameters used in process-based models for regional scale assessments may be prohibitively large.

3 Selected Assessment Methodologies

Generally, the more complex and detailed assessment methods require more complex and detailed knowledge of the system being assessed. Simpler methods incorporate more approximations and are less precise, but require less detailed information about the system being assessed. Based on this evaluation of available groundwater vulnerability assessment methods and an understanding of available hydrogeologic, water quality, and PCA information for the Study Area, a statistical method was selected for the sensitivity assessment to provide an objective framework within which to identify the local hydrogeologic factors that most influence contaminant transport and, in turn, quantify the sensitivity to contamination of the Shallow Aquifer and Principal Aquifer. The statistical method selected for the sensitivity methodology is called logistic regression. Nitrate concentrations and distribution in groundwater were used to statistically determine and rank the most important hydrogeologic factors affecting groundwater sensitivity. For the PCAs risk assessment, an index based method based on the DWSAP guidelines and observation and experience was used to rank risk factors. For the PCAs ranking, emphasis was placed on accurately characterizing the maximum risks so as not to underestimate potential risks. Accordingly, the PCA with the highest ranking in any given area was used to determine the risk in that area. Finally, the sensitivity and PCA risk are combined to determine the overall vulnerability. A more detailed discussion of the methodologies and results is presented in the main section of the Groundwater Vulnerability Study Report.

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Appendix B
Literature and Data Review Summary

Santa Clara Valley Water District
San Jose, California

Literature and Data Review Summary
for

Groundwater Vulnerability Study

Santa Clara County, California

September 2009

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1 Introduction

1.1 Background

The Santa Clara Valley Water District (District) is the primary water resources agency in Santa Clara County. Since 1929, the District has been responsible for water supply, flood protection, and watershed management across Santa Clara County's 1,300 square mile area. The District's groundwater management objectives are to recharge the groundwater basin, conserve water, increase water supply, and prevent waste and diminution of the District's water supply with the end goal of ensuring that water resources are sustained and protected.

Protection of groundwater from contamination is an important component of ensuring a reliable water supply for Santa Clara County (County). Over the past 20 years the District, in cooperation with other research and governmental agencies, has managed numerous investigations and developed comprehensive groundwater monitoring and protection programs. This Groundwater Vulnerability Study (Study) is being conducted for the District in order to predict sensitivity and vulnerability of groundwater to contaminating land use conditions and practices using existing groundwater quality, hydrogeologic, and land use data. For this Study, *groundwater sensitivity* is defined as the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest and is a function of the intrinsic characteristics of the geologic materials in question and the overlying unsaturated materials. Groundwater sensitivity is not dependent on land use and contaminant characteristics. On the other hand, *groundwater vulnerability* is defined as the relative ease with which a contaminant on or near the land surface can migrate to the aquifer of interest under a given set of land use management practices, contaminant characteristics, and groundwater sensitivity conditions (USEPA, 1993). Groundwater may be highly sensitive to contamination, but the characterization of contaminant sources is needed to determine its vulnerability to contamination.

1.2 Task Purpose and Objectives

Existing literature and data collection, review, and documentation was one task of the Groundwater Vulnerability Study (Study). The purpose of this task was to acquire and compile all data necessary to complete the groundwater sensitivity and vulnerability analyses for the Santa Clara, Coyote, and Llagas groundwater subbasins (Study Area). An additional component of this task was to identify any data gaps that may limit determination of sensitivity and vulnerability. The general categories of information needed to conduct this Vulnerability Study include hydrogeology, water quality, and potentially contaminating activities/land use. Each of these categories is discussed in this memorandum along with an identification of data gaps. In addition, previous studies conducted to assess groundwater sensitivity and vulnerability in Santa Clara County (County) have been reviewed.

1.3 Report Contents

Section 2 discusses sources of data. Section 3 briefly describes current and historic land use in the Study Area. Section 4 describes water supply sources in the County. The hydrogeology and water quality in the Study Area are presented in Sections 5 and 6, respectively. Section 7 discusses potentially contaminating activities and Section 8 describes previously conducted sensitivity and vulnerability studies conducted in the Study Area. All references cited in this Appendix are included at the end of the main text of the Groundwater Vulnerability Study report.

2 Data Sources Overview

2.1 Santa Clara Valley Water District

The Districts has provided various reports, data, and databases collected, prepared, or commissioned by the District as well as from other sources. The District also provided various GIS coverages. The data provided by the District covers hydrogeology, water quality, potentially contaminating activities (PCAs), land use, and previous sensitivity and vulnerability studies. The District has commissioned numerical groundwater flow models for the Santa Clara, Coyote, and Llagas subbasins, results of which have been made available for this Study. The District monitors groundwater levels and quality in a number of wells and has compiled those data and water quality data available from the California Department of Public Health (DPH) in a database provided for this Study. Prior to July 1, 20004, the District oversaw the leaking underground storage tank (LUST) program in Santa Clara County and developed a related database.

2.2 State Water Resources Control Board and Regional Water Quality Control Board(s)

The State Water Resources Control Board (SWRCB) provides comprehensive protection for waters of the state. The SWRCB maintains the GeoTracker database of environmental release sites in California, which is available online. The SWRCB manages the Groundwater Ambient Monitoring and Assessment (GAMA) Program, which is intended to improve statewide ambient groundwater quality monitoring and assessment and increase the availability of information about groundwater quality to the public. Several special subbasin-wide studies have been conducted in Santa Clara County under the GAMA Program.

The Regional Water Quality Control Boards (RWQCBs) develop and enforce water quality objectives and implementation plans to protect waters of the state. Generally, the RWQCBs oversee the remediation of environmental sites where contaminant releases have impacted groundwater. The San Francisco Bay Region RWQCB (SFRWQCB) oversees sites in the northern Santa Clara County including the Coyote and Santa Clara subbasins. The Central Coast RWQCB (CRWQCB) oversees sites in the southern Santa Clara County including the Llagas Subbasin.

2.3 California Department of Toxic Substances Control

The Department of Toxic Substances Control (DTSC) regulates hazardous waste, cleans-up existing contamination, and looks for ways to reduce the hazardous waste produced in California. As such, the DTSC oversees some environmental release sites in Santa Clara County. The DTSC maintains the online EnviroStor database of environmental release sites overseen by DTSC. The database also includes information on United States Environmental Protection Agency (USEPA) Superfund sites.

2.4 California Department of Public Health

The California Department of Public Health (DPH) regulates drinking water quality in the state. Water purveyors are required to report groundwater quality testing results to the

DPH. These data are collected by the District and included in the water quality data base provided for this project. The DPH also oversees the Drinking Water Source Assessment and Protection (DWSAP) program, which evaluates the sensitivity and vulnerability of drinking water sources to contamination. Results of the DWSAP program assessments are intended to be used as a tool in developing drinking water protection programs.

2.5 United States Environmental Protection Agency

The USEPA is the lead regulatory agency overseeing Superfund sites in Santa Clara Valley. In addition, the USEPA has developed guidelines for conducting sensitivity and vulnerability assessments.

2.6 California Department of Water Resources

The California Department of Water Resources (DWR) maintains a library of water well drillers reports in California. The DWR has also produced some of the seminal hydrogeologic reports in Santa Clara County (County).

2.7 United States Geological Survey

The United States Geological Survey (USGS) has produced geologic and topographic maps of the Study Area. USGS has also conducted GAMA water quality studies and constructed a groundwater/surface water flow model of Santa Clara Valley. The USGS has also conducted sensitivity and vulnerability studies and has assessed and developed guidelines for these types of studies.

2.8 Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory (LLNL) has conducted two GAMA water quality and age dating studies in the Study Area.

2.9 Santa Clara County Department of Environmental Health

The Santa Clara County Department of Environmental Health (DEH) currently oversees LUST sites in the Study Area and also regulates septic systems. The County has prepared general land use maps for the County.

2.10 Local Cities

Local cities have prepared land use maps, general plans, and zoning maps.

3 Current and Historic Land Use

An understanding of both current and historic land use in the Study Area is important in assessing potential contaminating activities. Land use data are available from Santa Clara County, the District, and individual cities. The various types and sources of land use data are discussed in the Potentially Contaminating Activities (PCAs) section. The Study Area is comprised of three groundwater subbasins: the Santa Clara, the Coyote, and the Llagas. Each has unique current and historic land uses as discussed below.

3.1 Santa Clara Subbasin

Land use in the Santa Clara Subbasin has changed dramatically over the last 100 years, from a largely rural, agricultural area to a highly developed urban area. Prior to the 1900s, most land in the Santa Clara Valley was used for grazing cattle and dry-land farming. In the early 1900s, agriculture was the chief economic activity. The release of nitrate associated with historic agricultural land use is a continuing groundwater concern in the subbasin. As in most coastal basins in California, urbanization since the late 1940s resulted in the transfer of agricultural lands to residential and commercial uses. Groundwater level declines of more than 200 feet occurred from groundwater development from the early 1900s to the mid-1960s (Poland and Ireland, 1988). Groundwater levels in the Santa Clara Subbasin have been recovering since the mid-1960s as a result of better resource management, conservation, imported water, and artificial recharge. Water use has also changed from predominantly agricultural prior to the 1960s to almost completely urban and industrial uses since the mid-1960s. The valley is currently undergoing continued urban expansion and redevelopment of formerly industrial areas to residential use. The Santa Clara Subbasin is currently highly developed with residential, commercial, and industrial areas and many associated industrial and commercial contaminant release sites along with the lingering impacts of agricultural releases.

3.2 Coyote Subbasin

Compared with the Santa Clara Subbasin, the Coyote Subbasin is relatively rural, undeveloped, and mostly unincorporated with far fewer industrial/commercial contaminant release sites. Coyote Valley has the most potential for future residential and commercial development. The Coyote Valley Specific Plan calls for a total of at least 26,400 residential units and 55,000 new jobs to be developed in Coyote Valley utilizing forecasted water demand of 18,500 acre-feet per year (AFY). Future development of the Coyote Valley is presented in the City of San Jose's 2020 General Plan, which defines three distinct land use designations: the North Coyote Campus Industrial Area encompassing 1,444 acres in the northern portion of the valley; the Coyote Valley Urban Reserve encompassing 2,072 acres in the central portion of the valley; and the Coyote Valley Greenbelt encompassing 3,621 acres in the southern portion of the valley (City of San Jose, March 2007). Existing water quality impacts in the subbasin are related to agricultural practices. Due to unconfined groundwater conditions, shallow depth to groundwater, and high permeability in the subbasin, it is highly vulnerable to contaminant releases at the ground surface. Future development in the subbasin will need to consider this vulnerability if groundwater resources are to be protected.

3.3 Llagas Subbasin

Residential and commercial development in the Llagas Subbasin is focused in the City of Morgan Hill in the north and the City of Gilroy in the south where water is supplied through large municipal wells and wastewater is handled at a municipal wastewater treatment facility. The central portion of the subbasin in the vicinity of San Martin is comprised predominantly of agricultural development and large (five to ten acre) residential parcels relying on individual wells and onsite septic systems. Based on the Santa Clara County 1995 General Plan, the Llagas Subbasin was 40 percent agricultural, 25 percent urban, 20 percent rural, 10 percent mixed use, and 5 percent open space. There has been an ongoing conversion of agricultural land to urban use in the subbasin over the past 30 years (LLNL, July 2005; CH2M HILL, May 2005).

Due to unconfined conditions and high permeability in some areas, portions of the subbasin are highly vulnerable to contaminant releases at the ground surface. The subbasin is currently impacted by high levels of nitrate associated with rural land use and agriculture and perchlorate from historic releases from a flare manufacturer.

4 Water Supply Sources

Water supply in Santa Clara County comes from a number of sources including local surface water, imported water, recycled water, and groundwater. Typically groundwater accounts for about 40 to 50 percent of the County water supply.

Ten reservoirs including Almaden, Anderson, Calero, Chesbro, Coyote, Guadalupe, Lexington, Uvas, and Vasona store local runoff and some imported water. Reservoir water is either recharged to the groundwater subbasins through a network of ponds and in-stream facilities or treated at one of the District's three water treatment plants prior to delivery to water retailers. The total storage capacity of the reservoirs is 170,000 acre-feet (AF).

The District imports water from the State Water Project's South Bay Aqueduct (SBA), San Luis Reservoir of the federal Central Valley Project's San Felipe Division (CVP). The San Francisco Water Department imports water via the Hetch-Hetchy Aqueduct. The Hetch Hetchy system operates independently of any District facilities, integrating with the District treated water supplies in the City of Milpitas.

Water from the SWP and CVP are both imported from the Sacramento-San Joaquin River Delta. SWP water was first delivered to Santa Clara County in 1965 through the SBA, with a contract entitlement of 100,000 AFY. The first CVP water was delivered to Santa Clara County in 1987 through the San Felipe Project, with a contract entitlement of 152,500 AFY.

Local reservoir water and imported water can be conveyed to District treatment plants and to local streams and groundwater recharge facilities (SCVWD, January 2007). The District operates and maintains 18 major recharge pond systems and numerous in-stream recharge facilities with an average annual recharge of approximately 104,000 AF when sufficient water is available. Generally recharge operations act to improve groundwater quality particularly in the unconfined Coyote and Llagas subbasins where recharge water acts to dilute nitrate and perchlorate plumes (LLNL, July 2005).

Four wastewater treatment plants are operated in the county to produce tertiary treated water that is recycled for landscape water features, landscape and agricultural irrigation, and industrial use. Recycled water accounted for 16,900 AF of the County water supply in 2007 or 4 percent. The District's Ends Policy 2.1.7 is to increase recycled water use to 5 percent (of the total supply) by 2010 and 10 percent by 2020. Advanced treatment of wastewater, including reverse osmosis and microfiltration, and use of this highly treated wastewater for stream flow augmentation, groundwater recharge, and other uses is being considered (SCVWD, December 2005). The District is currently conducting a study to evaluate potential impacts from expanded recycled water use for irrigation. The City of San Jose is currently conducting a study to evaluate over ten years of groundwater monitoring data collected in areas where recycled water is being used for irrigation (Todd Engineers, August 11, 2009). While current recycled water use is limited to irrigation and industrial water uses, the use of recycled water for stream augmentation, active groundwater recharge, and other uses may be implemented in the County in the future. While advanced treatment is proposed for recycled water used for stream augmentation and active groundwater recharge, water quality impacts will need to be fully assessed for these potential future recycled water uses in Santa Clara County.

5 Hydrogeology

The Study Area includes the Santa Clara, Coyote, and Llagas groundwater subbasins. Each of these subbasins has unique hydrogeologic characteristics as discussed below.

5.1 Santa Clara Subbasin

The South Bay Area of Santa Clara Valley Groundwater Basin is identified as Basin No. 2-9.02 by DWR (2004) and includes both the Santa Clara and Coyote subbasins. The Santa Clara Subbasin is the largest of the three subbasins and extends from the Coyote Narrows at Metcalf Road to the County's northern boundary in the San Francisco Bay. The Santa Clara Subbasin is approximately 22 miles long and 15 miles wide, with a surface area of 225 square miles (Reymers and Hemmeter, July 2001). Much of the land over Santa Clara Subbasin has been converted over the past 100 years from agricultural to commercial/industrial and urban uses.

The key references for hydrogeologic characteristics of the Santa Clara Subbasin include the following:

- DWR, updated February 2004, California's Groundwater Bulletin 118, Santa Clara Groundwater Basin (Santa Clara Subbasin)
- Fostersmith et al., (SCVWD), January 2005, Groundwater Conditions 2002/2003
- Hanson et al., (USGS), 2004, Documentation of the Santa Clara Valley Regional Ground-Water /Surface-Water Flow Model, Santa Clara County, California
- Iwamura, T.I, 1995, Hydrogeology of the Santa Clara and Coyote Valleys Groundwater Basins, California
- Moran et al., (LLNL), July 2004, California Aquifer Susceptibility, A Contamination Vulnerability Assessment for the Santa Clara and San Mateo Groundwater Basins
- Reymers and Hemmeter, (SCVWD), July 2001, Santa Clara Valley Water District Groundwater Management Plan
- Reymers and Hemmeter, (SCVWD) July 2002, Groundwater Conditions 2001

Below is a summary of the hydrogeology of the Santa Clara Subbasin based on these and other cited references.

5.1.1 Geologic Structure

The Santa Clara Subbasin is located in a structural trough that is bounded by the Santa Cruz Mountains to the west and the Diablo Range to the east (Reymers and Hemmeter, July 2001; Fostersmith et al., January 2005; and DWR, August 1967 and 1975). The groundwater subbasin's northern boundary is formed by contact with thick low permeability Bay Mud deposits at the San Francisco Bay, and the southern boundary is defined by the Coyote Narrows (City of San Jose, 2007). The northwestern (San Mateo Subbasin) and northeastern (Niles Cone Subbasin) boundaries generally coincide with

Santa Clara County's borders. These subbasin boundaries are based on institutional rather than hydrogeologic conditions. The subbasin's bottom boundary is formed by bedrock or consolidated sediments of very low permeability.

Ground surface elevations vary from sea level at San Francisco Bay to about 280 feet above mean sea level (msl) at the Coyote Narrows, and the basin floor gradually slopes from the southern edges to the northern basin interior (Fio and Leighton, 1995).

The northwesterly trending intermountain San Francisco Bay depression is a large structural trough created by a combination of movement along faults in the Santa Cruz Mountains and Diablo Range and tectonic downwarping of the intervening area (DWR, August 1967). Sediments have washed into this structural depression from the flanking mountains forming a substantial thickness of unconsolidated alluvial materials comprising the valleys and San Francisco Bay. The accumulation of permeable alluvial fill within the valleys constitutes the groundwater subbasin (Iwamura, 1995).

Major northwesterly trending faults flank the structural trough and include the San Andreas Fault System in the Santa Cruz Mountains, the Hayward Fault along the eastern edge of the trough, and the Calaveras Fault in the Diablo Range (Iwamura, 1995). Faults occurring within the valley are largely concealed under the uppermost, younger alluvial fill materials. Faults within the valley include the Silver Creek and Evergreen faults in the east and the Monte Vista and New Cascade faults in the west. The groundwater flow system may be affected by the presence of faults that potentially act as hydrologic flow barriers (Hanson et al., 2004).

Past differential movements of the faults within the basin have produced a highly irregular bedrock basement surface beneath the alluvial basin fill forming a series of parallel blocks. There is a bedrock high in the basement rocks in the vicinity of the Coyote Hills, which forms the Coyote Narrows with generally greater depths to bedrock to the north (DWR, August 1967).

5.1.2 Geologic Units

Three primary geologic units occur in the Santa Clara Valley area and include from oldest to youngest: the Franciscan Formation, Santa Clara Formation, and the Pleistocene to Holocene alluvial sediments. The Franciscan Formation forms the bedrock basement of the Santa Clara Subbasin, consists of metamorphosed marine deposits, and is not considered to be a major water bearing unit (Iwamura, 1995). The Santa Clara Formation and alluvium lie unconformably on the consolidated basement rocks of the Franciscan Formation and constitute the water bearing units in the subbasin.

The Santa Clara Formation is of Plio-Pleistocene age and is exposed only on the west and east sides of the Santa Clara Valley. Where exposed, it is composed of poorly sorted deposits ranging in grain size from boulders to silt. (DWR, August 1967 and 1975). Its occurrence beneath the valley deposits is uncertain as it has not been identified in many deeper wells (Hanson et al., 2004).

The Pleistocene to Holocene alluvium is the most important water bearing unit and the unit screened by most production wells in the subbasin. The permeability of the valley alluvium is generally high and almost all large production wells derive their water from it (DWR, 1975). Comprised generally of unconsolidated gravel, sand, silt, and clay, it was deposited principally as series of convergent alluvial fans. Materials were deposited from debris washed out of the local mountain ranges; with coarser materials generally dominating near the mountains and lighter, finer particles closer to the San Francisco Bay. More coarse-grained sands and gravels are the product of alluvial dominated depositional environments; these units are interbedded with the silts and clays throughout the Holocene sequence. Coarse-grained facies subparallel to and beneath selected stream channels potentially provide enhanced permeability, and fine-grained facies beneath other selected stream channels reduce permeability (Hanson et al., 2004).

Laterally and vertically extensive silt and clay layers were deposited in times of higher sea levels, when the Santa Clara Valley was under a shallow estuarine and bay environment. These fine-grained materials form an extensive regional aquitard. The top of the aquitard occurs within the northern areas of the subbasin at depths ranging from 75 feet near the recharge areas to 160 feet in the northern interior portion of the subbasin (CH2M Hill, July 1992) and beneath San Francisco Bay. The thickness of this regional aquitard varies from about 20 feet to over 200 feet. The total thickness of the alluvium exceeds 1,500 feet in some portions of the subbasin (Newhouse et al., 2004; DWR, August 1967 and 1975).

