NITRATE CONCENTRATION PATTERNS IN CALIFORNIA GROUNDWATER

by

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DEDICATION

This is dedicated to my wonderful husband Kevin who has supported this effort from the beginning and my son Shane for kick starting the process.

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I would like to thank my thesis committee for their support and advice. Without their assistance I would not be where I am today as a scientist and a student. My family has been invaluable during this process and I owe to them my success on this project.

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ABSTRACT

NITRATE CONCENTRATION PATTERNS IN CALIFORNIA GROUNDWATER

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This thesis used publically available data on nitrate concentrations in California water supply wells to analyze nitrate concentration patterns in California's groundwater. Delaunay triangulation was used with nitrate values in water supply wells to create polygons representing areas predicted to be above California's Maximum Contaminant Level for nitrate as $NO^3$of 45 mg/L. These areas were used to analyze what types of land use, soil types, and groundwater basins might be found in areas of high nitrate concentration. These areas were also buffered at 1, 5, and 10 miles and the buffer areas used to analyze proximity to environmental management wells where high nitrate concentrations were monitored by the State. Zones of high nitrate concentrations were created using the entire year's worth of data and were created for each month individually. The monthly breakouts allowed for patterns of seasonality to be considered during the analysis.

INTRODUCTION

The Sacramento River Hydrologic Region (SHR) covers about 17.4 million acres in north-central California – it is a HUC4 level watershed numbered 1802. HUC stands for hydrological unit code – a sequence of numbers or letters that identify a hydrological feature or area. HUC range from 2 – 12 digits (in even number sequences) and HUC 4 level identifies a subregion that is about 16,800 square miles. The Sacramento Valley forms the core of the region and the Sacramento metropolitan area and the surrounding communities make up most of the population in this area. The SHR is the main water supply for much of California's urban and agricultural areas and the annual runoff averages nearly one-third of the State's total natural runoff (CDWR 2003). Groundwater provides about 31 percent of the water supply for the urban and agricultural uses in the region. Groundwater quality in the SHR is generally excellent although there are local groundwater problems. In this region, human-induced impairments like nitrate are generally associated with agriculture and septic tanks. Nitrate has been identified as a possible impairment and modeling the flow of past nitrate levels in the SHR may help identify target areas for focusing water quality program efforts.

The California Department of Public Health regulates nitrate as a drinking water contaminant. The State has set the Maximum Contaminant Level (MCL) for nitrate as NO^3 at 45 mg/L (SWCB GAMA 2010). California is the only state that has set a MCL for nitrate in units of NO^3 rather than nitrate-N (UC 2002). This accounts for the apparent disparity between the California standard (45 mg/L) and the federal standard set by USEPA at 10 mg/L. However, these two limits are comparable measures of nitrogen levels. Nitrate-N standards are only concerned with the amount of nitrogen and not the oxygen. The atomic weight of NO^3 is 62.01 and that of N is 14.01 – thus NO^3 is 4.4 times as heavy as N. California's standard of 45 mg/L divided by the conversion factor of 4.4 is essentially equal to the federal standard of 10 mg/L nitrate-N. As a point of reference, nitrate concentrations in natural groundwaters are typically less than 2 mg/L nitrate as nitrogen, which is equivalent to approximately 9 mg/L nitrate as NO^3.

California's Groundwater Update of 2003, a summary of water quality from public supply water wells sampled from 1994 through 2000, showed 74 of 1,356 wells having constituents that exceeded one or more of the State's MCLs for drinking water. Nitrates were one of the most frequently exceeded constituents (CDWR 2009). In June of 2010, 1,077 standby and drinking water wells out of 13,153 sampled through the GeoTracker GAMA program had concentrations of nitrate above the MCL – and these figures did not include private domestic wells, nor wells used by smaller systems not regulated by the California Department of Public Health (SWCB GAMA 2010).