5.1.3 Groundwater Occurrence

Aerially, the Santa Clara Subbasin is divided into a confined zone and an unconfined zone. Confined conditions are found in the northern portion of the subbasin where the principal water bearing units are overlain by a laterally and vertically extensive, low-permeability, confining layer. Areas in the southern portion of the subbasin and along the margins of the subbasin are generally unconfined to semi-confined and contain no thick laterally continuous clay layers (Reymers and Hemmeter, July 2001). The area of greatest groundwater production in the Santa Clara Subbasin is in the region just south of the San Francisco Bay, underlying the City of San Jose. This area is made up of thick sequences of recent high transmissivity alluvial sediments, and to a lesser extent, Santa Clara Formation sediments.

Vertically, the northern and valley lowland areas are comprised of three general hydrogeologic layers: the upper Shallow Aquifer, the regional clay aquitard, and the Lower Aquifer zone, also commonly referred to as the Principal Aquifer. In upland areas of the valley, the clay aquitard is absent, and the Shallow and Lower aquifers merge. Most of the groundwater recharge occurs at the edges of the subbasin near the surrounding hills and in the south. The confined Lower Aquifer and unconfined to semi-confined recharge area areas comprise the primary sources of groundwater in the valley. The confined Principal Aquifer is as much as 800 feet thick. (Hanson et al., 2004; DWR, August 1967 and 1975). The Shallow Aquifer is generally not used for water supply in the Santa Clara Subbasin; although, it is currently being evaluated for potential beneficial use.

5.1.4 Aquifer and Vadose Zone Properties

Parameters used to characterize the hydraulic properties of an aquifer include aquifer transmissivity (T value), aquifer hydraulic conductivity (K value), aquifer storativity (S value), effective porosity, well specific capacity, well yield, and groundwater velocity.

Analysis of data collected from constant discharge pumping tests is the best method for obtaining reliable estimates of T, K, and S values. However, because data from constant rate pumping tests conducted in the subbasin are not widely available, other sources of aquifer parameters, including slug tests, lab permeability testing of core samples, and specific capacity data from initial well development, have been relied upon. For groundwater modeling, the USGS estimated K values from lithologic categories and thicknesses (Hanson et al., 2004).

Generally, aquifers in the Santa Clara Subbasin are comprised of intermediate to highly permeable sediments (Iwamura, 1995), with permeability generally increasing from west to east (DWR, 2004). K values are generally higher in the Shallow Aquifer than in the Principal Aquifer (Hanson et al., 2004).

A pumping test was conducted in a Principal Aquifer well located near the San Jose Airport (TRC, January 2006). Recovery data from the pumping test yielded a T value of 14,500 feet squared per day (ft^2/d), K value of 45 feet per day (ft/d), and S value of 0.013.

Groundwater is produced from the Santa Clara Formation in the western portion of the Santa Clara Subbasin. K values of the Santa Clara Formation are believed to increase from west to east in this region. Pumping tests of wells located near Los Altos indicate that K values range from 0.1 to 1 ft/d (DWR, August 1967).

The USGS conducted slug tests in individual depth-discrete ports of three nested wells recently constructed in the subbasin (Newhouse et al., 2004 and Hanson et al., 2004). One of the monitoring wells is located in the confined zone, another in the recharge area near the edge of the subbasin, and the third near the boundary between the confined and unconfined zones. For the confined zone well, K values ranged from 40 to 342 ft/d, and T values (based on a range of S values) ranged from 650 to 3,421 ft^2/d. For the well located near the boundary of the confined and unconfined zones, K values ranged from 4 to 583 ft/d, and T values ranged from 70 to 5,830 ft^2/d. For both wells, K values were highest in the shallowest ports. For the recharge area well, K values ranged from 0.1 to 10 ft/d, and T values ranged from 2 to 196 ft^2/d. Vertical K values for the finer grained sands, silts, and clays, based on lab permeability tests of selected whole cores, ranged from 0.0008 to 0.3 ft/d.

For a groundwater model of the Santa Clara Subbasin, the USGS assigned average K values and S values for each of six model layers and modified them based on estimated fractions of thickness for different fine- and coarse-grained lithologic materials on a cell-by-cell basis (Hanson et al., 2004). The average assigned K value was 900 ft/d for the Shallow Aquifer, 5 ft/d for the confining layer, and between 0.05 and 380 ft/d for the layers beneath the confining zone. The deepest layer was assigned the lowest K value (0.05 ft/d).

The CH2M Hill calibrated model (December 1992) had a range of K values for the Principal Aquifer from 5 ft/d near the Bay to 100 ft per day in the southern portion of the subbasin. The confining layer hydraulic conductivity was 10 ft/d and the Shallow Aquifer K value was 70 ft/d.

Production wells range in depth from 200 to 1,200 feet in the Santa Clara Subbasin (DWR, 1967). Relatively higher specific capacities are observed along the axis and in the central portions of the subbasin (100 to greater than 300 gallons per minute per foot of drawdown (gpm/ft of dd)), with lower values in the recharge area and northern portion of the subbasin (less than or equal to 10 gpm/ft of dd) (DWR, August 1967). Well yields in the valley range from 300 to 2,500 gallons per minute (gpm).

Based on age dating data, LLNL (Moran et al., 2004) provided a rough estimate of groundwater velocities in the subbasin. A rate of 1.4 ft/d was estimated in the Principal Aquifer; although, it was noted that flow rates are likely to be highly variable over short distances, and the groundwater flow velocity is likely to be highest in the Shallow Aquifer and may be significantly higher than 1.4 ft/d in the shallow sediments of the recharge area.

5.1.5 Groundwater Levels and Flow

Groundwater level declines of more than 200 feet occurred from groundwater development from the early 1900s to the mid-1960s in the Santa Clara Subbasin (Poland and Ireland, 1988). These historic water level declines induced about 12 feet of ground subsidence resulting in degradation of the aquifer adjacent to the bay from saltwater intrusion. Inelastic subsidence was effectively halted by about 1970 as a result of surface water importation to the subbasin, with residual rates decreased to 0.01 feet per year by the 1980's (Reymers and Hemmeter, July 2002). Groundwater levels have been recovering since the mid-1960s as a result of better resource management, conservation, imported water, and artificial recharge.

Currently, groundwater levels in the Shallow Aquifer range from less than 10 feet in the central and southern portions of the subbasin to greater than 100 feet along the lateral edges of the subbasin (Pierno, 1999). Groundwater levels are regularly monitored by the District. Current hydrographs of the groundwater levels for subbasin index wells can be accessed online at www.scvwd.dst.ca/gwuse/gwmimap.htm.

Groundwater in the Santa Clara Subbasin flows in the general direction of ground surface topography, towards the interior of the subbasin and northerly towards San Francisco Bay. Localized drawdown cones form near major pumping centers in the center of the subbasin primarily during the end of the major pumping season (Fostersmith and Judd, January 2005). The hydraulic gradient varies in different parts of the subbasin (Reymers and Hemmeter, July 2002; Fostersmith et al., January 2005). The steepest gradients are observed along the western boundary of the subbasin along the Santa Cruz Mountains, where hydraulic gradients vary from 0.05 to 0.07. The lowest gradients are observed in the center of the basin, where the hydraulic gradient is on the order of 0.001. Elsewhere in the subbasin, the hydraulic gradient varies from 0.005 to 0.02 with a typical hydraulic gradient of approximately 0.01. Seasonal variations in the hydraulic gradient appear to be minimal in the subbasin. The hydraulic gradient does appear to steepen along the western margin during the wetter winter and spring seasons (Reymers and Hemmeter, July 2002; Fostersmith et al., January 2005).

Water level data collected from a network of nested monitoring wells installed by the USGS in cooperation with the District indicate seasonal water level fluctuations as great as 60 feet and water level differences between aquifers as great as 10 feet (Newhouse et al., 2004, Hanson et al., 2004). Except during periods of extended drought and significantly lowered water levels in the Principal Aquifer, the vertical gradient in the confined part of the subbasin is upward. The vertical gradient in the recharge areas is downward.

5.1.6 Groundwater Age

Mean groundwater ages were calculated by the LLNL (Moran et al., 2004) and USGS (Hanson et al., September 2002) using the stable isotope oxygen-18, tritium/helium ratios, noble gas and "Excess Air" concentrations, and carbon-14 dating. The results indicate that groundwater is typically 10 to 20 years old in the southern recharge area of the subbasin. As a result, the southern recharge zone is considered highly vulnerable to the vertical transport of contamination. Wells in the confined zone exhibit relatively greater age, with age increasing to the north. Evaluation of tritium concentrations in depth-specific samples collected from nested monitoring wells and the relationship between age and top of well perforations indicate a sharp contrast in age above and below the major clay confining units. Overall, the data indicate a lack of vertical transport from the Shallow Aquifer, where contamination is widespread, to the deeper, confined Principal Aquifer. Nonetheless, the existence of a large number of lost and/or improperly sealed and destroyed wells in the subbasin provide the potential for downward migration along these vertical conduits.

5.1.7 Surface Water

5.1.7.1 Streams and Reservoirs

The two major surface water drainage systems in the Santa Clara Subbasin are the Guadalupe River and Coyote Creek and their tributaries, which drain northward into the San Francisco Bay. The Coyote Creek system originates in the Diablo Range, while the Guadalupe River system originates in the Santa Cruz Mountains. Other smaller creeks that flow from the Santa Cruz Mountains to San Francisco Bay include Stevens, Permanente, San Antonio, Matadero, and San Francisquito (SWRCB, June 1955).

The District owns and operates several surface water reservoirs within the major watersheds as summarized in Table B-1 (Black and Veatch, 2003). These surface water reservoirs are operated for storm water management and/or to capture winter watershed runoff for water supply. Only four surface water reservoirs are permitted sources of supply for the District's water treatment plants, including Anderson, Coyote, Calero, and Almaden reservoirs.

5.1.7.2 Imported Water

Water from the California State Water, Central Valley, and Hetch-Hetchy projects are imported to meet Santa Clara Valley water demands (Reymers and Hemmeter, 2002). Supplies are imported into the District's water conveyance and treatment systems from the SWP's South Bay Aqueduct and the CVP's San Felipe Project. In addition, water imported from the Hetch-Hetchy System is delivered to some cities in the northern part of the County through water retailer contracts with the City of San Francisco. This imported water supply reduces demands on groundwater in the northern portions of the subbasin; however, it is noted that several water retailers are considering increased groundwater use in the face of reduced Hetch-Hetchy deliveries.

In the early 1960s, the District contracted with the State for an entitlement of 100,000 AFY of water through the South Bay aqueduct. In 1967 the District began delivering surface water treated at the Rinconada Water Treatment Plant (WTP) to north county residents, reducing groundwater extraction and allowing for some basin recovery. Between 1960 and 1970, the county population doubled. In 1974 the Penitencia WTP began delivering treated water to some county residents, reducing demand for groundwater. In 1987 delivery of water from the CVP began, and in 1989 the Santa Teresa WTP began treating and delivering surface water.

5.1.7.3 Recharge Facilities

Groundwater recharge occurs naturally from infiltration of precipitation and runoff, and also by a variety of manmade mechanisms including in-stream and off-stream recharge facilities. The District operates a complex network of facilities to supply, treat, and distribute water to their customers. A total of 18 major manmade recharge systems exist (primarily along the Los Gatos Creek, Guadalupe River, and Coyote Creek drainages). Based on data collected between 1994 and 2006 and provided by the District, an average of approximately 80,000 AFY of water was recharged to the Santa Clara Subbasin through artificial recharge; this included 43,000 AFY through off-stream ponds and 37,000 AFY through the in-stream recharge program.

5.1.8 Groundwater Surface Water Interaction

Due to confining layers, creek and river infiltration in the central and northern part of the subbasin does not recharge the Principal Aquifer. Significant creek recharge to groundwater does occur along the west side of the subbasin near the Santa Cruz Mountains (San Francisquito, Stevens, San Tomas Aquinas, and Los Gatos creeks), south (Guadalupe River and Coyote Creek), and east (Penetencia Creek) sides of the subbasin and this water ultimately can recharge the Principal Aquifer as subsurface flow. Surface water recharge above the confined zone recharges the Shallow Aquifer and ultimately discharges to San Francisco Bay (DWR, August 1967).

5.2 Coyote Subbasin

The Coyote Subbasin is identified by DWR (2004) as part of the South Bay Area (Basin No. 2-9.02) of the Santa Clara Valley Groundwater Basin. The Coyote Subbasin is roughly 7 miles long and 2 miles wide, with a corresponding surface area of about 15 square miles. Groundwater is the sole source of drinking water supply in the Coyote Subbasin. A small amount of recycled water is used for industrial uses. As such, aggressively maintaining and protecting groundwater in the subbasin is critical to the local water supply. A groundwater divide at Cochrane Road separates northerly flow toward San Francisco Bay from water in the Llagas Subbasin which drains to the south toward the Pajaro River and eventually Monterey Bay. The actual location of the groundwater divide has historically been observed to move as much as one mile to the north or south of the designated boundary at Cochrane Road due to hydrologic conditions. The northern boundary is defined by the Coyote Narrows.

Groundwater is the sole source of drinking water supply in the Coyote Subbasin. As such, aggressively maintaining and protecting groundwater in the subbasin is critical to the local water supply. A small amount of recycled water is used for industrial purposes at the Metcalf Energy Center located in north Coyote Valley, where recycled water supplied by SBWRP is used for cooling water. The primary land uses in the subbasin are agricultural and rural residential. The Coyote Subbasin is generally unconfined and has no significant, laterally-extensive clay layers. It generally drains north into the Santa Clara Subbasin (Reymers and Hemmeter, July 2001).

The key references found for the Coyote Subbasin include the following:

- Abuye, C.W., (SCVWD), November 2005, Coyote Valley Groundwater Flow Model (CVGM)
- DWR, February 2004, California's Groundwater Bulletin 118, Santa Clara Groundwater Basin (Santa Clara Subbasin)
- DWR, May 1981, Evaluation of Ground Water Resources south San Francisco Bay, Vol. IV: South Santa Clara County Area, Bulletin 118-1
- Iwamura, T.I, 1995, Hydrogeology of the Santa Clara and Coyote Valleys Groundwater Basins, California
- Moran et al., (LLNL), July 2004, California Aquifer Susceptibility, A Contamination Vulnerability Assessment for the Santa Clara and San Mateo Groundwater Basins
- McCloskey and Finnemore, December 1996, Estimating Hydraulic Conductivities in an Alluvial Basin from Sediment Facies Models

Below is a summary of the hydrogeology of the Coyote Subbasin based on these and other cited references.

5.2.1 Geologic Structure

The Coyote Valley is a shallow, elongated northwest–southeast trending alluvial groundwater basin. The valley is bound by the Santa Cruz Mountains on the west and the Diablo Range on the east. The bedrock hills are composed of essentially non-water bearing Jurassic bedrock, which also defines the base of the groundwater subbasin. The southern boundary is defined by a groundwater divide in the vicinity of Cochrane Road. The southern boundary is defined by the Coyote Narrows, where foothills of the Santa Cruz Mountains and Diablo Range nearly merge and form a constriction to groundwater movement, and in turn separate the Coyote Subbasin from the Santa Clara Subbasin to the north (DWR, May 1981).

The northwesterly-trending Shannon Fault cuts obliquely through Coyote Valley from the eastern foothills, passes beneath Laguna Seca through the bedrock units of the Santa Cruz Mountains and continues into the Santa Clara Valley (Iwamura, 1995). It is not known if water bearing alluvial deposits in Coyote Subbasin are offset by the Shannon Fault; however, there is no evidence that groundwater flow is impacted by the fault (Iwamura, 1995). The Coyote Creek Fault runs along the east side of the basin at the range front of the Diablo Range.

5.2.2 Geologic Units

The Coyote Subbasin is bounded vertically and horizontally by the Franciscan Formation (bedrock), an assemblage of folded, faulted, and sheared marine sediments deposited during the Jura-Cretaceous period. The Franciscan Formation underlies basin fill deposits in the Coyote Subbasin and outcrops in the Santa Cruz Mountains, the central Diablo Range near Coyote Narrows, and the hills east of Coyote Creek. Due to a lack of verifiable data for the area, depth to bedrock is unconfirmed. DWR-generated contours for the bottom of basin fill sediments based on well driller's logs (DWR, 1975). The contours indicate that the elevation of the bottom of the alluvial deposits ranges from sea level to 200 feet msl. As such, the maximum thickness of basin fill sediments is approximately 390 feet. Sediments are thicker along the eastern margin of the valley due to larger stream systems in the Diablo Range.

Basin fill deposits in the Coyote Subbasin include the Santa Clara Formation and overlying alluvial deposits. The Santa Clara Formation is exposed in the hills on the east side of Coyote Valley, and overlies the Franciscan Formation in much of the Coyote Subbasin. It is a major water-bearing formation that is possibly tapped by deeper wells in subbasin. It is comprised of semi-consolidated silt, clay, and sand with some zones of gravel, and may be inter-bedded with volcanic rocks in places. The Santa Clara Formation is considered to be less than 100 feet thick throughout the subbasin (Iwamura, 1995). It difficult to differentiate the Santa Clara Formation from overlying alluvium based on driller's logs.

Alluvial fans that overly the Franciscan and Santa Clara formations are a heterogeneous mix of unconsolidated to semi-consolidated clay, silt, and sand, with some gravel lenses. Older and younger alluvium overly alluvial fans and older deposits, and are estimated at up to 125 and 100 feet thick, respectively. Both units are comprised of unconsolidated floodplain deposits of silt, sand, and clay, with sandy gravel deposits occurring in areas of ancient stream channels. Older alluvium is distinguished from younger alluvium by its dense clayey character, which has low recharge potential and retards vertical flow. Within the alluvial deposits in the Coyote Subbasin are two networks of interconnected buried stream channels left behind by the ancient Coyote Creek. The older network is found below sea level and follows the path of a southward flowing Coyote Creek; while the upper system is found above sea level and follows a later, northward flowing Coyote Creek (Iwamura, 1995). Fluvial deposits dominate the central and western sections of the valley overlying the Franciscan Formation. Layers of alluvial sediments dominate the eastern edge of the subbasin along the Diablo Range. Deposits include sheet and debris flows and braided stream channels (McClosky and Finnemore, 1996).

The maximum thickness of the water bearing deposits is about 500 feet at the southern topographic divide and up to about 150 feet at the Coyote Narrows.

The valley floor is largely comprised of permeable sediments that allow for infiltration of precipitation into the deeper water bearing layers. However, permeability throughout Coyote Valley is non-uniform, and certain locations provide more natural groundwater recharge than others.

5.2.3 Groundwater Occurrence

Unlike portions of the Santa Clara and Llagas subbasins, no significant laterally extensive clay layers exist in the Coyote Subbasin. As a result, groundwater generally occurs under unconfined conditions in the younger alluvium and under unconfined to semi-confined conditions in the older alluvium (i.e., Santa Clara Formation). Historically, low-lying areas in the north and western portions of the Coyote Valley have experienced drainage difficulties due to high groundwater conditions at the Coyote Narrows. Perched groundwater occurs in these areas as a result of shallow, discontinuous clay deposits. The perched groundwater tends to impact low-lying areas, including the Coyote Recharge Ponds just north of the Coyote Subbasin (City of San Jose, 2007).

The direction of groundwater flow through Coyote Subbasin is to the north to northwest towards the Coyote Narrows, where groundwater exits the subbasin and enters the Santa Clara Subbasin as subsurface flow. Groundwater converges near the Coyote Narrows, where it naturally begins to rise near the ground surface. Due to the moderate to high permeability of the water bearing alluvial fill, groundwater levels are highly responsive to the volume of runoff in streams (Iwamura, 1995).

The Coyote Subbasin abuts the Llagas Subbasin in the south. The Coyote and Llagas subbasins are hydraulically separated from each other by the groundwater divide along the axis of the Coyote Fan in the vicinity of Cochrane Road (DWR, February 2004).

5.2.4 Aquifer and Vadose Zone Properties

Aquifer properties were obtained from 11 pumping tests conducted in the subbasin. The data indicate that K values vary across the basin, ranging from 5.4 to 570 ft/d (McCloskey and Finnemore, December 1996). Higher K values are estimated in the northwest corner of the subbasin, while lower K values were estimated in the southwest corner of the subbasin (Iwamura, 1995; Abuye, November 2005). Estimated K values for the Santa Clara Formation are significantly lower than for overlying alluvium (McCloskey and Finnemore, December 1996). Using a hydraulic gradient of 0.002 (Fostersmith, et al, January 2005), a hydraulic conductivity of 100 ft/d, and an effective porosity of 0.08 (DWR, May 1981; Abuye, November 2005) yields a groundwater velocity of 2.5 ft/d.

Vadose zone materials consist of high permeable sands and gravels in the eastern portion of the valley and low permeable silts and clays to the west (Abuye, 2005).

5.2.5 Groundwater Levels and Flow

Groundwater elevations in the Coyote Subbasin range from 330 feet msl in the northern portion of the valley to 220 feet msl near the Coyote Narrows. Depth to groundwater ranges from about 75 feet in the south to less than 5 feet in the north near the Coyote Narrows and is commonly less than 20 feet throughout the subbasin (Pierno, 1999).