Studies of Nitrate in Ground Water

Given the importance of groundwater in California, it is important to monitor pollutants of possible concern. It is estimated that about 10% of California public drinking water supply wells produce water that exceeds the State MCL and many more produce water which approaches the limit (UC 2005). According to the Lawrence

Livermore National Laboratory, the activities that contribute anthropogenic nitrate to groundwater include animal operations, crop fertilization, wastewater treatment discharge and septic systems. These are ongoing and essential to the industry and commerce of the State of California (UC 2002). The SHR is currently a primarily agriculturally-based area with many of its rural residents using septic systems (CDWR 2003).

Land Use/Land Cover

The relationship between land use and water quality has been well studied. Point and nonpoint sources can pollute surface and groundwaters and to manage pollutants a link to sources must be identified. Nitrates can enter groundwater through runoff from agricultural or developed lands, through leaking septic systems, from agricultural ponds, or in wastewater discharged from treatment plants. The link between nitrate concentrations and land use is an important aspect of analysis.

Through analysis of groundwater nitrate concentrations on Nantucket Island, Massachusetts, it was demonstrated that historic nitrate concentrations downgradient from agricultural land were significantly higher than nitrate concentrations elsewhere. Tobit regression results were able to demonstrate that the number of septic tanks and the percentages of forest, undeveloped and high-density residential land within a 1000-foot radius of a well were reliable predictors of nitrate concentration in groundwater. Logistical regression revealed that percentages of forest, undeveloped, and low-density residential land were good indicators of groundwater nitrate concentrations great than 2 mg/L (Gardner and Vogel 2005). A study in Italy showed that poor management of irrigation and fertilization practices cannot be separated from unfavorable hydrodynamic conditions. Higher nitrate levels corresponded with early planting and fertilization times in local agricultural areas (Guimera 1998).

A study of the Sierra Pelona Watershed in southern California examined a small rural groundwater basin where water has been seriously impacted by nitrate – 42% of wells sampled in this area were above the USEPA MCL for drinking water. Three distinctive modes of contamination were illustrated. Isolated contaminations referred to individual wells with high nitrate concentrations that were flanked by neighboring wells with lower to negligible levels. This type of contamination linked land use with local geologic characteristics – the paper notes that this pattern of contamination implies a ubiquitous contaminant reaching groundwater through several similarly and highly localized conduits (or there could be a non homogenous aquifer that was sampled at different heights by the neighboring wells). Aquifers with localized contamination showed fractured basement-rock. The observations pointed to septic and/or animal sources for the contaminants as the sampled water wells were in close proximity to these types of contamination. Regional contamination had more moderate nitrate values over a larger area. The paper found that animal and human wastes were a likely contaminant source for these areas (Williams et al 1998).

Soil Characteristics

Hydraulic conductivity (expressed as mathematical variable K) is the ability of a porous medium to transmit a specific fluid under a unit hydraulic gradient and is a function of both the characteristics of the medium (soil) and the properties of the fluid transmitted (groundwater). K is sometimes used interchangeably with the term permeability, but permeability refers to the specific soil property designating the rate at which liquids can flow through the soil. Relative permeability and K are related with very porous materials being of high permeability and high K (e.g. gravel or cavernous limestone) and nonporous materials being of low permeability and low K (e.g. silt or mudstone) (Ward and Trimble 2004). Soil characteristics affect groundwater flow and are important to consider when looking at the spatial distribution of nitrate concentrations.

Groundwater flow modeling has been studied and Felletti, Bersezio, and Giudici noted that realistic models of groundwater flow through alluvial aquifers relies on the knowledge of the distribution of porosity and K of sediments. Their work modeled groundwater flow in a Pleistocene glaciofluvial gravel-sand aquifer analogue (this was exposed at a quarry site in the southern Ticino Valley, in northern Italy.) A realistic model of the 3D hydraulic conductivity field was developed at the scale of the elements of the depositional architecture. This modeling effort used a multidisciplinary approach combining sedimentology, geostatistics, and numerical analysis.

Many groundwater studies of nitrate concentrations have noted the soil types of the study areas. High nitrate concentrations do seem to correspond to areas with soils that transmit groundwater easily. The Nantucket Island, Massachusetts study above was done in a community with a shallow water table that is overlain with highly permeable materials (Gardner and Vogel 2005). The Guimera study looked at coastal aquifers and noted that those heavily polluted by nitrate composition tend to be of coarse detrital nature. These areas form alluvial fan complexes which interfinger with marine sand bodies and consist mainly of unconsolidated materials with a low percentage of clay and silt. Transmissivity vales in these areas are high (10^{-5} to 10^{-3} m^2/s) (Guimera 1998).

Well Depth and Aquifer Configuration

The vertical groundwater profile is another important aspect of consideration for nitrate concentration analysis. Many studies have noted the effects of well penetration depth on observed chemical concentrations. There is also discussion about aquifer composition – depth, recharge zones, and physical characteristics. Sampling site characteristics can affect the concentrations of nitrate observed – shallow wells are more likely to have higher concentrations than deeper wells, wells in recharge zones may have higher concentrations than those in more static areas, and the physical characteristics of the sampled aquifer can affect groundwater flow patterns.

Guimera relates nitrate concentrations to agricultural areas located in aquifer recharge zones. This type of area sees a great flux in new water verses the older, deeper part of the aquifer. Zones of depleted water table display highest concentration of contaminant due to shallow recycling, not including deeper water and therefore shallow quality gets worse. The study also noted some generalities about partial penetration wells: samples taken higher in the water table will be more concentrated than those taken from deeper penetration. The study results showed that shallow wells which exploit only a thin layer of the aquifer just below the water table were variable from year to year and tended towards higher nitrate concentrations than deeper wells (Guimera 1998).

The Sierra Pelona watershed (located in southern California) study noted the geology of the region in its review of all three types of contamination modes. Individual contamination noted that contaminants were likely to flow through conduits and the areas with the highest contaminant levels was commonly in fracture basement-rock aquifer regions. Isolated fractures in the basement-rock could connect individual wells to near-surface nitrate sources. Areas of cluster contamination in a single region where sheetflow runoff flowed into a local canyon. Chemical and isotopic data from rock and soil staples proposed a dominance of natural soil and rock nitrate – this was suggested to flow into groundwater through drainages, coarse canyon sediments, and faulting. Moderate nitrate levels in areas of regional contamination were linked to flow from other regions through permeable sediments (Williams et al 1998).

Seasonality

In the Guimera study, an observation of sample plots noted that aquifer pollution occurred mainly at the beginning of the growing season due to overwatering. Later in the season as the plants became adult, fertilization and watering were better adjusted to plant needs (Guimera 1998). Williams et al noted large shifts in ion composition following intense rainfall and flooding of the valley during the winter rainy season – though rainfall was more than double the long-term mean rainfall for the region and nearly four times greater than the annual rainfall. During the dry period levels began to return to preflood conditions (Williams et all 1998). This is not a link from anthropomorphic sources of nitrate to groundwater contamination, but it does demonstrate that local conditions matter and that it is important to consider dry vs wet seasons during data analysis.

Studies of Nitrate in California Groundwater by the State

Nitrate concentrations in California groundwater have been studied in a number of locations – a number of these studies have been funded by the State. The California State Water Resource Control Board (SWRCB) established the Groundwater Ambient Monitoring and Assessment (GAMA) Program in 2000. GAMA is the State's comprehensive groundwater quality program and its goals include improving statewide groundwater monitoring and increasing the availability of groundwater quality information to the public. One study of the sources and transport of nitrate in shallow groundwater in Santa Clara County (Llagas Basin) noted that nitrate is, "the most pervasive and intractable contaminant in California groundwater (UC 2005, page 3)" and thus is the focus of a number of GAMA Program studies. Best management practices were noted as reducing source loading but not eliminating it and the expense of nitrate removal was considered. The study noted that those factors made nitrate the greatest contaminant threat to the State drinking watery supply (UC 2005).