The hydraulic gradient ranges from 0.001 to 0.004 based on groundwater elevation maps constructed for the subbasin. The average hydraulic gradient for the Coyote Subbasin is approximately 0.0025 (Reymers and Hemmeter, July 2002). Groundwater elevations in the Coyote Narrows are controlled by discharge to surface water features and do not vary much seasonally. The hydraulic gradient is slightly steeper during periods of high groundwater levels, which typically occur in the winter and spring.

The District maintains groundwater elevation data for monitoring wells in the Coyote Subbasin dating back to 1937. Most monitored wells are production wells screened at multiple depths. As a result, groundwater elevation data represent average elevations in the various water bearing formations. Three index wells are used to represent general groundwater level data for the subbasin (Fostersmith et al., January 2005). While groundwater levels in the Coyote Subbasin have remained relatively stable over time, water levels do respond quickly to changes in circumstances and precipitation. Groundwater levels are significantly higher in the spring compared with the fall as a result of increased precipitation in the winter and increased agricultural pumping in the summer (Fostersmith et al., January 2005).

Groundwater is the sole source of drinking water supply in the subbasin. Groundwater production in the Coyote Subbasin is primarily from domestic and agricultural wells. Although, the installation and operation of several large retailer wells has resulted in a significant increase in groundwater pumping over the past several years.

5.2.6 Groundwater Age

Analysis of tritium-helium isotopes determined a mean groundwater age range between 13 and 21 years, along Coyote Creek, indicating recent recharge (Carle et al., 2004).

5.2.7 Surface Water

5.2.7.1 Streams and Reservoirs

Coyote Creek is the major surface water drainage in the Coyote Subbasin. Originating in the Diablo Range, Coyote Creek enters the Coyote Valley at its southeastern end and flows northwesterly along the northeast side of the Coyote Subbasin, through the Coyote Narrows and Santa Clara Valley, before discharging to San Francisco Bay. Coyote Creek flow is regulated by releases upstream from the Coyote and Anderson reservoirs. Leakage of surface water through the bottom of Coyote Creek is the principal source of recharge to the Coyote Subbasin (DWR, May 1981). Small tributaries drain the west side of the subbasin into Fisher Creek, which enters Coyote Creek just before the narrows.

The Coyote Canal is located to the east of Coyote Creek and parallels Highway 101. This facility was built to manage water resources in the valley. Historically, the canal conveyed water around the Coyote Creek recharge area between Highway 101 and the Coyote Creek Golf Course, mitigating high groundwater levels in this area (McCloskey and Finnemore, December 1996).

The Coyote and Anderson reservoirs are located to the east of the Coyote Subbasin in the Diablo Range and have capacities of 22,925 and 89,073 AF, respectively (SCVWD, January 2007). The Coyote Reservoir is upstream of and releases water to the Anderson Reservoir. The Anderson Reservoir can also receive imported water from the San Luis Reservoir through the Santa Clara Conduit and the Anderson Force Main (SCVWD, January 2007). Surface water released from the Anderson-Coyote Reservoir is recharged within Coyote Creek for groundwater recharge. Water from the Anderson/Coyote

Reservoir can also be delivered to the District's water treatment plants for subsequent distribution to water retailers and individual user.

5.2.7.2 Recharge Facilities

Historically, the Coyote Canal has been used to manage groundwater in the Coyote Subbasin and prevent the loss of water supplies upstream of the Metcalf Percolation Ponds and the Santa Clara Subbasin (Iwamura, 1995); although it is no longer in use.

Groundwater recharge is regulated by releases from the Coyote and Anderson reservoirs into Coyote Creek. Between 1994 and 2006, the average groundwater recharge from upper Coyote Creek in the Coyote Subbasin was 9,171 AFY.

5.2.7.3 Groundwater Surface Water Interaction

Upstream of the Coyote Creek Golf Course, Coyote Creek is a losing stream and recharges groundwater. Groundwater flows from Coyote Creek toward Fisher Creek to the west and north. The subbasin narrows and thins near the Coyote Narrows, causing groundwater to discharge to Coyote Creek in this area.

Prior to the installation of an artificial drain system in the Laguna Seca area, part of the subsurface flow would discharge to the surface at Laguna Seca, creating a swampy condition as it overflowed into Coyote Creek.

5.3 Llagas Subbasin

The Llagas Subbasin extends in the north from about Cochrane Road to the Santa Clara/San Benito county line at the Pajaro River in the south. The Llagas Subbasin abuts the Coyote Subbasin on the north and the Bolsa Subbasin of San Benito County in the south. The Llagas and Bolsa subbasins comprise the Gilroy-Hollister Valley Groundwater Basin. Surface water and groundwater in the subbasin flows south toward the Pajaro River. Surface water and groundwater north of the Coyote/Llagas subbasin divide flows north toward San Francisco Bay.

The Llagas Subbasin is approximately 14 miles long, 3 miles wide along its northern boundary, and 6 miles wide along the Pajaro River. The surface area of the subbasin is approximately 67 square miles (CH2M HILL, May 2005). The northern and central part of the subbasin is unconfined to semi-confined. Confining layers become more frequent and laterally extensive in the southern portion of the subbasin, where confined conditions exist.

Groundwater is the sole source of drinking water supply in the Llagas Subbasin. A small amount of recycled water is used for irrigation and industrial uses. In addition, some local reservoir water has been used for irrigation historically. As such, aggressively maintaining and protecting groundwater in the subbasin is critical to the local water supply. Based on the Santa Clara County 1995 General Plan, the Llagas Subbasin was 40 percent agricultural, 25 percent urban, 20 percent rural, 10 percent mixed use, and 5 percent open space. There has been an ongoing conversion of agricultural land to urban use in the subbasin over the past 30 years (LLNL, July 2005; CH2M HILL, May 2005). Residential and commercial development in the subbasin is focused in the City of Morgan Hill in the north and the City of Gilroy in the south, where water is supplied through large municipal wells operated by the cities. The central portion of the subbasin in the vicinity of San Martin is comprised dominantly of agricultural development and large (five to ten acre) residential parcels with individual agricultural and domestic wells.

Important references and sources of hydrogeologic information for the Llagas Subbasin include:

- Abuye, C.W., September 2003, Llagas Subbasin Conceptual Hydrogeologic Model, Draft Summary, Hydrogeologic and Geologic Data for the Development of Conceptual Hydrogeology Model of Llagas Subbasin
- CH2M HILL, May 2005, Llagas Basin Numerical Groundwater Model
- DWR, May 1981, Evaluation of Groundwater Resources South San Francisco Bay, Vol. IV: South Santa Clara County Area, Bulletin 118-1
- LLNL, July 2005, California GAMA Program: Sources and Transport of Nitrate in Shallow Groundwater in the Llagas Basin of Santa Clara County, California
- MACTEC, August 3, 2007, Llagas Subbasin Groundwater Model Development, Santa Clara County, Olin/Standard Fusee, Morgan Hill, California
- MACTEC, January 30, 2008, Llagas Subbasin Characterization – 2007, Santa Clara County, Olin/Standard Fusee Site, Morgan Hill, California

5.3.1 Geologic Structure

The Llagas Subbasin is a northwest-trending depression bounded by the Diablo Range on the east and the Santa Cruz Mountains on the west. The Diablo Range rises steeply to elevations over 3,000 feet msl. The Santa Cruz Mountains rise more gently to attain similar elevations. The ground surface of the subbasin slopes from northeast to southwest. Elevations on the northeast side of the basin are highest, approximately 475 feet msl, where alluvial deposits of Coyote Creek form a fan or cone adjacent to the Diablo Range foothills. The Coyote Fan forms the surface water and groundwater divide between the Llagas Subbasin and the Coyote Subbasin to the north. The Llagas Subbasin floor is relatively flat and slopes gradually down to about 115 feet msl on the southwest side of the subbasin where the Pajaro River leaves the valley.

A number of faults have been mapped in the vicinity of the subbasin including the Calaveras, Coyote Creek, and Chesbro faults. The faults displace older formations but are not thought to affect general groundwater flow within the subbasin (DWR, 1981). These faults were formed by regional transverse compressional forces that uplifted bedrock units east and west of the valley floor. Alluvial sediments were subsequently deposited in the structural low of the valley forming the groundwater basin.

5.3.2 Geologic Units

Geologic formations in the subbasin can be divided into water-bearing and non-water bearing. Non-water bearing formations transmit only limited quantities of water and include the mountainous areas to the east and west and the basement complex beneath the subbasin (Iwamura, May 1995). Bedrock of the Franciscan Formation, Great Valley Sequence, Temblor Formation, and Purisima Formation is exposed or underlies portions of the Diablo Range and Santa Cruz Mountains. With the exception of the Purisima Formation, these units are considered essentially non-water bearing (DWR, 1981).

The primary water bearing units that constitute the groundwater subbasin include Holocene age poorly consolidated to unconsolidated alluvial fan deposits, young and old alluvium, and stream channel and overbank deposits. Groundwater also occurs in the underlying consolidated Plio-Pleistocene age Santa Clara Formation. The alluvial deposits are heterogeneous mixtures of interbedded gravel, sand, silt, and clay. Relatively coarser-grained paleochannels were deposited at depth by the ancestral Coyote Creek, which at one time entered the subbasin near the Anderson Reservoir Dam and flowed south to the Pajaro River (DWR, 1981). These channels provide preferential pathways for groundwater flow (DWR, 1981; MACTEC, January 2008). The Santa Clara Formation is comprised of interbedded silt, clay, sand, and some gravel zones. Because the Santa Clara Formation is consolidated and has a higher clay content than the alluvium, hydraulic conductivities are thought to be lower than in the overlying alluvium (CH2M HILL, May 2008). The Santa Clara Formation is similar in composition to the overlying alluvial deposits, and it is difficult to differentiate the units on available well logs (DWR, 1981).

The alluvial fan deposits are derived from the erosion of the bordering mountains. The stream deposits derive mainly from Coyote Creek, which formerly drained southward through the valley and Uvas and Llagas creeks.

The contact between the base of alluvial materials and underlying bedrock dips inward from the east and west toward the axis of the subbasin and reaches maximum thicknesses at the southern extent of the subbasin (DWR, 1981). Depths to bedrock in the center of the basin in the Morgan Hill area are as much as 650 feet. Further south, east of Gilroy, the water-bearing formations (Santa Clara and valley fill) reach thicknesses over 950 feet. The unconsolidated alluvium is as much as 500 feet thick in the southern part of the subbasin (CH2M HILL, May 2005). Regional, hydrogeologic cross sections indicate that the alluvial materials form locally continuous layers and dip to the south (MACTEC, January, 2008 and DWR, 1981).

South Santa Clara Valley and north Hollister Valley are thought to have been the site of at least two large lakes (Lake San Benito and Lake San Juan) during the last 10,000 years. These lakes deposited significant amounts of fine-grained silts and clays, which form confining layers within the subbasin. The fine-grained lacustrine deposits extend as far north as San Martin Avenue and thicken toward the south beneath the Pajaro River (DWR, 1981). These fine-grained deposits account for the confined conditions observed in the southern portion of the subbasin.

5.3.3 Groundwater Occurrence

The Llagas Subbasin is part of the larger Gilroy-Hollister Groundwater Basin, which includes the Bolsa Subbasin to the south. The Llagas and Bolsa subbasins are in hydraulic communication. The Llagas Subbasin abuts the Coyote Subbasin on the north. The Llagas and Coyote subbasins are hydraulically separated from each other by the groundwater divide along the axis of the Coyote Fan in the vicinity of Cochrane Road (DWR, February 2004).

Groundwater in the Llagas Subbasin occurs primarily in alluvial deposits of the Santa Clara Formation and valley fill materials (DWR, 1981). The water-bearing sediments occur in discontinuous and heterogeneous lenses that do not form well-defined laterally continuous layers. Nonetheless, MACTEC has divided the subbasin into shallow, intermediate, and deep aquifer zones, which are helpful in describing differences in hydrogeolgic conditions with depth (January 2008). The paleochannels deposited by the ancestral Coyote Creek provide preferential pathways for groundwater flow. Paleochannels exist in the intermediate and deep aquifers and are thicker and more coarse-grained along the axis of the subbasin east of Highway 101. Most domestic supply wells in the basin penetrate the intermediate aquifer, while municipal wells intersect the intermediate and deep aquifers.

Groundwater in most of the Llagas Subbasin occurs under unconfined to semi-confined conditions. Due to the lenticular and discontinuous distribution of fine- and coarse-grained materials, local areas of confinement occur throughout the subbasin. Toward the south end of the subbasin, confining layers become more frequent and laterally and vertically extensive. Thus in the vicinity of the Pajaro River the aquifer system is mostly confined (DWR, 1981).

DWR has noted that the degree of confinement varies with changing recharge conditions and pumping in the subbasin. The vertical movement of groundwater appears to be restricted in periods of heavy pumping or drought when water levels are below confining units. During wet years and periods of reduced pumping, groundwater levels recover to nearly the same level in all wells in the local area (DWR, 1981).

5.3.4 Aquifer and Vadose Zone Properties

Review of the available references show that data from only two constant rate pumping tests in production wells were available in the Llagas Subbasin. Pumping, slug, and core tests were conducted as part of environmental investigations at the Olin facility. In addition to pumping, slug, and core testing, well specific capacity data were used to estimate T values using the following empirical equation (Driscoll, 1989):

$$T = [(Q \div dd) \times 1{,}500 \text{ (unconfined) or } 2{,}000 \text{ (confined)}] \div \text{well efficiency}$$

where, T = aquifer transmissivity, in gpd/ft^2
Q = well discharge, in gpm
dd = water level drawdown, in feet

Specific capacity data presented for municipal production wells operated by the cities of Morgan Hill and Gilroy, and other larger production wells between Morgan Hill and Gilroy were compiled to estimate T values using Driscoll's empirical method.

Specific capacities and estimated T and K values are lower in the northern part of the subbasin compared with the southern portion of the subbasin. K values in the northern part of the basin range from about 4 to 133 ft/d, with an average of 39 ft/d. K values in the middle part of the basin range from about 6 to 457 ft/d, with an average of 100 ft/d. K values in the southern part of the basin range from about 25 to 350 ft/d, with an average of 131 ft/d.

Data collected as part of investigations of perchlorate contamination in the subbasin show that K values in the shallow and intermediate aquifer zones are generally greater than 100 ft/d and are much higher than estimated K values for the deep aquifer zone, which are generally less than 10 ft/d. Buried, relatively coarser-grained, paleochannel deposits associated with the ancestral Coyote Creek represent preferential pathways for groundwater flow (MACTEC, January 2008). Relatively higher K values are found along the axis of the subbasin east of Highway 101 in the intermediate and deep aquifer zones (MACTEC, January 2008; Lurhdorf & Scalmanini, March 2003).

Well yields are also reportedly lower in production wells in the northern portion of the subbasin compared with the southern portion of the subbasin. Yields from Morgan Hill production wells range from about 200 to 1,500 gpm, whereas yields from Gilroy production wells range from about 1,200 to 3,000 gpm (Fugro, February 2004). Well yields are higher along the axis of the subbasin where saturated thicknesses are greater (Fugro, February 2004).

Groundwater velocities are higher in the shallow and intermediate zones compared with the deep zone. Estimated shallow zone groundwater velocities range from 0.8 to 4.7 ft/d; intermediate zone velocities range from 0.2 to 8 ft/d; and deep zone velocities range from 0.04 to 0.7 ft/d. Based on tritium/helium ratios, shallow groundwater velocities have been estimated at 3.5 to 16 ft/d, while vertical groundwater velocities in the shallow zone have been estimated at 0.0145 to 0.0178 ft/d (LLNL, July 2005).

5.3.5 Groundwater Levels and Flow

The District monitors groundwater levels in a network of wells in the County and prepares water level contour maps. However, because most of the monitored wells are production wells, which are pumped on a regular basis and may screen more than one water-bearing zone, the maps are general in nature and may not be representative of local flow conditions. Nonetheless, they generally illustrate groundwater flow in the subbasin and changes in flow patterns over time.

Under natural conditions, groundwater in the Llagas Subbasin moves from the boundary with the Coyote Subbasin in the north to the southeast toward the Pajaro River, roughly in the same direction as the surface water drainage. Groundwater is thought to flow south beneath the Pajaro River toward pumping depressions in the Bolsa Subbasin (Yates, December, 2002).

Spatially-varying recharge and discharge can locally modify the regional southeasterly groundwater flow pattern (e.g., pumping depressions form around production wells, and groundwater mounds form around recharge areas). These local flow conditions are evident on the District groundwater level contour map. Between 1950 and 1999, the horizontal hydraulic gradient in the subbasin varied from 0.002 to 0.003 feet/feet to the southeast with an average gradient of 0.0026. From 1996 to 1998, when groundwater levels where relatively steady and high, the average horizontal hydraulic gradient in the northern part of the subbasin was 0.005 and 0.002 in the vicinity of Gilroy (CH2M HILL, May 2005).

Depth to groundwater in an index well in the subbasin has varied from approximately 10 to over 100 feet over the period of record (1969 to 2003) (Reymers and Hemmeter, July

2002 and January 2005). Depth to groundwater varies seasonally in response to precipitation patterns and over the long-term in response to prolonged drought and wet periods. The District's index well located near Church Avenue shows seasonal fluctuation in water levels between about 15 and 40 feet; long-term variations in the well have been as much as 100 feet (Reymers and Hemmeter, July 2002 and January 2005). City of Gilroy production wells show similar seasonal groundwater elevation fluctuations from approximately 20 to 40 feet (Fugro, February 2004).

5.3.6 Groundwater Age

Evaluation of tritium/helium ratios suggests a dynamic shallow groundwater flow system with significant recharge and relatively high groundwater velocities over a large part of the subbasin. Accordingly, LLNL (July 2005) concluded that the Llagas Subbasin is highly vulnerable to contamination. Wells along Uvas Creek, the subbasin margins, and near recharge facilities have groundwater less than three years old. Shallow ports of nested wells in the southern confined portion of the basin also have very young groundwater. Groundwater in the deep aquifer zone is greater than 50 years old.

5.3.7 Surface Water

5.3.7.1 Streams and Reservoirs

The Llagas Subbasin is an inland valley that is drained to the south by tributaries of the Pajaro River, which include Llagas Creek, the West Fork of Llagas Creek, Little Llagas Creek and Uvas Creek. Uvas, Llagas, Little Llagas, and West Branch Llagas creeks enter the valley from the Santa Cruz Mountains on the west. Nearly all of the Diablo Range east of the subbasin is part of the Coyote Creek catchment, which drains northward through the Coyote Subbasin. Thus, on the east side of the Llagas Subbasin, only the immediate range front drains directly into the subbasin via small tributaries of Llagas Creek. The Pajaro River flows westerly along the subbasin's southern boundary and discharges to Monterey Bay.

Examination of well logs indicate that the Coyote Creek flowed southward through the subbasin prior to about 15,000 years ago. The present position of Coyote Creek, immediately against the faulted Diablo range front in the Coyote Subbasin, suggests that a switch from southerly to northerly flow may have been caused by down-warping along the Diablo range front fault segment (Blair, December 2007).

In the vicinity of the Llagas Subbasin, local runoff is captured in the Chesbro, Uvas, Coyote, and Anderson reservoirs. The Coyote and Anderson reservoirs are located to the east and northeast of the subbasin in the Diablo Range and have capacities of 22,925 and 89,073 AF, respectively (SCVWD, January 2007). The Coyote Reservoir is upstream of and releases water to the Anderson Reservoir. The Anderson Reservoir can also receive imported water from the San Luis Reservoir through the Santa Clara Conduit and the Anderson Force Main (SCVWD, January 2007). The Chesbro and Uvas reservoirs are located in the Santa Cruz Mountains west of the subbasin and have maximum capacities of 8,952 and 9,935 AF, respectively. Surface water released from Uvas, Chesbro, and Anderson-Coyote reservoirs is recharged within creeks and off-stream percolation ponds for groundwater recharge. Water from the Anderson/Coyote Reservoir can also be delivered to the District's water treatment plants for subsequent distribution to water retailers and individual users.