The Llagas Basin study found that time series reconstructions of past nitrate concentrations from monitoring data showed a statistically significant upward trend from the 1960's through the study year. The most recent data used showed flat or slightly increasing trends when compared with previous data. A nitrate management plan has been in place in the area since 1997 and the trends in the report show that despite best efforts nitrate continues to be a water quality issue in the area. Shallow wells showed higher nitrate concentrations than deeper wells – the transition from high to low nitrate could be due to hydrogeologic factors – a laterally extensive aquitard could be recharged with nitrate-laden water but remain isolated from more pristine waters below. CO^2 partial pressure values did not support manure and/or septic discharge as dominant sources of nitrate in the samples tested but nitrate in the most contaminated wells had a fertilizer source signature. Groundwater age and recharge patterns also affected results – the wells with the highest nitrate concentrations all had young groundwater ages (between 4 years and less than 1 year) which means that a high nitrate flux to groundwater is ongoing in areas of natural recharge. One major source of recharge was conjectured to be irrigation return flow making rapid recycling of high-nitrate groundwater used for irrigation a plausible scenario (UC 2005).

Another study of nitrate fate and transport was conducted in Livermore, CA by the Lawrence Livermore National Laboratory in cooperation with the California SWRCB. Nitrate MCL exceedances occurred in 6 of the 13 public supply wells in the contaminated portion of the basin. A multiple-analysis approach using current and historical data allowed a study of nitrate sources in the basin. Water sources were identified using stable isotopes and groundwater residence times and transport behavior were described with tritium-helium age dating. Dissolved gas and nitrate isotope evidence indicated that nitrate movement is conservative in the groundwater. Nitrate isotope measurements were combined with information about land use history to identify contaminant sources. Fertilizer and natural soil nitrogen were significant contributors. Nitrate concentrations were amplified by artificial recharge in the source area – an unconfined aquifer with high vertical recharge. The approach can be used in other areas to help manage groundwater resources.

GAMA includes the Domestic Well Project which provides volunteers with free domestic well water sampling for commonly detected pollutants. Nitrate is one of the nutrients tested for through the program. Of the five different county focus areas sampled to date, three are in the SHR – El Dorado, Tehama, and Yuba. During 2003 and 2004 there were 398 private domestic wells sampled in El Dorado County and nitrate was one of the three most common primary contaminants. 256 domestic wells had detections of nitrate, 100 had concentrations above 9 mg/L and seven were listed for nitrate higher than the allowable standard (SWRCB GAMA 2005). GAMA sampled 223 wells in Tehama County during 2005. 208 domestic wells had detections of nitrate and two were listed for nitrate levels above the MCL (SWRCB GAMA 2009). Yuba County had 128 wells sampled in 2002. Nitrate was detected in 76 wells and two had concentrations above the MCL (SWRCB GAMA 2012).

Interpolation in Groundwater Studies

Groundwater data collection is generally limited by time and funding and the spatial sample size can often be insufficient to map concentrations over larger areas in order to point out "trouble spots." Spatial interpolation is one way to create a map of the sampling area when a limited number of datapoints is available. The kriging method of interpolation has been used with soil and hydrologic data successfully in the past and is a standard tool in groundwater quality research.

Kriging is a geostatistical method of interpolation, as opposed to a deterministic interpolation method such as the inverse distance weighted or Spline methods. Geostatistical methods are based on statistical models that include autocorrelation (the statistical relationships among the measured points). Geostatistical methods provide a measure of accuracy for their predictions because of the underlying processes (ESRI 2011). Kriging is divided into two tasks: quantifying the spatial structure of the data (variography) and then producing a prediction. Variography involves fitting a spatial-dependence model to the data. Kriging uses the fitted model, the spatial data configuration, and the values of the measured sample points around the prediction location to produce the interpolation data layer (ESRI 2009).