5.3.7.2 Recharge Facilities

A number of artificial recharge facilities have been constructed and are operated by the District to enhance recharge in the subbasin and augment local supplies. These facilities include four off-stream percolation facilities (Main Avenue, San Pedro, and Church Avenue Ponds, and, Madrone Channel) and in-stream facilities along Tennant, Llagas, and Uvas creeks. The Main Avenue Ponds have an area of 6 acres, were constructed in 1955, and recharged an average of about 1,800 AFY between 1994 and 2006. Recharge volumes vary seasonally and from year to year based on available local and imported water supplies and the District's operational considerations. The Madrone Channel is 6.5 acres in area, was constructed in 1975, and has recharged approximately 5,300 AFY (1994-2006). The San Pedro Ponds are 20 acres in area, were constructed in 1990, and recharged about 2,400 AFY (1994-2006). The Church Avenue Ponds are 35 acres in area, were constructed between 1977 and 1979, and recharged 1,200 AFY (1994-2006). In-stream recharge along Tennant, Llagas, and Uvas creeks was about 70, 4,000, and 6,800 AFY, respectively from 1994 to 2006. The source of recharge water in the Church Avenue Ponds is precipitation and stream flow originating from local runoff and releases from the Chesbro and Uvas reservoirs. The main source of recharge in the Main Avenue, San Pedro, and Madrone ponds is imported water, with local runoff contributing some flow. Prior to about 1987, some surface water from the Coyote/Anderson Reservoir was also recharged in the Main and Madrone ponds via a pipeline. Currently, water from the Coyote/Anderson Reservoir is moved to the north as supply and for recharge in the Coyote Subbasin and northern Santa Clara County. Between 1994 and 2006, groundwater recharge from the various facilities in the Llagas Subbasin has averaged about 22,000 AFY.

The significant recharge operations in the Llagas Subbasin serve to reduce nitrate and perchlorate contamination via dilution/mixing with imported and local water (LLNL, July 2005; MACTEC, January 2007).

5.3.8 Groundwater Surface Water Interaction

Groundwater levels are below the base of the creeks throughout most of the Llagas Subbasin except in the very southwest corner of the subbasin beneath the Pajaro River or during periods of elevated groundwater levels during the wet season.

6 Water Quality

Groundwater quality is controlled by natural interactions between rock minerals and water infiltrating into the subsurface. Naturally occurring contaminants are present in rocks and sediments, and when dissolved may be found in high concentrations in groundwater. Anthropogenic (man-made) chemicals released into the environment, including fertilizers, industrial solvents, and fuel-related products, may also affect groundwater quality. Contaminants from leaking fuel tanks or toxic chemical spills may enter the groundwater and contaminate the aquifer, while pesticides and fertilizers applied to lawns and crops can accumulate and migrate to the water table.

The District Board Ends Policy directs staff to ensure that the groundwater subbasins are aggressively protected from contamination and the threat of contamination. In cooperation with local water retailers, the RWQCBs, and other agencies, the District has implemented numerous groundwater quality protection programs to monitor general groundwater quality and address specific issues, including those related to nitrate, saltwater intrusion, well construction and destruction, wellhead protection, LUST systems, spills and releases of solvents and other toxic chemicals, and land use and development review. Together, these activities help the District identify existing and potential groundwater quality issues and prevent and mitigate groundwater contamination. This section describes the District and other water quality monitoring and management programs and summarizes the available water quality data for each of the three subbasins relevant to the Groundwater Vulnerability Study.

6.1 Recharge Water Monitoring

The District's sources of recharge water include imported water and local reservoirs. These waters are susceptible to potential contamination from a variety of land use practices, such as agricultural and urban runoff, recreational activities, historic mining practices, livestock grazing, commercial stables, residential and industrial development, industrial contamination, septic systems, and sewage spills (SCVWD, January 2007). The imported sources are also at risk from wastewater treatment plant discharges, seawater intrusion, and wild land fires in open space areas (SCVWD, December 2002).

The District recently developed a recharge water quality monitoring program at 11 recharge facilities in the County (Barrientos, December 1, 2008) and initiated implementation of the program in 2009.

The District does not routinely monitor water quality in local reservoirs used solely for groundwater recharge, but does regularly monitor drinking water reservoirs that provide water to the District's water treatment plants for sale to retailers. Since the early 1970's, the District has regularly monitored drinking water reservoir and imported water quality. Water supply reservoirs include Anderson, Coyote, Calero and Almaden. Sampling in 2003 showed that all results met maximum contaminant limit (MCL) standards for drinking water (Barrientos, May 2005). The 2001-2005 watershed survey for the drinking water reservoirs found overall good water quality (SCVWD, January 2007). The Stevens Creek Reservoir was also monitored in February 2002 and no evidence of problems with priority pollutants was found (Barrientos, May 2005). Given these results, it is likely that other local reservoirs also provide acceptable water quality.

It is noted that both LLNL and MACTEC have concluded that recharge water appears to dilute the man-made nitrate and perchlorate plumes in the Llagas Subbasin (LLNL, July 2005; MACTEC, January 2008).

6.2 Recycled Water Monitoring

The District has a policy to expand water recycling in Santa Clara County in order to provide a more reliable water supply to its residents. The District's targets for water recycling in the County are 5 and 10 percent of total water use by 2010 and 2020, respectively. Currently, four tertiary wastewater treatment plants (WWTPs) provide disinfected tertiary treated recycled water that meets the water quality requirements under DPH Title 22, Article 3, Permitted Uses of Recycled Water for unrestricted body contact. The WWTPs include the San Jose/Santa Clara Water Pollution Control Plant, Sunnyvale Water Quality Control Plant, Palo Alto Regional Water Quality Control Plant, and South County Regional Water Authority (SCRWA) Plant.

The San Jose/Santa Clara Water Pollution Control Plant provides water for the South Bay Water Recycling Program (SBWRP) which was initiated in 1997 to deliver recycled water to the cities of Milpitas, Santa Clara, and San Jose for landscaping, playing fields, golf courses, cemeteries, industrial processing, dual-plumbing, agriculture and other non-potable uses. Recycled water is provided to users by the City of Milpitas, City of Santa Clara, San Jose Water Company, and San Jose Municipal Water System. Currently, there are approximately 100 miles of recycled water pipelines, of which about 75 percent is located in the confined portion of the Santa Clara Subbasin, with the remaining 25 percent located in the southern unconfined portion of the subbasin (Evergreen area of San Jose). Total SBWRP water use was 8,000 AFY in 2006.

Water quality data for SBWRP water has been monitored at the San Jose/Santa Clara Water Pollution Control Plant since 1997 for various inorganic parameters, including major and minor ions and general physical parameters. Prior to initiation of recycled water irrigation, the City of San Jose developed the Groundwater Monitoring and Mitigation Program (GMMP), and began monitoring groundwater quality. The purpose of the GMMP is to monitor and evaluate chemical quality of groundwater in the Santa Clara Subbasin to ensure it is not adversely impacted as a result of irrigating with recycled water. The monitoring program includes sampling of 12 groundwater monitoring and supply wells and analysis of 15 chemicals considered to be geochemical indicators of recycled water.

As of 2002, the Sunnyvale Water Quality Control Plant produced 600 AFY of recycled water primarily for urban landscape irrigation and, to a much lesser extent, industrial uses. The Palo Alto Regional Water Quality Control Plant produced 100 AFY for golf course irrigation.

The SCRWA operates a recycled water system that currently recycles up to three million gallons of water, which is distributed to five customers for irrigation in the area south of the City of Gilroy (Carollo, December 2005).

The District has assessed the feasibility and need for providing higher quality recycled water in the County than is currently available for a variety of enhancement uses, including large landscape and agricultural irrigation, industrial and environmental uses, and for augmenting both potable and non-potable water supplies (Black and Veatch, 2003). Water quality constituents of concern related to recycled water application include nitrate, total organic carbon, disinfection byproducts (DBPs) (e.g., total trihalomethanes and haloacetics acids), and unregulated emerging contaminants (e.g., NDMA and pharmaceuticals). As part of the assessment, the vulnerability of each groundwater subbasin to potential water quality degradation for various recycled water applications was evaluated. The primary factors on which the evaluation was based included the existing groundwater quality; the depth to groundwater and the capacity for contaminant attenuation in the subsurface; the presence of a clay aquitard separating the local aquifer into confined and unconfined zones; and the potential end users above each subbasin. Findings indicate that the area most sensitive to water quality degradation from recycled water applications is the Coyote Subbasin, followed by the unconfined zones of the Santa Clara and Llagas subbasins. The two least sensitive are the confined zones of the Santa Clara and Llagas subbasins.

6.3 Groundwater Monitoring

6.3.1 General Groundwater Quality Monitoring

A primary responsibility of the District is to ensure that overall water quality objectives are met for all beneficial uses (including municipal, domestic, agricultural, industrial service, and industrial process water supply uses) as designated by the RWQCBs. Through its General Groundwater Quality Monitoring Program (GGQMP), the District monitors groundwater quality across each of the three subbasins to assess current conditions, evaluate trends, and identify areas of concern. The monitoring program also provides an indication of the effectiveness of various groundwater protection programs implemented by the District and others.

The District monitors groundwater quality in a number of wells in the Santa Clara, Coyote, and Llagas subbasins. Most of the monitoring wells are screened in the deeper Principal Aquifer (i.e., the zone tapped by water supply wells), with a smaller number of the wells having a top of screen depth less than 100 feet below ground surface. As such, the monitoring well network is not designed to track shallow groundwater contamination in the Shallow Aquifer (i.e., the zone above confining layers) associated with chemical releases from regulated environmental facilities. GGQMP wells are analyzed for major and minor ions, nitrate, general physical parameters, DBPs, radiological constituents, volatile organic chemicals (VOCs) and synthetic (non-volatile) organic chemicals (SOCs). Included in the monitoring program are eight nested monitoring wells installed as part of a cooperative study between the USGS and the District from 1999 to 2003 at strategic locations in the Santa Clara Subbasin. The nested wells were completed to a maximum depth of 1,000 feet at seven sites and 1,300 feet at one site allowing for depth-discrete water quality sampling. The District also monitors several well pairs in the Llagas Subbasin.

The District has also performed an extensive well testing program for nitrate in the Llagas Subbasin. In 1988 and 1998, the District sampled over 450 and 600 private domestic wells for nitrate, respectively. Since 1998, the District has offered a free nitrate analysis to all private water supply well users. More than half of the 600 wells tested have exceeded the MCL for nitrate.

The District's water quality monitoring program is supplemented with groundwater quality data received from the DPH for approximately 300 public water supply wells submitted by water retailers to comply with their Title 22 requirements.

The SWRCB sponsors the GAMA Program, which has collected water quality data in Santa Clara County and across the state.

The District works with the CRWQCB through their stakeholder process regarding the Olin/Standard Fusee (Olin) contaminant release site. Publicly available groundwater quality data collected to characterize the extensive perchlorate plume in the Llagas Subbasin were obtained. The Olin database includes perchlorate data for numerous private domestic and shallow monitoring wells outside of the District's general water quality monitoring well network.

Water quality data (collected through 2007), obtained from the District, DPH, GAMA Program, and Olin, have been incorporated into a single Microsoft Access™ database. Data were carefully reviewed to identify duplicate and anomalous analytical results and these were removed as necessary. A summary of available general water quality data is provided in Table B-2. The table shows the total number of wells that have been sampled for each respective Title 22 constituent and the number of wells that detected and/or exceeded the MCL at least once by constituent. Further discussion of water quality conditions for each subbasin are provided in Section 6.5 through 6.7.

6.3.1 GAMA Program

The Ambient GAMA Program, sponsored by the SWRCB, aims to assess water quality and to predict relative susceptibility of groundwater resources to contamination throughout the state of California. The USGS and the Lawrence Berkeley National Laboratory (LLNL) have conducted three GAMA Program studies in Santa Clara County.

The first study, conducted in 2001 and 2002, was an assessment of the relative vulnerability of groundwater used for public water supply to contamination from surface sources in San Mateo and Santa Clara counties (Moran, et al., 2004). The study sampled wells for ultra low-level VOCs and groundwater age (using tritium-helium-3 method) to help define the flow field of the groundwater subbasins, and indicate the degree of vertical connection between near-surface sources of contamination, and deeper production zone groundwater. A total of 262 samples at 173 wells in Santa Clara County.

The second study, in the Llagas Subbasin, was conducted to identify the main source(s) of nitrate, determine whether denitrification is acting to reduce nitrate levels, and evaluate the impacts of the District's Nitrate Management Plan implementation on nitrate concentrations (LLNL, July, 2005). A total of 56 wells were sampled for major anions and cations, nitrogen and oxygen isotopes of nitrate, dissolved excess nitrogen, tritium and groundwater age, and trace organic compounds.

The third study, conducted in 2007, was designed to provide a spatially unbiased assessment of groundwater quality, as well as a statistically consistent basis for comparing water quality throughout California. A total of 79 wells in San Francisco, San Mateo, Santa Clara, and Alameda counties were sampled as part of the study (Ray et al., 2009). Groundwater samples were analyzed for low-level VOCs, pesticides, pharmaceutical compounds, wastewater indicators, perchlorate, N-nitrosodimethylamine, naturally occurring inorganic constituents, radioactive constituents, naturally occurring isotopes, and dissolved gases. At the time of this report, the study was under review by the District and accordingly, the data results were not incorporated into the project water quality database.

6.3.2 Monitoring of Regulated Environmental Facilities

The SWRCB tracks regulatory data about LUST; Spills, Leaks, Investigations, and Cleanup (SLIC); Department of Defense (DoD); and Landfill sites. In September 2004, the SWRCB adopted regulations requiring Electronic Submittal of Information (ESI) for groundwater cleanup programs. For several years, parties responsible for cleanup of leaks from underground storage tanks have been required to submit groundwater analytical data, surveyed locations of monitoring wells, and other data to the GeoTracker database over the Internet. As of January 1, 2005, electronic submittal of information has been required by all groundwater cleanup programs including LUST, SLIC, DoD, and Land Disposal programs.

Analytical data collected for each of the regulated sites have been obtained electronically from the SWRCB in Microsoft Access™ format. The database includes nearly 1.5 million analytical results for 7,864 monitoring locations. Analytical data include monitoring well samples, borehole samples, gas and vapor samples, groundwater grab samples, piezometer samples, stockpile samples and, samples from drinking water wells. In addition to the analytical database, the SWRCB has recently added a tool that allows for easy screening of regulated sites for methyl tert-butyl ether (MtBE) above a user-defined concentration. Search results can be downloaded electronically in Microsoft Excel™ format.

6.4 Groundwater Quality Management Programs

As mentioned previously, the District in cooperation with other agencies has implemented numerous groundwater quality protection programs. The management programs considered most relevant to the Groundwater Vulnerability Study are summarized below. Also included are descriptions of the available water quality data collected for each program and the results of special water quality studies conducted by the District and other agencies.

6.4.1 Nitrate Management Program

Nitrate in the environment comes from both natural and anthropogenic sources. Naturally occurring nitrate is formed in the soil by bacteria. Human activities that contribute nitrate to groundwater include animal operations, crop fertilization, wastewater treatment discharge, and septic systems. Low concentrations of nitrate (<10 milligrams per liter (mg/L)) are normal, but higher concentrations indicate an anthropogenic source (Fostersmith et al., 2005).

Elevated nitrate levels can make groundwater unsuitable for drinking water supplies due to health concerns. The primary MCL for nitrate (as NO_3) is 45 mg/L and for nitrate plus nitrite (as nitrogen) is 10 mg/L. The District initiated the implementation of the Nitrate Management Program in 1991 in an effort to address increasing nitrate concentrations observed in the Llagas Subbasin. The program has since been expanded to include also the Coyote and Santa Clara subbasins. The main elements of the program consists of assisting growers in evaluating and adopting the use of in-field nitrate testing and nitrogen management planning, conducting public outreach and education, and working with other agencies to reduce nitrate loading. The District also offers free nitrate analysis for private water supply well owners.

In addition to its general groundwater quality monitoring network, the District began regular monitoring of nitrate in a number of wells in the Coyote and Llagas subbasins in February 1999.

6.4.2 Solvent and Toxics Liaison Program

With the high density of urban land uses in the Santa Clara Subbasin (including major industrial manufacturing and processing facilities), point-source contamination is prevalent but generally contained in the shallow unconfined aquifers (Judd, 2001). To ensure the protection of the groundwater subbasins from water quality degradation as a result of solvent and toxic releases and to track the progress of cleanup activities, the District has implemented the Solvents and Toxics Liaison Program. Working closely with the RWQCBs, DTSC, and USEPA, the District peer reviews and tracks the progress of cases involving the release of solvents, metals, and pesticides. Currently, there are 385 active SLIC sites in the county, most in the Santa Clara Subbasin.

In 2001, as part of a pilot electronic data reporting and plume mapping project, the SFRWQCB mapped the VOC groundwater plumes in the South San Francisco Bay Area, which included the Niles Cone, San Mateo Plain, and Santa Clara groundwater basins (only plumes in the Santa Clara Subbasin were mapped in Santa Clara County). The maps present contamination plume outlines as of February 2001 for the most dispersed VOC from 68 sites, of which 54 sites are located in the Santa Clara Subbasin. Plume outlines were submitted by responsible parties pursuant to a November 2000 request by the SFRWQCB and represent generalized two-dimensional approximations based on water quality analyses from groundwater monitoring wells. As part of this Study the map was expanded to include SLIC sites in the Coyote and Llagas subbasins.

During the summer and fall of 2001, the District assisted the SFRWQCB in conducting a groundwater sampling project in the Santa Clara Subbasin. The project, called the California Aquifer Susceptibility (CAS) Assessment Project, involved sampling 58 public water supply wells and additional monitoring wells for VOCs using low level detection limits. The overall objective of the study was to identify groundwater areas susceptible to contaminant releases.

6.4.3 Leaking Underground Storage Tank Oversight Program

In 1988, the District and County entered into a contract with the SWRCB to provide local regulatory oversight of the investigation, cleanup, and closure of sites that have been affected by petroleum hydrocarbons and additives such as methyl-tert-butyl ether (MTBE) from LUSTs. At the time, over 1,000 fuel leaks had been reported in the County. The LUST oversight program agreement between the District, County, and SWRCB is amended annually.

Protection of groundwater resources from MTBE is a high priority of the District due to the high solubility, slow degradation, and resultant high mobility of MtBE in groundwater. To date, there are more than 2,000 LUST sites in the County, of which less than 500 are undergoing active assessment, remediation, and verification monitoring. The majority of these sites are impacted by MTBE (SWRCB, 2008). Since 1995, responsible parties have been required to monitor for MTBE in groundwater, and in 1998 State regulations required that operating USTs be upgraded with leak prevention and monitoring systems. The District has aggressively protected groundwater resources from MTBE contamination by working closely with the RWQCBs and other agencies to manage and analyze UST site information and conduct focused investigations to evaluate the impacts of historic LUST sites and sites with operating USTs. In 1999 and 2000, the District conducted two focused investigations to determine the effectiveness of 1998-upgrade-complient USTs in protecting groundwater from MTBE contamination (LFR, 1999; Tulloch, 2000). The first study, the Free Well Water MTBE Testing Study, provided free MTBE analysis to owners of a domestic well within a 0.5-mile radius of a LUST site. Out of the 301 wells that met this criterion, 51 wells were sampled, and 4 wells had detectable concentrations of MTBE. The second study, the Focused Groundwater MTBE Monitoring Program, involved the monitoring of five specific areas in the County, each covering approximately four square miles. The study included 104 water supply and monitoring wells located across the County (Tulloch, 2000). Findings from both studies showed that fuel releases at operating gasoline tank facilities with upgraded USTs were routinely occurring and were often undetected by in-place monitoring systems.

Due to the complete phase out of MTBE in gasoline in 2004, most of the remaining open LUST cases involving MTBE are relatively low risk compared to other groundwater contaminant issues. As a result, the LUST oversight program was transferred to the Santa Clara County Department of Environmental Health as of July 1, 2004. The District continues to coordinate high priority LUST case oversight with the County. During the period of its oversight of the LUST program, the District maintained a database of information related to the sites.

6.5 Santa Clara Subbasin Water Quality

Important references and sources of water quality information for the Santa Clara Subbasin include:

- Levine Fricke, July 22, 1999, Summary Report, Santa Clara Valley Water District Groundwater Vulnerability Pilot Study, Investigation of MtBE Occurrence Associated with Operating UST Systems
- Moran, Jean E., G. B. Hudson, G. F. Eaton, and R. Leif, (LLNL), 2004, California Aquifer Susceptibility, A Contamination Vulnerability Assessment for the Santa Clara and San Mateo Groundwater Basins
- Newhouse, M.W., R.T. Hanson, C.M. Wentworth, R.R. Everett, C.F. Williams, J.C. Tinsley, T.E. Noce, and B.A. Carkin, (USGS), 2004, Geologic, Water-Chemistry, and Hydrologic Data from Multiple-Well Monitoring Sites and Selected Water-Supply Wells in the Santa Clara Valley, California, 1999–2003

- Tulloch, C.A., (SCVWD), May 2000, An Evaluation of MtBE Occurrence at Fuel Leak Sites with Operating Gasoline USTs

Groundwater quality in the Santa Clara Subbasin is generally good with drinking water standards met at public water supply wells without treatment. High mineral salt concentrations have been identified in the Shallow Aquifer (less than 100 feet deep) of the baylands adjacent to the southern San Francisco Bay (Fostersmith, et al, January 2005)Saltwater intrusion within the Shallow Aquifer is primarily attributed to historic pumping and land subsidence resulting in an inland groundwater flow direction. Saltwater intrusion has also been observed along the Guadalupe River and Coyote Creek, where saltwater (moving upstream during high tides) infiltrates into the Shallow Aquifer when this zone is pumped (Reymers and Hemmeter, July 2002). Total Dissolved Solids (TDS) concentrations in the Principal Aquifer are generally below 500 mg/L, the lower end of MCL range for TDS. TDS concentrations in the Shallow Aquifer are below 1,000 mg/L, the higher end of MCL range.

6.5.1 Recycled Water Impacts

Water quality data for SBWRP water from 1997 through 2007 is available online at the City of San Jose's website. Overall, the SBWRP water is generally high in quality relative to groundwater in Santa Clara County, with average nitrate concentrations below 10 mg/L and average boron concentrations of 0.5 mg/L. Average TDS concentrations for SBWRP water is 729 mg/L, above the recommended drinking water standard of 500 mg/L. SBWRP water is not analyzed for DBPs.

The District evaluated the impact of SBWRP water use in the southeastern portion of the Santa Clara Subbasin (Barrientos, 2005). Data for baseline (pre-1998) and post-reclaimed water application (1998/1999-2007) were statistically analyzed to identify trends for 9 of the 13 analyzed inorganic and physical water quality parameters in 6 shallow and 6 deep monitoring wells. The shallow monitoring wells were installed in 1997 and provided one to two years of baseline water quality data. Baseline conditions for deeper monitoring wells were based on water quality data dating as far back as 1939. The District study found increasing trends for sodium, magnesium, calcium, sulfate, chloride, boron, and TDS in the shallow wells after 1998. A decreasing trend in nitrate concentration was observed in three of the six shallow monitoring wells, while stable or no trends were observed for the other three shallow wells. For the deep monitoring wells, increasing trends were observed for sulfate in two wells, for boron in three wells, and for calcium and chloride in four wells. Increasing trends in nitrate concentrations were observed in deep wells during both pre- and post-reclaimed water use thus making it difficult to identify the impacts of reclaimed water application. Although the time of arrival for recycled water to the deep wells is reasonable, it is possible that reclaimed water flow to the Principal Aquifer is being short-circuited possibly through abandoned wells in the vicinity of reclaimed water application.

Recently, Todd Engineers (August 11, 2009) conducted an assessment of the GMMP data for the City of San Jose and concluded that while some changes in water quality were observed, particularly in the Shallow Aquifer, it was not possible to determine whether the changes were due solely to recycled water use or to other sources.

The District is currently working to initiate the preparation of a regional salt and nutrient management plan in accordance with the SWRCB 2009 Final Policy on Recycled Water Use.

6.5.2 Nitrate

Typical nitrate concentrations in the Shallow Aquifer in the Santa Clara Subbasin are between 2 and 12 mg/L. Nitrate concentrations in the Principal Aquifer in the subbasin are between 13 and 16 mg/L. Higher concentrations in the Principal Aquifer are likely a result of historic nitrate sources.

Although current nitrate concentrations in the Santa Clara Subbasin are generally low, elevated nitrate concentrations have been observed in some areas. Table B-3 shows that nitrate concentrations have exceeded the MCL in 24 wells since 1946. In 2002, the North Santa Clara County Nitrate Study evaluated nitrate occurrence and trends in the Principal Aquifer in the Santa Clara Subbasin. The study indicated that nitrate concentrations in the subbasin appear to have declined from 1984 to 2000. Although some individual wells showed increasing trends in concentrations, 91 percent of the wells showed no apparent trend or a decreasing nitrate concentration (Fostersmith, et al, January 2005). Since land uses affiliated with nitrate contamination are no longer present in the North County, increasing nitrate concentrations in some areas may indicate the movement of an old nitrate plume or plumes from past sources.

6.5.3 Volatile Organic Compounds

VOCs are used in a variety of commercial, industrial, and manufacturing activities, including gasoline stations, circuit board manufacturing, dry cleaning, semiconductor manufacturing, and automotive repair. VOCs are have generally been detected at only trace concentrations in public water supply wells. However, localized VOC contamination has been severe enough to cause four wells to be destroyed.

There are more than 400 of SLIC sites in Santa Clara County, with the majority located in the Santa Clara Subbasin. There are 47 mapped VOC plumes in the Santa Clara Subbasin covering a total of 1,750 acres. Seven sites account for 1,300 acres of the mapped plumes in the Santa Clara Subbasin and include:

- Middlefield-Ellis-Whisman & Moffett Field (349 acres)
- National Semiconductor (195 acres)
- Varian, 601 California Ave. (175 acres)
- Hewlett-Packard, 395 Page Mill Rd. (175 acres)
- Hewlett-Packard, 640 Page Mill Rd. (175 acres)
- FEI (TRW), 825 Stewart Dr. (124 acres)
- Mohawk Laboratories (110 acres)

Fortunately, these sites are located in the in northern portion of the subbasin where groundwater contamination is limited to the Shallow Aquifer, which is separated hydraulically from the deeper Principal Aquifer by a horizontally extensive confining unit. In fact, only three of the mapped plumes in the subbasin extend deeper than 100 feet below ground surface (ft-bgs). Of the remaining plumes, the average maximum plume depth is 40 ft-bgs. VOC contamination affiliated with the Fairchild San Jose (SLIC #43s0036) and IBM (SLIC #43s0056) sites have impacted public water supply wells in the southern recharge area.

Overall, the District's groundwater protection programs, including its well permitting, well destruction, and LUST programs, have been effective in protecting the groundwater subbasin from contamination. Table B-2 shows that VOCs have been detected in several wells but Principal Aquifer groundwater generally meets drinking water standards. MCLs have been exceeded for carbon tetrachloride (1 well), dichloromethane (3 wells), and tetrachloroethylene (1 well). The most commonly found VOC in groundwater is 1,1,1-trichloroethane, which has been detected in 47 wells at concentrations below the MCL but above the Detection Limit for Reporting (DLR) since 1982. Of the SOCs, benzo(a)pyrene has been detected above the MCL in one well.

In 2001, the District assisted the SWRCB and LLNL in conducting a groundwater vulnerability study in Santa Clara County involving in part the sampling and analysis of VOCs in 58 public water supply wells and other monitoring wells using ultra low-level detection limits. VOCs were detected at low concentrations (below MCLs) in many of the public water supply wells indicating that sampled water represents groundwater impacted by urban development. VOCs were detected in several wells, with the most common constituents being MTBE, trihalomethanes (THMs), and tetrachloroethylene. The results indicate that contamination pathways exist allowing for migration of VOCs into the Principal Aquifer; however, the low concentrations of VOCs also indicate that water quality management and monitoring programs have, for the most part been, successful in protecting the Principal Aquifer from anthropogenic sources of contamination.

6.5.4 LUST Sites

Of the more than 2,000 LUST sites in the County, most are located in the Santa Clara Subbasin. The majority of the LUST sites are closed; although, several hundred LUST sites in the subbasin are currently undergoing active investigation, monitoring, and/or soil and groundwater remediation. Shallow Aquifer groundwater has been impacted in nearly all of the active cases. Historic MTBE contamination has caused impacts to two public water supply wells located in the recharge area of the subbasin.

6.6 Coyote Subbasin Water Quality

Important references and sources of water quality information for the Coyote Subbasin include:

- Fostersmith et al., (SCVWD), January 2005, Groundwater Conditions 2002/2003
- Reymers and Hemmeter, (SCVWD), July 2002, Groundwater Conditions 2001

Groundwater quality in the Coyote Subbasin is good and is in compliance with primary drinking water standards with the exception of nitrate. Currently, the Coyote Subbasin is predominantly rural and is thus not impacted by most commercial and industrial sources of pollution. Nitrate detections in the southern half of the subbasin result from historic use of fertilizers and other agriculture-related practices in this area.

6.6.1 Recycled Water Impacts

The Metcalf Energy Center located in north Coyote Valley uses recycled water supplied by SBWRP for cooling water. Approximately 80 percent of the water evaporates into the atmosphere. The remaining processed recycled water is discharged to the San Jose sewer system. There is currently no recycled water land application in the Coyote Subbasin. However, estimated long-term future irrigation demand in Coyote Valley could be on the order of 3,000 to 4,000 AFY depending on degree of urban development. This demand could possibly be realized in the 2010 to 2020 timeframe (Black and Veatch, 2003). The District has determined that any recycled water used in the Coyote Subbasin to augment water supplies will need advanced treatment to avoid potential groundwater impacts.

6.6.2 Nitrate

Elevated nitrate levels occur in the southern half of the Coyote Subbasin, where nitrate sources associated with agriculture and septic systems are concentrated. The typical concentration range of nitrate in the Coyote Subbasin is from 10 to 47 mg/L (Reymers and Hemmeter, July 2002). With no significant separation between the land surface and groundwater, aquifers in the Coyote Subbasin are vulnerable to non-point source contamination, including agricultural drainage and sewer collection systems (i.e., septic tanks). Table B-2 shows that of the 91 wells in the Coyote Subbasin sampled for nitrate, 29 wells have exceeded the MCL at least once.

6.6.3 Volatile Organic Compounds

Of the historic regulated environmental sites in the subbasin, none are SLIC sites. However, there are ongoing investigations and remediation at a closed rocket manufacturing plant (United Technologies Corp. Chemical Systems, SLIC #43s0286a) located in the hills immediately north of Anderson Reservoir and east of the subbasin.

Table B-2 shows that VOCs and SOCs have not been detected above MCLs in wells sampled in the Coyote Subbasin.

6.6.4 LUST Sites

All of the regulated environmental sites in the subbasin are LUST sites; however, none of the sites are currently active. If and when the Coyote Subbasin becomes more urbanized in the future, new potential contamination sources, including potential LUST sites, are expected to pose a threat to groundwater quality. To address these concerns, the District has recommended steps above and beyond those required by state and federal law including the following: 1) avoiding high-risk land uses such as underground chemical storage; 2) establishing wellhead protection zones and locating the most hazardous PCAs far away from and downgradient of drinking water supply wells; 3) implementing best management practices with respect to collection, conveyance, and treatment of urban storm water runoff; 4) enforcing rigorous commercial and industrial pre-treatment programs to minimize discharges to the sanitary sewer system; and 5) constructing deep excavations and facilities to standards that prevent hydraulic connection between surface water and groundwater (SCVWD, April 2005).

6.7 Llagas Subbasin Water Quality

Important references and sources of water quality information for the Llagas Subbasin include:

- Fostersmith et al., (SCVWD), January 2005, Groundwater Conditions 2002/2003
- Reymers and Hemmeter, (SCVWD), July 2002, Groundwater Conditions 2001
- MACTEC, January 30, 2008, Llagas Subbasin Characterization – 2007, Santa Clara County, Olin/Standard Fusee Site, Morgan Hill, California
- MACTEC, August 3, 2007, Llagas Subbasin Groundwater Model Development, Santa Clara County, Olin/Standard Fusee, Morgan Hill, California
- LLNL, July 2005, California GAMA Program: Sources and Transport of Nitrate in Shallow Groundwater in the Llagas Basin of Santa Clara County, California

Natural groundwater quality within the Llagas Subbasin is generally good and is acceptable for potable, irrigation, and livestock uses.

Groundwater contamination associated with human activity (environmental releases) has been widely detected in the Llagas Subbasin. Nitrate and perchlorate represent significant contaminants in the subbasin, while solvents and petroleum hydrocarbons are rarely detected in the Principal Aquifer .

6.7.1 Nitrate

Nitrate is widely detected in the Llagas Subbasin above the MCL (see Table B-2). Elevated levels of nitrate in the subbasin are thought to be due primarily to synthetic fertilizer application (LLNL, July 2005). As of the 1995 Santa Clara County General Plan, approximately 40 percent of the subbasin area was agricultural, which is a potential source of fertilizers. Other sources of nitrate in the subbasin include septic systems, greenhouse operations, urban runoff, manure used for fertilizers, feedlots and dairies, egg farms, food packaging operations, cogeneration facility, and treated wastewater disposal.

Trends in land use include a gradual retiring of agricultural land to suburban housing, an increase in nursery and greenhouse operations, reduction in the number of feedlots and dairies, improvements in municipal wastewater treatment, and increased volumes of treated wastewater disposed and recycled water use. The areas of the subbasin between the cities of Gilroy and Morgan Hill and on the outskirts of the cities rely on onsite septic systems for wastewater handling. Wastewater from the cities of Morgan Hill and Gilroy is treated at the Gilroy-Morgan Hill Municipal Wastewater Treatment Facility (WWTF) located in the southern portion of the subbasin. The WWTF currently treats wastewater to tertiary levels. Treated wastewater is disposed in evaporation-percolation ponds and/or to the Pajaro River in the winter. The SCRWA operates a recycled water system that currently recycles up to three million gallons of water, which is distributed to five customers for irrigation in the area south of the City of Gilroy (Carollo, December 2005). Due to the tertiary level of treatment, the wastewater has low levels of nitrate (less than 2 mg/L) and other contaminants (CRWQCB, September 2004). Nonetheless, the LLNL (July 2005) isotope study suggests that wells near the recycled water use sites show a nitrate signature reflecting a mixture of the recycled water source and a soil or fertilizer source.

As shown in Table B-2, of the 675 wells sampled for nitrate, it has been detected above the MCL, at least once in 355 wells. In 2001, nitrate was detected above its MCL in almost half of the 93 wells sampled in the Llagas Subbasin. A comparison of 1988 and 1998 water quality data indicates that overall nitrate levels in the subbasin are increasing (Reymers and Hemmeter, July 2002). The median nitrate concentration in the Llagas Subbasin in 1998 was 47.1 mg/L (Hemmeter, January 2002). LLNL (July 2005) found that deep production wells in the Llagas Subbasin have increasing nitrate concentrations even though the District initiated implementation of a Nitrate Management Program in 1997 (SCVWD, 1996), with more complete implementation in 2000. However, recent nitrate trend analyses (1999 to 2008) indicate that nitrate levels are beginning to decline in the subbasin. For wells in the Shallow Aquifer, 16 exhibited no apparent trend, three showed an increasing trend, and two showed a decreasing trend. For wells in the Principal Aquifer, 32 wells showed no apparent trend, two showed an increasing trend, and 11 showed a decreasing trend.

Nitrate concentrations are consistently higher in shallow monitoring and production wells compared with wells screened at greater depths. The typical range in nitrate concentration is 13 to 46 mg/L in the Shallow Aquifer and 25 to 34 mg/L in the Principal Aquifer (Fostersmith et al., January 2005). Wells with top perforations deeper than 250 feet have near zero nitrate concentrations (LLNL, July 2005). The decline in nitrate concentrations with depth may be the result of denitrifying conditions or hydrogeologic factors (i.e., presence of aquitards that separate shallow, younger, contaminated water from deeper, older pristine water). Nitrate concentrations are highest east of Highway 101 in the central and southern subbasin with some of the highest concentrations in the southeast part of the subbasin. Nitrate levels fluctuate seasonally, with higher levels in the winter and lower levels in the summer. This is thought to be due to increased precipitation infiltration and/or higher water levels in the winter mobilizing stored nitrate in the vadose or soil zone (LLNL, July 2005).

Nitrate levels in wells with an isotopic signature of recharge water from artificial recharge operations are extremely low indicating that the Districts recharge operations may dilute nitrate in the subbasin (LLNL, July 2005).

6.7.2 Volatile Organic Compounds and LUST Sites

Of the LUST sites in the Llagas Subbasin, more than 50 are open cases undergoing active assessment, remediation, and/or verification monitoring. Most of the open cases are located in the cities of Morgan Hill and Gilroy and along Highway 101. Although MTBE has been detected above the MCL in 4 shallow wells in the basin (see Table B-2), based on the District's and DPH-required monitoring data, there have been no detections of petroleum hydrocarbons or MTBE above MCLs in the Principal Aquifer used for water supply.

Due to the relatively rural and residential nature of the subbasin, there are only a handful of active SLIC sites. Based on the District's and DPH-required monitoring data, VOCs associated with SLIC sites have not been detected above MCLs in the Principal Aquifer. There is a plume of trichloroethylene (TCE) with concentrations greater than the MCL in the Shallow Aquifer associated with the Castle Vegtech site located near Morgan Hill (DBD, July 2007). In addition, tetrachloroethylene (PCE) has been detected below the MCL in two active City of Gilroy production wells.

Based on the available data, there are no vertically and laterally extensive VOC groundwater plumes in the Principal Aquifer (i.e., water supply zones) in the Llagas Subbasin.

6.7.3 Perchlorate

The most significant single environmental release in the Llagas Subbasin is the perchlorate contamination associated with the Olin site. The California MCL for perchlorate is 6 micrograms per liter (ug/L). Based on second quarter 2008 monitoring data collected by MACTEC, perchlorate concentrations greater than 6 ug/L extended approximately 9 miles downgradient from the site in the intermediate groundwater zone impacting a total of 38 domestic water supply wells (MACTEC, July 2008). As of the fourth quarter of 2008, wells 9 miles downgradient of the site remained impacted above 6 ug/L; however, the total number of domestic supply wells with concentrations above the MCL had declined to 17 wells. The monitoring data indicate that ongoing remediation and attenuation processes are reducing perchlorate concentrations in the plume (MACTEC, January 31, 2009a). The highest concentrations of perchlorate are detected immediately downgradient of the Olin site. The plume has spread farthest in the primary groundwater flow direction to the southeast. Dispersion, aquifer heterogeneity, and variability in pumping and recharge have induced lateral spreading and irregularities in the shape of the plume. For instance, a zone of wells that have not detected perchlorate is noted in the vicinity of the Church Avenue recharge ponds west of Highway 101 near Church Avenue. These non-detects are likely the result of dilution from the ponds. Remedial extraction wells show seasonal variation in perchlorate concentrations with relatively higher concentrations in the spring compared with the fall (MACTEC, June 2006). It is likely that during wet periods when groundwater levels rise, perchlorate contamination in the vadose zone is mobilized. Thus some of the recent declines in groundwater concentrations may be due to lowered groundwater levels due to ongoing drought conditions.

Recent data collected by MACTEC show significant perchlorate contamination in permeable paleochannel deposits in the Deep Aquifer extending at least two miles downgradient of the site (January 29, 2009a). Relatively coarse-grained deposits associated with Coyote Creek represent preferential pathways and may strongly influence perchlorate distribution.

Remediation at the Olin site has been ongoing since February 2004 and has included onsite soil excavation and remediation, in-situ soil treatment, groundwater extraction and treatment, and installation of groundwater treatment systems on five municipal and 12 domestic water supply wells. In additional, bottled water has been provided to a number of businesses and residents in the subbasin (MACTEC, June 2006).

6.8 Contaminant Mobility

The Study considered the relative mobility of contaminants of concern in assessing PCAs. Recalcitrant compounds such as MtBE, nitrate and perchlorate do not readily biodegrade, undergo chemical degradation, or adsorb to soil particles, and thus are more mobile in groundwater compared with other constituents.

7 Potentially Contaminating Activities

The identification, mapping, and analysis of potentially contaminating activities (PCAs) was a key component for the vulnerability analysis. The DPH Drinking Water Source Water Assessment and Protection (DWSAP) program evaluates the sensitivity and vulnerability of drinking water sources (i.e., individual water supply wells) to contamination. Results of the DWSAP program assessments are intended to be used as a tool in developing drinking water protection programs. The DWSAP guidelines provide a comprehensive inventory and ranking of PCAs. Table B-3 summarizes the DPH's PCA master list according to relative ranking (i.e., very high risk, high risk, etc.). The DWSAP PCA inventory was used to focus data collection efforts. The District, other public agencies, and private database search firms were contacted to determine what data are readily available. As part of this data collection effort, land use information was also researched and compiled. The focus was directed toward data that were available in GIS compatible format.

Several different approaches were identified for mapping PCAs:

- Use parcel, zoning, and/or general plan maps and designations to identify areas where PCAs have a high probability of being located (e.g., industrial or commercial)
- Use a private search company to identify and map individual facilities that handle contaminants of concern
- Determine if the results from individual DWSAP PCA surveys in the Study Area (over 300) could be acquired digitally for mapping and statistical analysis
- Target areas where PCAs are known to have contaminated groundwater by mapping existing plumes and regulated sites (LUST, SLIC, DoD, etc.)

Prior to fully developing the vulnerability assessment methodology, each mapping approach was pursued. Initially, data for very high and high risk PCAs were prioritized. Table B-4 summarizes the data sources that have or can provide specific PCA locations. The data sources are described in the following sections.

7.1 Data Sources

In addition to data obtained from the District, PCA data were accessed from the following entities:

- California Department of Public Health (DPH)
- University of California at Davis (UC Davis)
- State Water Resources Control Board (SWRCB)
- Regional Water Resources Control Board, San Francisco Bay Region (SFRWQCB)
- Regional Water Resources Control Board, Central Coast Region (CRWQCB)
- Department of Toxic Substance Control (DTSC)
- Santa Clara Valley Water District (District)

- Environmental Data Resources, Inc. (EDR), a private database search firm
- InfoUSA, a private database search firm
- Santa Clara County
- Cities in Santa Clara County (Campbell, Cupertino, Gilroy, Los Altos, Los Gatos, Milpitas, Morgan Hill, Mountain View, Palo Alto, San Jose, San Martin, Santa Clara, Saratoga, and Sunnyvale)

A discussion of the data and data sources is presented below.

7.1.1 California Department of Public Health

The DPH has developed and implemented a DWSAP program to ensure that the quality of drinking water sources is maintained and protected. The assessments include delineation of the areas (watersheds and capture zones) surrounding drinking water sources through which contaminants might migrate and impact the source. The program guidelines suggest identification of PCAs in surface water supply watersheds and within the capture zones of water supply wells. The DPH DWSAP program guidelines identified and ranked over 100 PCAs broadly grouped into four categories: commercial/industrial, residential/municipal, agricultural/rural, and other (e.g., known plumes, historic gas stations, and mining). Each PCA was identified by DPH after considering the potential for contaminants of concern (COCs) handled at the facility to impact drinking water supplies. The relative risk of each PCA (i.e., very high, high, medium, low) was determined by the general types of activities and contaminants associated with them. The ranking did not consider the size, age, or specific practices of individual facilities. Some COC fate and transport considerations were included in the ranking of microbiological constituents. For example, septic systems have higher risk for wells that are within a two year capture area of a well. Table B-3 shows the PCAs sorted by relative risk.

7.1.1.1 University of California at Davis

The DPH contracts with UC Davis Information Center for the Environment (ICE) to provide technical support for the DWSAP program. Statewide data collected as part of the DWSAP program are compiled and managed by UC Davis ICE. DPH requested that UC Davis ICE provide the DWSAP program data for all wells in Santa Clara County for this Study. According to ICE, this is the first time that this database has been made available. The DWSAP program is intended to be used as a tool for the development of water supply protection programs. As such, use of the DWSAP data for this Vulnerability Study is an important step in meeting program goals. The DWSAP Access™ database contains identified PCAs for approximately 300 wells and surface water sources in the County. The PCA data is referenced to DPH system and source numbers. Well coordinates were not provided due to security concerns. However, DWSAP data were matched to the public water supply wells in the District-provided database.

7.1.2 State Water Resources Control Board and Regional Water Quality Control Boards

Beginning in 2005, all regulated facilities were required to submit their reports and data electronically to the SWRCB. Previously, only LUST program sites were required to submit data. In the SWRCB GeoTracker database there are over 3,700 records for Santa Clara County including LUST, SLIC, landfill, and DoD program sites. All the information previously contained in the Leaking Underground Storage Tank Information System (LUSTIS) database has been integrated into the GeoTracker database. GeoTracker has recently been updated to enable users to download databases directly without using the mapping function. Using this new option, the Santa Clara County GeoTracker databases have been obtained. These data were queried to help characterize water quality conditions in the Study Area.

In 2003, the SFRWQCB completed a special study to describe and review the effectiveness of groundwater protection programs in the Niles Cone, Santa Clara Valley (including Coyote Valley), and San Mateo Plain areas. Agencies from all three areas participated with the SFRWQCB in the study. The project developed GIS coverages of public water supply wells and pollution sites (including LUST, SLIC, and landfills). The SFRWQCB provided relevant shape files from this Study. Shape files of interest include municipal landfills, and LUSTs/above-ground tanks.

7.1.3 Department of Toxic Substances Control

DTSC maintains the EnviroStor data management system. EnviroStor provides online access to information regarding hazardous waste permitted and corrective action facilities, as well as existing site cleanup information. The database also contains information on USEPA regulated sites (Superfund Sites). Data for Santa Clara County were downloaded as a GIS shape file. Within the Study Area, there are 23 Superfund Sites, 57 non-operating hazardous waste sites, 12 sites with a hazardous waste permit, 7 school clean-ups, 53 state response sites, and 51 voluntary cleanup sites, as of 2008.

7.1.4 Santa Clara Valley Water District

The District has provided GIS coverages and related data for several PCA's. Individual shape files provided include:

- parcels,
- fuel leaks sites,
- contaminant plumes,
- railroads,
- percolation ponds,
- mines (historic and active), and
- storm water outfalls.

7.1.4.1 Leaking Underground Storage Tank Program

Until July 1, 2004 the District provided oversight for the LUST program in Santa Clara County, after which the County DEH assumed responsibility. During their oversight tenure, the District maintained a database of information related the LUST sites. This database was provided by the District.

7.1.4.2 Dry Cleaner Study

In 2007, the District completed a detailed study of dry cleaner facilities. From this study, locations of active and historic dry cleaners were mapped based on:

- Bay Area Air Quality Management District (BAAQMD) permit files,

- DTCS hazardous waste manifest records,
- Publicly Owned Treatment Works (POTW) pretreatment records,
- Fire Department Hazardous Material Management Program (HMMP) records, and
- Business license records.

The shape files from this study were provided by the District. Based on these data compilation, 224 operating facilities were identified as active facilities. The study concluded that current dry cleaner facilities do not present a significant source of contamination assuming hazardous waste laws are followed. Although rare, violations of environmental regulations by dry cleaners have been documented in Santa Clara Valley. A national investigation cited by this study found that sewer lines and storage tanks were the more frequent sources of releases.

7.1.5 Environmental Data Resources, Inc.

Environmental Data Resources, Inc. (EDR) is a private database search firm. Within a prescribed area, EDR provides maps and data summaries of sites of potential concern, oil and gas pipelines, and flood zones. EDR also offers a new service called "EDR On-Demand". This service enables the user to purchase subscriptions to all their government and proprietary databases. Databases may be queried on an as-needed basis during the subscription period.

Given the size of the Study Area for this Vulnerability Study, the data generated from an EDR survey would be unwieldy and costly. Additionally, the EDR service is not GIS-based, and information must be queried by site name and/or address. EDR provided a demo of their services, and after careful review it was determined that an EDR search could not meet the needs of this Study. Because it was more efficient and economical to collect PCA information by other means as described below, an EDR search was not conducted for this Study.

7.1.6 InfoUSA

InfoUSA is a national search firm that provides location information and Standard Industrial Classification (SIC) codes for industrial and commercial facilities. SIC codes were developed by the United States Government to classify economic activity by industrial sector in order to publish statistics related to the economy. Although SIC codes were replaced by the North American Industry Classification System (NAICS) in 1997, SIC codes are still widely in use and can be cross-referenced with the NAICS if needed. In order to locate PCAs within the Study Area, each PCA was matched to a SIC code. Using SIC codes, it is possible to select only the types of facilities that actually handle potentially contaminating constituents. For example, dry cleaning establishments that do not actually perform the cleaning onsite can be distinguished from dry cleaning plants where the cleaning occurs.

InfoUSA data comes from telephone directories, public records data from county courthouse filings, Securities and Exchange Commission, and the Secretary of State. Each month they update addresses with the United States Postal Service National Change of Address information. Site coordinates are provided in North American Datum 1983 for easy importation into GIS. The cost to query SIC codes for PCA sites for the entire Study Area was significantly less than the cost of a comparable EDR search.

Initially, data for a selected subset of SIC codes for three zip code areas within the Study Area were requested from InfoUSA to check the usability and accuracy of the data. Three zip codes (Sunnyvale, Campbell, and San Jose) were searched for four SIC codes:

- 5541 (gasoline service stations),
- 7216 (dry cleaning plants),
- 7218 (industrial launderers); and
- 36 (electronic components).

A full record was requested for each facility to better understand the extent of information available from InfoUSA. A special request also was made to receive the latitude and longitude of the facilities to be GIS-ready.

Table B-5 summarizes the results of the InfoUSA subset search by zip code and SIC code. Within the three zip codes searched, a total of 87 electronics manufacturing, 37 automotive gas stations, and two dry cleaners were reported. In order to perform quality control checks on the results, locations of dry cleaners were compared to the existing District database for dry cleaners. The InfoUSA search generated far fewer dry cleaners than were found in the District database for the three zip codes. For example, in the Campbell zip code, eight dry cleaners are listed as active in the District database, while the InfoUSA database contains only two. One dry cleaner identified by InfoUSA is not contained in the District database. Given the high level of effort to compile records for the District database, it may be more accurate than the InfoUSA database. However, it is noted that 30 to 40 percent of the records in the District database may not have housed actual dry cleaning equipment (Mohr, September 2007).

Initially, SIC codes were collected for high and very high risk property uses, as defined in the DWSAP guidance. The high and very high PCAs identified with SIC codes were tabulated and compared to known contamination sites. There was an excellent agreement between high and very high PCAs and known contaminated sites. However, there were also some medium and low ranked DWSAP PCA’s associated with known contamination sites. Therefore a group of 7 additional SIC codes associated with medium and 2 SIC codes associated with low ranked PCA’s were searched in the InfoUSA database. Table B-6 summarizes the final SIC code search.

Within the Study area there are 55 zip codes (Table B-6).

7.1.7 Compilation of Existing Data Sources

The known contaminated site data from SWRCB (Geotracker), DTSC (EnviroStar), and the District (SLIC) were combined and edited to correct errors and remove duplicates. The resulting database contains 2,839 sites. SIC codes were assigned to 2,238 sites where the type of activity could be identified.

7.1.8 Land Use Data

The District has developed land use data as part of special studies. The County maintains parcel data and has general plan land use for unincorporated areas. Cities maintain their own land use data for the urban areas of the Study Area.

7.1.8.1 Santa Clara Valley Water District

The District provided a shape file of land use in the County. The shapefile includes 434,405 individual parcels grouped within 234 residential, industrial, commercial, and other land use types. This database was lasted updated on December 29, 2006.

In addition to the District land use shapefile, the District sponsored two special studies which generated digitized land use data. The first study, the Llagas Basin Numerical Model conducted by CH2M HILL (May, 2005), created land use coverage for the years 1978 and 1990. The 1978 land use coverage was based on a digitized District map, while the 1990 land use coverage was based on a DWR paper map. The CH2M HILL maps merge cover crops into five categories with similar characteristics: 1) wine grapes, deciduous, citrus and subtropical; 2) truck crops and field crops; 3) alfalfa, pasture and turf; 4) barren lands; and 5) native vegetation.

The second special District study, the Habitat Conservation Plan/Natural Communities Conservation Plan, was conducted though a local and federal partnership. The local partners are San Jose, Gilroy, Morgan Hill, Santa Clara County, Santa Clara Valley Transportation Authority, and the District. The goal of this project is to produce a long-range plan focusing on areas where land development activity is in conflict with the survival of endangered or threatened species. The study area includes the Coyote and Llagas subbasins and a portion of the Santa Clara Subbasin (the City of San Jose). The land use mapping is divided into five categories: urban development, rural residential, ranchland/woodland, agriculture, urban parks and open space, rural parks and open space. The first administrative draft of the Plan was released on August 4, 2008. The District provided a copy of the land use coverages.

7.1.8.2 Santa Clara County

Santa Clara County provided general plan land use shape files that cover unincorporated lands. These data were last updated in May 2008. The data were originally created by the Santa Clara County Planning Office in 2000. The County also provided zoning maps for unincorporated areas created in January 2005. These data are regularly updated to reflect corrections, annexations, and re-zoning. The last update occurred in November 2008.

7.1.8.3 City Data

Within Santa Clara County, there is not a single clearing house for land use data, rather, each individual city planning department maintains their own land use data files and have their own unique data sharing provisions. Based on our research, the following cities maintain GIS coverages of land use: Campbell, Cupertino, Los Gatos, Milpitas, Morgan Hill, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, and Sunnyvale. Each city was contacted to arrange for data transfer. GIS files from Gilroy were not yet available for this Study; therefore, land uses were classified using the County parcel database. Land use for Los Altos was also classified from the County parcel database.

The City of San Jose's Data Use Agreement (see Appendix A) requires that any hard copies of their land use data must acknowledge them as the data provider. In addition, the City of San Jose must provide written consent before the data are shared with any other party. The City of Mountain View's Nondisclosure Agreement (see Appendix A) restricts the use of their land use data. Under this agreement land use data is considered confidential and its use is limited to this Vulnerability Study. The District may access the data as a "representative" of the Contractor, but must follow the stipulations set forth in the Nondisclosure Agreement.

8 Groundwater Sensitivity and Vulnerability

8.1 DRASTIC

The District performed a DRASTIC analysis of groundwater in the Santa Clara, Coyote, and Llagas subbasins to determine sensitivity to contamination based on intrinsic hydrogeologic characteristics (Pierno, December 1999). DRASTIC is the most commonly used index method and was developed by the USEPA (Aller et al., 1987). DRASTIC is an acronym standing for the seven hydrogeologic variables considered in the method: **D**epth to Water, Net **R**echarge, **A**quifer Media, **S**oil Media, **T**opography, **I**mpact of Vadose Zone, and Aquifer Hydraulic **C**onductivity. DRASTIC ranks intrinsic hydrogeologic properties and does not consider PCAs.

Depth to water and impacts of the vadose zone have the greatest influence on the DRASTIC sensitivity rating using this method. The study found the Llagas, Coyote, and southern Santa Clara subbasin to be relatively more sensitive compared with northern confined Santa Clara Subbasin. The study identified high sensitivity in the Great Oaks/Santa Teresa areas in the Santa Clara Subbasin. The western recharge area of the Santa Clara subasin in the vicinity of Los Altos, Mountain View, and Cupertino was found to a have a relatively low sensitivity due to deep groundwater.

The District study did not differentiate shallow groundwater above confining layers from groundwater in the deeper water supply zones. Depth to water was input as the shallowest groundwater encountered in the LUST database. As such, the District study likely overestimates sensitivity in confined areas.

8.2 Lawrence Livermore National Laboratory Studies

The Ambient GAMA program, sponsored by the SWRCB, aims to assess water quality and to predict relative susceptibility of groundwater resources to contamination throughout the state. In 2001 and 2002, LLNL (Moran et al., 2004) completed a vulnerability study of the groundwater basins in Santa Clara County. The investigation included the collection of ultra low-level VOCs, age dating parameters (tritium-helium3), and stable isotopes of oxygen from 146 wells. A later LLNL study focused on determining the main source(s) of nitrate in the Llagas Subbasin. The investigation included analysis of anions and cations, nitrogen and oxygen isotopes of nitrate, dissolved excess nitrogen, tritium and groundwater age, and trace organics (LLNL, July 2005).

The studies determined that the following were most vulnerable to contamination:

- The south and southeast recharge areas of the Santa Clara Subbasin, especially the most southerly group of wells tested;
- The unconfined area of the Llagas Subbasin; and
- Shallow groundwater, generally.

The studies also provided the following information on groundwater quality, age, and flow:

- There are very few detections of VOCs in the Santa Clara Subbasin in the confined aquifer (four VOC and two MTBE detections).
- VOC detections are most frequent in the recharge areas of the Santa Clara Subbasin.
- Groundwater pumping affects the flow field in the recharge area of the Santa Clara Subbasin.
- Groundwater in the south and southeast Santa Clara Subbasin is less than 20 years old.
- Groundwater in large areas of the north and west confined Santa Clara Subbasin is greater than 50 years old.
- The groundwater velocity in the Santa Clara Subbasin is about 1.4 ft/d and probably greater in the shallow sediments of the recharge area.
- The Edenvale Thrust Fault may inhibit transport from the southeast part of the Santa Clara Subbasin recharge area to the rest of the basin.
- Synthetic fertilizer is the most likely source of nitrate in the Llagas Subbasin.
- Nitrate problems in Llagas are amplified by high vertical recharge rates and rapid lateral transport.
- Artificial recharge provides remediation for contamination in the Llagas Subbasin.
- The factors that most affect the occurrence of VOCs include: 1) population density due to increased number of sources, 2) LUST density, 3) proximity of wells to sources, and 4) presence or absence of vertical pathways.

8.3 Study of Dry Cleaner Operations

The District conducted a comprehensive study of current and historic dry cleaners in Santa Clara County to provide a basis for ranking the sites according to their potential to impact groundwater quality (Mohr, September 2007). The District used the SiteRank method (Small, 2003). This method accounts for aquifer conditions, source strength, well vulnerability and pumping, and contaminant fate and transport. The SiteRank algorithm provides a simplified process-based, travel-time representation of contaminant fate and transport, combined with index-based scaling factors for chemical hazard and vertical migration.

The study found that historic dry cleaners are more likely to be the source of contamination. Currently permitted dry cleaners have more rigorous regulatory standards for equipment, operating practices, and inspection. The incidence of tetrachloroethylene (PCE) in drinking water wells is very low. Only 3.3 percent of wells tested between 1986 and 2003 had detections of PCE and only two wells had detections above the 5 micrograms per liter (ug/L) MCL. Groundwater vulnerability is highest where hydrogeologic features allow shallow contamination to migrate to deeper aquifers. These features include high permeability unconfined aquifers and man-made or natural vertical conduits. Vulnerability of individual municipal supply wells to surficial contamination varies with well construction features such as well seal depth, depth to first perforated interval, well age, and other well bore flow. Vertical groundwater gradient also affects supply well susceptibility to contamination. Where groundwater is moving downward, there is an increased potential for contamination, whereas upward vertical groundwater gradients prevent downward migration of dissolved contaminants.

APPENDIX B - TABLES

Table B-1: Summary of District Reservoirs and Associated Groundwater Recharge Facilities

Reservoir	Reservoir Capacity (AF)	Tributary Area (mi^2)	Watershed	Groundwater Recharge Areas Downstream From Reservoir Spillway
Almaden	1,586	12	Guadalupe	Alamitos Creek
Anderson	89,073	193	Coyote	Coyote Creek Coyote Recharge Ponds Ford Road Recharge Ponds
Calero	10,050	6.9	Guadalupe	Calero and Alamitos Creeks
Coyote	22,925	120	Coyote	Coyote Creek Coyote Recharge Ponds Ford Road Recharge Ponds
Guadalupe	3,228	5.9	Guadalupe	Los Capitancillos Ponds Guadalupe and Alamitos Creeks
Lexington	19,044	36.9	Guadalupe	Los Gatos Creek
Stevens Creek	3,452	17.5	Lower Peninsula	Stevens Creek
Vasona	400	43.9	Guadalupe	Los Gatos Creek Camden Recharge Ponds

AF = acre-feet
Mi^2 = square miles

Table B-2: Summary of Santa Clara County Groundwater Quality Data

Category	Constituent	MCL	DLR	Sample Dates	Wells Sampled in GW Subbasins	Santa Clara			Coyote			Llagas		
						Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL
DBP	Haloacetic Acids	0.06		2003-2007	15	9	1	**1**	0			6		
DBP	Total Trihalomethanes	0.1		1986-2007	356	285	42	**41**	16	5	**4**	55	8	**4**
Inorganic	Aluminum	1	0.05	1984-2007	484	336	223	**3**	29	10		119	40	**1**
Inorganic	Antimony	0.006	0.006	1987-2007	443	305	81	**3**	28			110	2	
Inorganic	Arsenic	0.01	0.002	1973-2007	518	368	191	**6**	29	7	**2**	121	19	**4**
Inorganic	Asbestos	7 (MFL)	0.2 (MFL)	1981-2007	142	106	14		11			25		
Inorganic	Barium	1	0.1	1972-2007	508	358	345		29	24		121	103	
Inorganic	Beryllium	0.004	0.001	1987-2007	447	307	83		27			113		
Inorganic	Cadmium	0.005	0.001	1975-2007	512	362	86	**7**	29			121		
Inorganic	Chromium (Total)	0.05	0.01	1962-2007	518	369	274	**3**	28	14		121	44	
Inorganic	Chromium (VI)		0.01	2001-2007	240	170	72		12	11		58	29	
Inorganic	Cyanide	0.15	0.1	1977-2007	303	249	5	**1**	15			39	2	**2**
Inorganic	Flouride	2	0.1	1946-2007	528	374	363	**12**	28	27		126	115	
Inorganic	Mercury	0.002	0.001	1971-2007	517	368	98	**2**	29			120	5	
Inorganic	Nickel	0.1	0.01	1987-2007	466	323	122		28			115	44	
Inorganic	Nitrite (as N)	1	2	1957-2007	263	263	78	**9**						
Inorganic	Nitrate (as NO3)	45	0.4	1946-2007	1,157	391	361	**24**	91	87	**29**	675	668	**355**
Inorganic	Nitrate + Nitrite (as N)	10		1993-2007	228	173	173		14	14	**3**	41	40	**5**
Inorganic	Perchlorate	0.006	0.004	1997-2008	2,013	200	3	**1**	26	4		1,787	1,251	**403**
Inorganic	Selenium	0.05	0.005	1973-2007	509	359	168	**1**	29			121	23	
Inorganic	Thallium	0.002	0.001	1987-2007	447	309	46	**1**	28			110		
Radionuclide	Radium 226	5[1] (pCi/L)	1 (pCi/L)	1982-2007	40	37	19		1	1		2		
Radionuclide	Radium 228	5[1] (pCi/L)	1 (pCi/L)	1982-2007	229	194	42		8	4		27	4	
Radionuclide	Gross Alpha activity	15 (pCi/L)	3 (pCi/L)	1979-2007	322	268	259	**8**	13	12		41	37	**1**
Radionuclide	Uranium	20 (pCi/L)	1 (pCi/L)	1991-2007	40	36	28		1	1		3		
Radionuclide	Tritium	20,000 (pCi/L)	1,000 (pCi/L)	1999-2003	57	57	52		0			0		

Includes data from DPH, GeoTracker, Regional Boards, and other sources
MCL = Primary Maximum Contaminant Level (values reported in mg/L unless otherwise noted)
MFL = Million fibers per liter
mg/L = milligrams per liter
pCi/L = picocuries per liter

DLR = Detection Limit for Reporting (values reported in mg/L unless otherwise noted)
DBP = Disinfection Bi-Product
GW = Groundwater
[1] MCL for Total Radium 226 + Radium 228 = 5 pCi/L

Table B-2: Summary of Santa Clara County Groundwater Quality Data (continued)

Category	Constituent	MCL	DLR	Sample Dates	Wells Sampled in GW Subbasins	Santa Clara			Coyote			Llagas		
						Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL
SOC	2,3,7,8-TCDD (Dioxin)	3.E-08	5.E-09	1993-2007	146	115			8			23		
SOC	2,4,5-TP Silvex	0.05	0.001	1980-2007	226	162			16			48		
SOC	2,4-D	0.07	0.01	1980-2007	228	164	2		16			48		
SOC	Alachlor	0.002	0.001	1984-2007	273	190			14			69		
SOC	Atrazine	0.001	0.0005	1984-2007	262	180	1		14			68		
SOC	Bentazon	0.018	0.002	1989-2007	210	147			16			47		
SOC	Benzo(a)pyrene	0.0002	0.0001	1986-2007	255	204	1	**1**	13			38		
SOC	Carbofuran	0.018	0.005	1985-2007	211	135	3		15			61		
SOC	Chlordane	0.0001	0.0001	1986-2007	253	172			13			68		
SOC	Dalapon	0.2	0.01	1989-2007	208	145			16			47		
SOC	Di(2-ethylhexyl)adipate	0.4	0.005	1993-2007	240	192	25		13			35		
SOC	Dibromochloropropane (DBCP)	0.0002	0.00001	1986-2007	242	164	1		14			64		
SOC	Dinoseb	0.007	0.002	1984-2007	217	147			16			54		
SOC	Diquat	0.02	0.004	1986-2007	184	142			11			31		
SOC	Endothall	0.1	0.045	1986-2007	195	143	3		12			40		
SOC	Endrin	0.002	0.0001	1986-2007	276	195			13			68		
SOC	Ethylene Dibromide (EDB)	0.00005	0.00002	1986-2007	241	167	1		14			60		
SOC	Glyphosphate	0.7	0.025	1990-2007	189	128	3		14			47		
SOC	Heptachlor	0.00001	0.00001	1984-2007	248	167			13			68	4	**2**
SOC	Heptachlor Epoxide	0.00001	0.00001	1984-2007	266	185			13			68		
SOC	Hexachlorobenzene	0.001	0.0005	1984-2007	273	204			14			55		
SOC	Hexachlorocyclopentadiene	0.05	0.001	1984-2007	268	200			14			54		
SOC	Lindane	0.0002	0.0002	1980-2007	283	202			13			68		
SOC	Methoxychlor	0.03	0.01	1980-2007	274	198			13			63		
SOC	Molinate	0.02	0.002	1989-2007	217	167			13			37		
SOC	Oxamyl	0.05	0.02	1984-2007	239	163	3		15			61		
SOC	Polychlorianted Biphenyls (PCBs)	0.0005	0.0005	1989-2007	220	156	3		12			52		
SOC	Pentachlorophenol	0.001	0.0002	1984-2007	264	197			16			51		
SOC	Picloram	0.5	0.001	1989-2007	208	145	2		16			47		
SOC	Simazine	0.004	0.001	1986-2007	262	180			14			68		
SOC	Thiobencarb	0.07	0.001	1989-2007	217	167			13			37		
SOC	Toxaphene	0.003	0.001	1980-2007	264	183			13			68		

Includes data from DPH, GeoTracker, Regional Boards, and other sources
MCL = Primary Maximum Contaminant Level (values reported in mg/L unless otherwise noted)
DLR = Detection Limit for Reporting (values reported in mg/L unless otherwise noted)
SOC = Non-Volatile, Synthetic Organic Compound
GW = Groundwater mg/L = milligrams per liter

Table B-2: Summary of Santa Clara County Groundwater Quality Data (continued)

Category	Constituent	MCL	DLR	Sample Dates	Wells Sampled in GW Subbasins	Santa Clara			Coyote			Llagas		
						Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL	Wells Sampled	Wells with Detects	>MCL
VOC	1,1-Dichloroethane	0.005	0.0005	1982-2007	587	402	4		36			149		
VOC	1,1-Dichloroethylene	0.006	0.0005	1982-2007	579	394	10		36			149		
VOC	1,2-Dichlorobenzene	0.6	0.0005	1984-2007	576	391	1		36			149		
VOC	1,2-Dichloroethane	0.0005	0.0005	1982-2007	585	392	1		36			157	3	**3**
VOC	1,2-Dichloropropane	0.005	0.0005	1982-2007	579	386	2		36			157	2	**1**
VOC	1,3-Dichloropropene	0.0005	0.0005	1982-2007	367	283	1		19			65		
VOC	1,4-Dichlorobenzene	0.005	0.0005	1984-2007	576	391	1		36			149	6	
VOC	1,1,1-Trichloroethane	0.2	0.0005	1982-2007	578	393	47		36			149	6	
VOC	1,1,2-Trichloro-1,2,2-Triflouroethane	1.2	0.01	1982-2007	495	355	4		27			113		
VOC	1,1,2-Trichloroethane	0.005	0.0005	1982-2007	575	390	1		36			149		
VOC	1,2,4-Trichlorobenzene	0.005	0.0005	1984-2007	499	356	1		27			116		
VOC	1,1,2,2-Tetrachloroethane	0.001	0.0005	1982-2007	575	390	1		36			149	1	
VOC	Benzene	0.001	0.0005	1982-2007	583	390	1		36			157	3	**3**
VOC	Carbon Tetrachloride	0.0005	0.0005	1982-2007	576	391	2	**1**	36			149		
VOC	cis-1,2-Dichloroethylene	0.006	0.0005	1986-2007	500	359	2		27			114		
VOC	Dichloromethane	0.005	0.0005	1982-2007	576	391	31	**3**	36	1		149	2	
VOC	Ethylbenzene	0.3	0.0005	1982-2007	582	389	7		36			157	3	**2**
VOC	Monochlorobenzene	0.07	0.0005	1982-2007	576	391	2		36			149		
VOC	Methyl *tert* butyl ether (MTBE)	0.013	0.003	1995-2007	523	362	2		27			134	8	**4**
VOC	Styrene	0.1	0.0005	1987-2007	491	351	1		27			113		
VOC	Tetrachloroethylene	0.005	0.0005	1982-2007	575	390	12	**1**	36	1		149	5	
VOC	Toluene	0.15	0.0005	1982-2007	582	389	5		36	1		157	5	**2**
VOC	trans-1,2-Dichloroethylene	0.01	0.0005	1982-2007	576	391	2		36			149		
VOC	Trichloroethylene	0.005	0.0005	1982-2007	576	391	4		36			149	2	
VOC	Trichloroflouromethane	0.15	0.005	1982-2007	575	390	4		36			149		
VOC	Vinyl chloride	0.0005	0.0005	1982-2007	575	390	1		36			149		
VOC	Xylenes	1.75	0.0005	1984-2007	573	380	4		36	1		157	5	

Includes data from DPH, GeoTracker, Regional Boards, and other sources
MCL = Primary Maximum Contaminant Level (values reported in mg/L unless otherwise noted)
DLR = Detection Limit for Reporting (values reported in mg/L unless otherwise noted)
VOC = Volatile Organic Compound
GW = Groundwater mg/L = milligrams per liter

Table B-3: Summary of DWSAP Relative Rank for PCAs

Very High	High	Medium	Low
Airports - Maintenance/ fueling areas	Automobile- body shops	Above ground storage tanks	Apartments and condominiums
Automobile- Gas stations	Automobile- repair shops	Artificial recharge- injection wells (non-potable water)	Appliance/electronic repair
Chemical/petroleum processing/storage	Boat services/repair/ refinishing	Artificial recharge- spreading basins (non-potable water)	Artificial recharge- injection wells (potable water)
Dry cleaners	Chemical/petroleum pipelines	Automobile- car washes	Artificial recharge- spreading basins (potable water)
Historic gas stations	Electrical/electronic manufacturing	Cement/concrete plants	Campgrounds/ recreational areas
Historic waste dumps/ landfills	Farm chemical distributor/ application service	Construction/demolition staging areas	Crops, nonirrigated (includes drip-irrigated crops)
Injection wells/ dry wells/ sumps	Farm machinery repair	Contractor or government agency equipment storage yards	Fire stations
Known Contaminant Plumes	Fleet/truck/bus terminals	Crops, irrigated	Hotels, motels
Landfills/dumps	Furniture repair/ manufacturing	Dredging	Medical/dental offices/clinics
Metal plating/ finishing/fabricating	Home manufacturing	Drinking water treatment plants	Office buildings/complexes
Military installations	Illegal activities/ unauthorized dumping	Fertilizer, pesticide/ herbicide application	Rental yards
Mining operations – active	Junk/scrap/salvage yards	Food processing	RV parks
Mining operations - historic	Lagoons / liquid wastes	Funeral services/graveyards	RV/mini storage
Plastics/synthetics producers	Lumber processing and manufacturing	Golf courses	Schools
Underground Injection of commercial/industrial discharges	Machine shops	Hardware/lumber/parts stores	Surface water - streams/ lakes/rivers
USTs- confirmed leaking tanks	Machine shops	Hospitals	Transportation corridors- roads/ streets
Animal feeding operations [1]	Mining - sand/gravel	Housing - high density (>1 house/0.5 acres)	USTs- decommissioned - inactive tanks
CAFOs[1]	NPDES/WDR permitted discharges	Managed forests	USTs- upgraded and/or registered - active tanks
Wastewater treatment plants [1]	Pesticide/fertilizer/ petroleum storage & transfer areas	Motor pools	Veterinary offices/clinics
Septic systems [2]	Photo processing/printing	Parking lots/malls (>50 spaces)	Wells – monitoring, test holes
	Railroad yards/ maintenance/ fueling areas	Parks	
	Recreational area—surface water source	Sewage sludge/biosolids application	
	Research laboratories	Storm drain discharge points	
	Salt Water Intrusion	Storm water detention facilities	
	USTs- Non-regulated tanks (tanks smaller than regulatory limit)	Transportation corridors- freeways/state highways	
	USTs- Not yet upgraded or registered tanks	Transportation corridors- historic railroad right-of-ways	
	Utility stations - maintenance areas	Transportation corridors- railroads	
	Wells - Agricultural/ Irrigation	Transportation corridors- road right-of-ways (herbicide use)	
	Wells – Oil, Gas, Geothermal	Waste transfer/recycling stations	
	Wood preserving/treating	Wells – water supply	
	Wood/pulp/paper processing and mills		
	Agricultural Drainage [3]		
	Grazing (> 5 large animals per acre) [3]		
	Other Animal operations [3]		
	Septic systems – low density (<1/acre) [4]		
	Sewer collection systems- Comm/Indus [4]		
	Sewer collection systems- Residential [4]		

[1] Very High in Zone A (two year capture zone);otherwise High	CAFOs = Concentrated Animal Feeding Operations
[2] High density (>1/acre)	USTs = Underground storage tanks
Very High if in Zone A; otherwise Medium	NPDES = National Pollutant Discharge Elimination System
[3] High in Zone A, otherwise Medium	WDR = Waste Discharge Requirements
[4] High in Zone A, otherwise Low	RV = Recreational Vehicle
	DWSAP = Drinking Water Source Assessment Program

Table B-4: Data Sources for Potentially Contaminating Activities

PCA	Primary Source	Comments
Very High Risk to Groundwater		
Airports - maintenance/ fueling areas	InfoUSA	
Automobile- gas stations	InfoUSA	SWRCB for other permitted USTs
Chemical/petroleum processing/storage	InfoUSA	
Dry cleaners	InfoUSA	SCVWD study also available as info layer
Historic gas stations	SFRWQCB	Leaking sites only
Historic waste dumps/ landfills	SFRWQCB	Shape file from special study[1]
Injection wells/ dry wells/ sumps		Not included in this study
Known contaminant plumes	SFRWQCB	Shape file from special study[1]
Landfills/dumps	SFRWQCB	Shape file from special study[1]
Metal plating/ finishing/fabricating	InfoUSA	
Military installations	SFRWQCB	
Mining operations – active	SCVWD	
Mining operations - historic	SCVWD	
Plastics/synthetics producers	InfoUSA	
Underground injection of commercial/ industrial discharges	N/A	No active injection identified
USTs- confirmed leaking tanks	SWRCB	
Animal feeding operations	SWRCB	
CAFOs	N/A	SWRCB confirms none are present
Wastewater treatment plants	SFRWQCB/ CRWQCB	Palo Alto, San Jose, South County Regional Waste Water Authority, and Sunnyvale
Septic systems - high density (>1/acre)		New coverage created for this study
High Risk to Groundwater		
Automobile- body shops	InfoUSA	
Automobile- repair shops	InfoUSA	
Boat services/repair/ refinishing	InfoUSA	
Chemical/petroleum pipelines	US DOT	National Pipeline Mapping Program
Electrical/electronic manufacturing	InfoUSA	
Farm chemical distributor/ application service	InfoUSA	
Farm machinery repair	InfoUSA	
Fleet/truck/bus terminals	InfoUSA	
Furniture repair/ manufacturing	InfoUSA	
Home manufacturing	InfoUSA	
Illegal activities/ unauthorized dumping	DTSC	Also SWRCB
Automobile- body shops	InfoUSA	

Table B-4: Data Sources for Potentially Contaminating Activities (continued)

PCA	Primary Source	Comments
High Risk to Groundwater (Continued)		
Lumber processing and manufacturing	InfoUSA	
Machine shops	InfoUSA	
Machine shops	InfoUSA	
Mining - sand/gravel	SCVWD	
NPDES/WDR permitted discharges	SCVWD	Not included in study
Pesticide/fertilizer/ petroleum storage & transfer areas	InfoUSA	
Photo processing/printing	InfoUSA	
Railroad yards/ maintenance/ fueling areas	InfoUSA	
Recreational area—surface water source	SCVWD	Not included in study
Research laboratories	InfoUSA	
Salt water intrusion	SCVWD	Not included in study
USTs- non-regulated tanks (small tanks)		Not available
USTs- not yet upgraded or registered tanks		Not available
Utility stations - maintenance areas	InfoUSA	
Wells - agricultural/irrigation	SCVWD	Used in sensitivity analysis
Wells - oil, gas, geothermal	SCVWD	Not included in study
Wood preserving/treating	InfoUSA	
Wood/pulp/paper processing and mills	InfoUSA	
Agricultural drainage	FMMP	Irrigated lands
Grazing (> 5 large animals per acre)		Not included in study
Other animal operations		Not included in study
Septic systems – low density (<1/acre)		New coverage created for this study
Sewer collection systems- comm./indus		Not included in study
Sewer collection systems- residential		Not included in study

[1] SFRWQCB et al., 2003
SFRWQCB = San Francisco Bay Regional Water Quality Control Board
CRWQCB = Central Coast Regional Water Quality Control Board
N/A = not applicable
SCVWD = Santa Clara Valley Water District
US DOT = United States Department of Transportation
DTSC = Department of Toxic Substances Control
CAFOs = Concentrated Animal Feeding Operations
NPDES = National Pollutant Discharge Elimination System
WDR = Waste Discharge Requirements
RV = Recreational Vehicle
FMMP = State of California Farmland Mapping and Monitoring Program

Table B-5: Summary of Targeted PCA Search

Zip Code	City	PCA /SIC Code Searched		
		Electronics Manufacturing	Automotive Gas Station	Dry Cleaner
94085	Sunnyvale	57	13	0
95008	Campbell	23	18	2
95126	San Jose	7	6	0

PCA = Potentially Contaminating Activity

Table B-6: Zip Codes within the Study Area

Zip Code	City
94022	Los Altos
94024	Los Altos
94035	Mountain View
94040	Mountain View
94041	Mountain View
94043	Mountain View
94085-87	Sunnyvale
94089	Sunnyvale
94301	Palo Alto
94303	Palo Alto
94304	Palo Alto
94305	Stanford
94306	Palo Alto
95002	Alviso
95008	Campbell
95013	Coyote
95014	Cupertino
95020	Gilroy
95032	Los Gatos
95035	Milpitas
95037	Morgan Hill
95046	San Martin
95050	Santa Clara
95051	Santa Clara
95053	Santa Clara
95054	Santa Clara
95070	Saratoga
95110 - 113	San Jose
95113	San Jose
95116	San Jose
95117- 119	San Jose
95119	San Jose
95121-139	San Jose
95148	San Jose
95192	San Jose

Table B-7: SIC Codes Searched and Corresponding DWSAP Category

DWSAP Category (Ranking)	SIC Code	SIC Description
Airports - Maintenance/ fueling areas (VH)	4581	Airports, Flying Fields, and Airport Terminal Services
Animal Feeding Operations (VH in Zone A, otherwise H)	02	Livestock & Animal Specialties
Automobile- Gas stations (VH)	5541	Gasoline Service Stations
Chemical/petroleum processing/storage (VH)	1311	Crude Petroleum and Natural Gas
Chemical/petroleum processing/storage (VH)	28	Manufacturing: Chemicals & Allied Products
Chemical/petroleum processing/storage (VH)	29	Manufacturing: Petroleum Refining
Chemical/petroleum processing/storage (VH)	42	Motor Freight Transportation And Warehousing
Chemical/petroleum processing/storage (VH)	5171	Petroleum Bulk stations and Terminals
Chemical/petroleum processing/storage (VH)	5172	Petroleum And Petroleum Products
Dry cleaners (VH)	7216	Drycleaning Plants, Except Rug Cleaning
Dry cleaners (VH)	7217	Carpet and Upholstery Cleaning
Dry cleaners (VH)	7218	Industrial Launderers
Landfills/Dumps (VH)	49	Electric, Gas, & Sanitary Services
Metal plating/ finishing/fabricating (VH)	33	Primary Metal Industries
Metal plating/ finishing/fabricating (VH)	34	Fabricated Metal Products
Military installations (VH)	9711	National Security
Mining operations – Active (VH)	10	Metal Mining
Plastics/synthetics producers (VH)	30	Rubber And Miscellaneous Plastics Products
Agricultural Drainage (H in Zone A, otherwise M)	01	Agricultural Production Crops
Automobile - Repair services	7542	Carwashes
Automobile - Repair shops (H)	5511	Motor Vehicle Dealers (New and Used)
Automobile- Body shops (H)	7532	Top, Body, and Upholstery Repair Shops and Paint Shops

Table B-7: SIC Codes Searched and Corresponding DWSAP Category (Continued)

DWSAP Category (Ranking)	SIC Code	SIC Description
Boat services/repair/ refinishing (H)	3732	Boat Building and Repairing
Boat services/repair/ refinishing (H)	4493	Marinas
Boat services/repair/ refinishing (H)	4499	Water Transportation Services, Not Elsewhere Classified
Chemical/petroleum pipelines (H)	4612	Crude petroleum pipelines
Chemical/petroleum pipelines (H)	4613	Refined Petroleum Pipelines
Chemical/petroleum pipelines (H)	4619	Pipelines, Not Elsewhere Classified
Electrical/electronic manufacturing (H)	35	Industrial And Commercial Machinery And Computer Equipment
Electrical/electronic manufacturing (H)	36	Electronic And Other Electrical Equipment And Components, Except Computer Equipment
Electrical/electronic manufacturing (H)	3711	Motor Vehicles And Motor Vehicle Equipment
Electrical/electronic manufacturing (H)	3824	Totalizing Fluid Meters and Counting Devices
Farm chemical distributor/ application service (H)	5191	Farm Supplies
Fleet/truck/bus terminals (H)	4173	Terminal and Service Facilities for Motor Vehicle Passenger Transportation
Fleet/truck/bus terminals (H)	7513	Truck Rental and Leasing, Without Drivers
Furniture repair/ manufacturing (H)	25	Furniture And Fixtures
Furniture repair/ manufacturing (H)	7641	Reupholstery and Furniture Repair
Junk/scrap/salvage yards (H)	5015	Motor Vehicle Parts, Used
Junk/scrap/salvage yards (H)	5093	Scrap and Waste Materials
Machine shops (H)	5013	Motor Vehicle Supplies and New Parts
Manufacturing, Instruments (H)	38	Measuring, Analyzing, And Controlling Instruments
Mining - Sand/Gravel (H)	14	Mining And Quarrying Of Nonmetallic Minerals, Except Fuels
NPDES/WDR permitted discharges (H)	49	Electric, Gas, & Sanitary Services

Table B-7: SIC Codes Searched and Corresponding DWSAP Category (Continued)

DWSAP Category (Ranking)	SIC Code	SIC Description
Pesticide/fertilizer/ petroleum storage & transfer areas (H)	0711	Soil Preparation Services
Pesticide/fertilizer/ petroleum storage & transfer areas (H)	0721	Crop Planting, Cultivating, and Protection
Photo processing/printing (H)	7384	Photofinishing Laboratories
Railroad yards/ maintenance/ fueling areas (H)	4011	Railroads, Line-Haul Operating
Railroad yards/ maintenance/ fueling areas (H)	4013	Railroad Switching and Terminal Establishments
Railroad yards/ maintenance/ fueling areas (H)	4789	Transportation Services, Not Elsewhere Classified
Research laboratories (H)	8731	Commercial Physical and Biological Research
Research laboratories (H)	8733	Noncommercial Research Organizations
Research laboratories (H)	8734	Testing Laboratories
Wood preserving/treating (H)	24	Lumber And Wood Products, Except Furniture
Machine shops (H)	7699	Repair Shops and Related Services, Not Elsewhere Classified
Construction/demolition staging areas (M)	1522	General Contractors-Residential Buildings
Construction/demolition staging areas (M)	1611	Highway and Street Construction, Except Elevated Highways
Construction/demolition staging areas (M)	1711	Plumbing, Heating and Air-Conditioning
Construction/demolition staging areas (M)	1761	Roofing, Siding, And Sheet Metal Work
Crops, Irrigated (M)	01	Agricultural Production Crops
Hospitals (M)	8062	General medical and surgical hospitals
Manufacturing, Food (M)	2099	Food Preparations, Not Elsewhere Classified
Parking Lots/Malls (> 50 spaces) (M)	5311	Department Stores
Colleges, Universities, and Professional Schools (L)	8221	Schools
Fire Stations (L)	9224	Fire Protection

VH = Very High Zone A = two year well capture zone
H= High
M= Medium
L=Low

Appendix B-A

Land Use Data Sharing Agreements for San Jose and Mountain View

Job ID#_______

CITY OF SAN JOSÉ
PLANNING DIVISION
DATA USE AGREEMENT

By and Between:

CITY OF SAN JOSÉ
*(Hereinafter referred to as **PROVIDER**)*

...and...

Todd Engineers
*(Hereinafter referred to as **RECIPIENT**)*

Entered into at Alameda, California

PROVIDER agrees to provide the data described in **Attachment A**
*(Hereinafter referred to as **PRODUCT**)* to RECIPIENT only for the PURPOSES stated below:

Santa Clara Valley Water District Groundwater Vulnerability Study
*(Hereinafter referred to as **PROJECT**).*

Ownership of PRODUCT and Attribution

PROVIDER is the legal owner, or licensor, of the PRODUCT described in Attachment A, and shall retain all rights, title, interest, and license of the PRODUCT. It is understood and agreed on by RECIPIENT that use of this data will be used exclusively and for the sole purpose of the PROJECT by RECIPIENT for the time period covered by the Contract. Any hard copy products derived from the PRODUCT must give credit to PROVIDER as the source of the information.

Restrictions on Use

RECIPIENT agrees that they will not use any information provided by PROVIDER for any purpose other than for PROJECT without the express written consent of PROVIDER. RECIPIENT also hereby acknowledges that the PRODUCT delivered by PROVIDER is for the use only by RECIPIENT and only for this PROJECT, and is not to be released in any form or re-distributed to any other party without the prior written consent of PROVIDER. RECIPIENT shall not share PRODUCT with other parties in violation of any licenses, proprietary ownership, data sharing agreement or the California Public Records Act (Government Code, Chapter 3.5, Sections 6250-6270). No provision of the agreement shall limit the application of the California Public Records Act or the Federal Freedom of Information Act (5 United States Code, Section 522). RECIPIENT may retain copies of the PRODUCT, including copies stored on magnetic media, for information and reference in connection with RECIPIENT'S use for the PROJECT.

Integrity of the PRODUCT

RECIPIENT hereby agrees to accept all responsibilities for maintaining the current level of integrity and accuracy of the PRODUCT. PROVIDER makes no representation as to the accuracy and suitability of the PRODUCT with respect to its use for the PROJECT. RECIPIENT hereby agrees to assume any and all responsibility for any results obtained in the use of this PRODUCT. RECIPIENT understands that the conversion of data from one system, format, and projection to an alternate system, format, or projection cannot be accomplished without the possibility of the introduction of inexactitudes, anomalies, and errors. RECIPIENT agrees to assume all risks associated therewith, and to the fullest extent permitted by law, to hold harmless and to indemnify PROVIDER from and against all claims, liabilities, losses, damages, and costs, including, but not limited to, attorneys' fees, arising therefrom, or in connection therewith. The parties to this agreement acknowledge that the PRODUCT is complex, and may contain some nonconformity, defects or errors. The PROVIDER does not warrant that the PRODUCT will meet the RECIPIENTS' needs or expectations, or that all nonconformity, defects, or errors can or will be corrected.

Security

RECIPIENT agrees to safeguard product from unauthorized intentional and unintentional release to third parties using a high degree of care and security.

Hold Harmless

RECIPIENT agrees to indemnify, defend, and hold harmless PROVIDER, its officers, agents, consultants, contractors, and employees from any and all claims, actions, or causes of action for damages, including, but not limited to, any costs of recovering, reprogramming, or reproducing any data sorted in or used with the specified PRODUCT, damage to property or for any lost profits, lost savings, or other statutory, special, incidental, or indirect damages arising out of the inaccuracy, unreliability, use of, or inability to use the PRODUCT, even if PROVIDER has been advised of the possibility of such damages.

Distribution Methods

Upon request of the RECIPIENT, the PROVIDER will inform the RECIPIENT what methods are available for distributing the PRODUCT. These include: using the File Transfer Protocol (FTP) to send the PRODUCT via the internet; distributing the PRODUCT on CD-ROM(s); distributing the PRODUCT using magnetic tapes and diskettes media.

Distribution Liability

Although these data have been processed successfully on a computer system at PROVIDER, no warranty, expressed or implied, is made regarding the accuracy or utility of the data on any other system, or for general or scientific purposes, nor shall the act of distribution constitute any such warranty. This disclaimer applies both to individual use of the data and aggregate use with other data. It is also strongly recommended that careful attention be paid to the contents of the metadata file associated with these data. PROVIDER shall not be held liable for improper or incorrect use of the data described and/or contained herein.

Transaction Costs and Fees

If the PRODUCT is **not** copyrighted and subject to a licensing fee, the PROVIDER will provide a copy of the PRODUCT with relevant documentation to the RECIPIENT. If the PRODUCT is subject to a licensing fee, or otherwise not available for transfer from PROVIDER, the PROVIDER will notify the RECIPIENT of the specifics of how the PRODUCT can be obtained from the OWNER.

Documentation

The PROVIDER will supply to RECIPIENT a copy of all readily-available documentation relating to the PRODUCT, including metadata and data dictionaries.

Standards

The parties to this agreement agree to apply, as possible and feasible, existing standards for documentation, metadata, data formats, geographic accuracy, and database design as promulgated by the Federal Geographic Data Committee.

Terms of Agreement

This agreement will remain in force until cancelled. The parties to this agreement have the right to withdraw from this agreement by giving written notice to all signatory parties.

Iris Priestaf
Signature

Iris Priestaf
Printed Name

President
Title

Todd Engineers
Company/Organization

Dec 11 2008
Date

510 747 6920
Telephone Number

ipriestaf@toddengineers.com
E-Mail Address

ATTACHMENT A

Description of PRODUCT

(Insert all metadata information here. Include any and all information necessary to completely identify and specify the PRODUCT that is the subject of this agreement.)

CITY OF MOUNTAIN VIEW

Public Works Department • Public Services Division • GIS/CMMS Section
231 N Whisman Road • Post Office Box 7540 • Mountain View, California 94039-7540 • 650-903-6480• FAX 650-968-5472

NONDISCLOSURE AGREEMENT

1. Todd Engineers ("Contractor") and the City of Mountain View, California ("City"), executed an agreement, entitled Groundwater Vulnerability Study, on 2/25, 2009 ("Agreement"). In order to facilitate performance under the Agreement, Contractor and City further agree to terms and conditions as set forth in this Nondisclosure Agreement ("NDA"). The parties further agree that the term of this NDA shall run concurrent with the term of the Agreement.

2. For purposes of this NDA, "Confidential Information" means information which is of a nonpublic, proprietary or confidential nature, including, without limitation, all reports and analyses, technical and economic data, studies, forecasts, trade secrets, research or business strategies, financial or contractual information, rates, certain sales market information, research, developmental, engineering, technical, marketing, sales, financial, operating, personnel, performance, cost, business and process information or data, know-how, and computer programming or other written or oral information. Confidential Information may be in any form whatsoever, including, without limitation, writings, recordings, electronic or oral data, computer programs, logic diagrams, component specifications, drawings or other media.

3. In order to enable Contractor carry out its responsibilities under the Agreement, the City may disclose or allow access to certain Confidential Information to Contractor and its subcontractors. Such disclosure shall be considered authorized and not a disclosure to the public or outside the City. Any such disclosure is subject to and shall be in accordance with all conditions and limitations set forth herein.

4. The Confidential Information: (i) may be used by Contractor solely in connection with performing the work required under the Agreement; and (ii) will be kept confidential and not disclosed by the Contractor to any other person, except that Confidential Information may be disclosed to any of the Contractor's affiliates, directors, officers, employees, attorneys and agents (collectively, its "Representatives") who require access to such information in connection with the performance of work under the Agreement. Contractor agrees that any of its Representatives to whom Confidential Information is disclosed will be informed of the confidential or proprietary nature thereof and of the Receiving Party's obligations under this Agreement. Each Party shall be responsible for any use of Confidential Information by any of its Representatives.

5. City or its agents shall grant access to all necessary information until such time as it is no longer required for the performance of work under the Agreement, the Agreement is completed or terminated, the Contractor requests termination of access or City terminates access to Confidential Information.

6. Intending to be legally bound, the Contractor accepts the obligations contained in this NDA in consideration of being granted access to all required information. The Contractor acknowledges that all obligations imposed by this NDA concerning use and disclosure of any information pertaining to the City's Information Technology infrastructure apply for the duration of the Agreement and at all times thereafter.

7. The Contractor agrees that Confidential Information shall be used only as needed for the performance of work under the Agreement.

8. The Contractor agrees to adopt operating procedures and physical security measures to properly safeguard Confidential Information from unauthorized use and from disclosure or release to unauthorized third parties and to provide documentation of these procedures to City for review.

9. The Contractor agrees to return to the City all copies of documents containing Confidential Information provided pursuant to this NDA upon request by the City, when the information is no longer required for the performance of work under the Agreement, or upon completion or termination of the Agreement, whichever comes first.

10. Each provision of this NDA is severable. If a court should find any provision of this Agreement to be unenforceable, all other provisions of this NDA shall remain in full force and effect.

☑ **Contractor/Vendor**

Date (mm/dd/yy): 02/25/09

Name: Iris Priestaf
(Typed or printed)

Signature: [signature]

Title: President

Address: 2490 Mariner Square Loop, Suite 215

City/Street/Zip: Alameda, CA 94501-1080

Phone Number/Fax Number: (510) 747-6920 (510) 747-6921

E-mail: ipriestaf@toddengineers.com

Submit to Public Services Division, GIS/CMMS Section

AS-12^(Nondisclosure Agreement)
(9/22/06)

Appendix C
Logistic Regression Model Results

Model 1

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Upper
Constant	-1.070650	0.796959	-1.34	0.179			
SOIL	0.289210	0.093641	3.09	0.002	1.34	1.11	1.60
DEPT TO WATER	-0.231517	0.051488	-4.50	0.000	0.79	0.72	0.88
RECHARGE ALT1	0.348786	0.062018	5.62	0.000	1.42	1.26	1.60
IMPACTVADOSE ALT1	-0.209718	0.056247	-3.73	0.000	0.81	0.73	0.91

Log-Likelihood = -273.216
Test that all slopes are zero: G = 60.289, DF = 4, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	34913	69.8	Somers' D	0.42
Discordant	13674	27.3	Goodman-Kruskal Gamma	0.44
Ties	1454	2.9	Kendall's Tau-a	0.19
Total	50041	100.0		

****

Model 2

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Upper
Constant	-2.73794	0.634455	-4.32	0.000			
SOIL	0.321253	0.0825956	3.89	0.000	1.38	1.17	1.62
RECHARGE ALT1	0.246499	0.0538315	4.58	0.000	1.28	1.15	1.42

Log-Likelihood = -286.852
Test that all slopes are zero: G = 33.017, DF = 2, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	25889	51.7	Somers' D	0.26
Discordant	12971	25.9	Goodman-Kruskal Gamma	0.33
Ties	11181	22.3	Kendall's Tau-a	0.12
Total	50041	100.0		

****

Model 3

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Upper
Constant	2.89835	0.828084	3.50	0.000			
DEPT TO WATER	-0.287201	0.0538072	-5.34	0.000	0.75	0.68	0.83
DEPTH TO 1ST SCREEN	-0.0034032	0.0008749	-3.89	0.000	1.00	0.99	1.00
RECHARGE ALT2	0.152616	0.0637240	2.39	0.017	1.16	1.03	1.32
SOIL	0.199136	0.0894290	2.23	0.026	1.22	1.02	1.45
IMPACTVADOSE ALT2	-0.400123	0.0850769	-4.70	0.000	0.67	0.57	0.79

Log-Likelihood = -270.072
Test that all slopes are zero: G = 66.577, DF = 5, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	35713	71.4	Somers' D	0.43
Discordant	14130	28.2	Goodman-Kruskal Gamma	0.43
Ties	198	0.4	Kendall's Tau-a	0.20
Total	50041	100.0		

****

Model 4

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Upper
RECHARGE ALT2	0.0603276	0.0321703	1.88	0.061	1.06	1.00	1.13
SOIL	0.256100	0.0777497	3.29	0.001	1.29	1.11	1.50

Log-Likelihood = -296.193
Test that all slopes are zero: G = 14.337, DF = 2, P-Value = 0.001

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	24207	48.4	Somers' D	0.11
Discordant	18619	37.2	Goodman-Kruskal Gamma	0.13
Ties	7215	14.4	Kendall's Tau-a	0.05
Total	50041	100.0		

****

Model 5

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Upper
Constant	0.573418	1.00987	0.57	0.570			
Conductivity ALT3	1.51973	0.290260	5.24	0.000	4.57	2.59	8.07
IMPACTVADOSE ALT2	-0.248075	0.0672467	-3.69	0.000	0.78	0.68	0.89
SOIL (1/4 Mile)	0.253179	0.120596	2.10	0.036	1.29	1.02	1.63
DEPTH TO 1ST SCREEN	-0.004596	0.0009049	-5.08	0.000	1.00	0.99	1.00
RECHARGE ALT 3 (1/4)	0.268238	0.0480945	5.58	0.000	1.31	1.19	1.44
DTWRATE	-0.277593	0.0589545	-4.71	0.000	0.76	0.67	0.85

Log-Likelihood = -225.913
Test that all slopes are zero: G = 154.895, DF = 6, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	40978	81.9	Somers' D	0.64
Discordant	8938	17.9	Goodman-Kruskal Gamma	0.64
Ties	125	0.2	Kendall's Tau-a	0.29
Total	50041	100.0		

****

Model 6

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Upper
Constant	-3.26206	0.684752	-4.76	0.000			
Conductivity ALT3	1.51076	0.277349	5.45	0.000	4.53	2.63	7.80
SOIL (1/4 Mile)	0.377499	0.110401	3.42	0.001	1.46	1.17	1.81
RECHARGE ALT 3 (1/4)	0.268592	0.047432	5.66	0.000	1.31	1.19	1.44
DEPTH TO 1ST SCREEN	-0.002599	0.000714	-3.64	0.000	1.00	1.00	1.00

Log-Likelihood = -240.425
Test that all slopes are zero: G = 125.871, DF = 4, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	39491	78.9	Somers' D	0.58
Discordant	10377	20.7	Goodman-Kruskal Gamma	0.58
Ties	173	0.3	Kendall's Tau-a	0.26
Total	50041	100.0		

****

Model 6 Standardized

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Upper
Constant	-0.437070	0.242151	-1.80	0.071			
CONDUCTIVITY AL3	1.51076	0.277349	5.45	0.000	4.53	2.63	7.80
SOIL MEDIA (1/4 MILE)	0.412228	0.120558	3.42	0.001	1.51	1.19	1.91
RECHARGE ALT3	0.693054	0.122391	5.66	0.000	2.00	1.57	2.54
DEPTH TO 1ST SCREEN	-0.427748	0.117589	-3.64	0.000	0.65	0.52	0.82

Log-Likelihood = -240.425
Test that all slopes are zero: G = 125.871, DF = 4, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	39491	78.9	Somers' D	0.58
Discordant	10377	20.7	Goodman-Kruskal Gamma	0.58
Ties	173	0.3	Kendall's Tau-a	0.26
Total	50041	100.0		

Nitrate Threshold Analysis

Model 10 mg/L - Step

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower
Constant	-3.26206	0.684752	-4.76	0.000		
Annual ProdGT100	1.51076	0.277349	5.45	0.000	4.53	2.63
SOILRATE_1320	0.377499	0.110401	3.42	0.001	1.46	1.17
REV_RECHARGERATE2_1320	0.268592	0.0474325	5.66	0.000	1.31	1.19
PERF1_TOP	-0.0025990	0.0007145	-3.64	0.000	1.00	1.00

Log-Likelihood = -240.425
Test that all slopes are zero: G = 125.871, DF = 4, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	39491	78.9	Somers' D	0.58
Discordant	10377	20.7	Goodman-Kruskal Gamma	0.58
Ties	173	0.3	Kendall's Tau-a	0.26
Total	50041	100.0		

****

Model 15 mg/L

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower
Constant	-2.49455	0.389045	-6.41	0.000		
Annual ProdGT100	0.953385	0.295160	3.23	0.001	2.59	1.45
REV_RECHARGERATE2_1320	0.349487	0.0483650	7.23	0.000	1.42	1.29
PERF1_TOP	-0.0015104	0.0006724	-2.25	0.025	1.00	1.00

Log-Likelihood = -268.996
Test that all slopes are zero: G = 109.807, DF = 3, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	42020	76.7	Somers' D	0.54
Discordant	12611	23.0	Goodman-Kruskal Gamma	0.54
Ties	153	0.3	Kendall's Tau-a	0.27
Total	54784	100.0		

Model 20 mg/L

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower
Constant	-4.03512	0.536008	-7.53	0.000		
Annual ProdGT100	0.965001	0.365212	2.64	0.008	2.62	1.28
REV_RECHARGERATE2_1320	0.501723	0.0624081	8.04	0.000	1.65	1.46
PERF1_TOP	-0.0019039	0.0007697	-2.47	0.013	1.00	1.00

Log-Likelihood = -225.933
Test that all slopes are zero: G = 142.692, DF = 3, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	39576	81.3	Somers' D	0.63
Discordant	8938	18.4	Goodman-Kruskal Gamma	0.63
Ties	150	0.3	Kendall's Tau-a	0.28
Total	48664	100.0		

****

Model 30 mg/L

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower
Constant	-7.28139	1.04465	-6.97	0.000		
Annual ProdGT100	2.22462	0.762428	2.92	0.004	9.25	2.08
REV_RECHARGERATE2_1320	0.704854	0.0951430	7.41	0.000	2.02	1.68
PERF1_TOP	-0.0036320	0.0010964	-3.31	0.001	1.00	0.99

Log-Likelihood = -146.527
Test that all slopes are zero: G = 166.018, DF = 3, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	30088	88.0	Somers' D	0.76
Discordant	4014	11.7	Goodman-Kruskal Gamma	0.76
Ties	98	0.3	Kendall's Tau-a	0.24
Total	34200	100.0		

Model 40 mg/L

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower
Constant	-8.29986	1.33668	-6.21	0.000		
REV_RECHARGERATE2_1320	1.02297	0.157026	6.51	0.000	2.78	2.04
PERF1_TOP	-0.0055913	0.0018093	-3.09	0.002	0.99	0.99

Log-Likelihood = -97.084
Test that all slopes are zero: G = 141.060, DF = 2, P-Value = 0.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	20715	92.2	Somers' D	0.85
Discordant	1684	7.5	Goodman-Kruskal Gamma	0.85
Ties	65	0.3	Kendall's Tau-a	0.17
Total	22464	100.0		