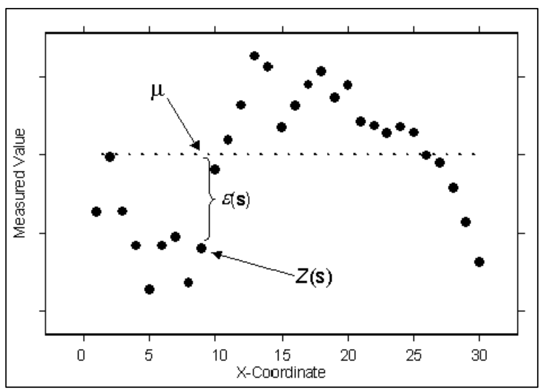


Figure 1: Example of Ordinary Kriging

Ordinary kriging assumes the model: Z(**s**) = μ + ε(**s**) where Z is the measured value, ε is the error and μ is the constant (but unknown) mean. It is the most general and widely used of the kriging methods and a reliable default. Data points for ordinary kriging must be sampled from a phenomenon that is constant in space. The data must have the appropriate transformation, may need to have global trends removed, has a covariance/semivariogram model applied, and takes into account the search neighborhood – the distance at which it is appropriate to apply the interpolation equation.

There are a number of data models available to be used with kriging data. These data models quantify the assumption that things near to each other tend to be more similar than those further apart. They measure the strength of statistical correlation as a function of distance. Ordinary kriging in ArcGIS 10 can be used with the following models: spherical, circular, exponential, Gaussian, or linear. The Geostatistical Wizard provides three different views of the empirical semivariogram values that can be used to identify the “best fit” model for the data at hand. The spherical model shows a progressive decrease of the spatial auto correlation until a point is reached where the autocorrelation is zero. This method fits a common understanding of nutrient data – data from counties miles apart are unlikely to be related to each other whereas adjacent counties are likely to have some type of correlation, though it may be weaker the further apart the samples get (ESRI 2011).

Nas and Berktay detailed the methodology for applying the kriging method of interpolation to groundwater parameters. The research produced a groundwater quality map of Konya City, Turkey and related water quality parameters to local soil and land use types. The research detailed data preparation including confirming normal distribution of the data. If the data were not normally distributed a log transformation was applied to bring the data closer to normal. The trending tool in ArcGIS was applied confirm no global trends in the data. A number of semivariogram models were applied and cross validations were performed to identify the best-fit model. An accurate model should produce a standardized mean error of close to 0 and the root-mean-square error (RMSE) and average standard error should be small (compared to the other models) and the root-mean square standardized error should be close to one. Those models where the average estimated prediction standard errors were close to the RMSE prediction from cross-validation were considered those where the prediction standard errors were appropriate.

Baxter and Oliver used the kriging method to explore the accuracy of predictions of the plant available N properties. Data from soil surveys are often sparse, even though they might be spatially autocorrelated, the lack of datapoints can lead to considerable uncertainty in the kriged predictions. Ordinary kriging was tested and intensive elevation data were used as the secondary variable for the following methods: cokriging, kriging with external drift and regression kriging. The mean squared errors of prediction from these methods of kriging were determined at validation sites where the values were known. Kriging with external drift resulted in the smallest mean squared error for two of the three properties examined, and cokriging for the other. The results suggest that the use of intensive ancillary data can increase the accuracy of predictions of soil properties in arable fields provided that the variables are related spatially.

Gundogdu and Guney note that kriging provides the best linear unbiased estimation for spatial interpolation. They tested different semivariogram models with universal kriging (with linear drift) and rated the accuracy of the semivariograms in predicting the water table values based on monthly water table observations in the Mustafakemalpasa irrigation system in the Marmara region of Turkey. The data needed a log transformation to help normalize the data prior to analysis. A variety of semivariogram models were then tested and their RMSE values compared through trial and error. The differences between RMSE values of the models were found statistically important and the lowest RMSE values were considered the best. The rational quadratic semiovariogram model was the most suitable for completing the missing data in water table measurements – but the spherical, circular, tetraspherical and pentaspherical semivariogram models gave nearly the same water table surface maps. (Gundogdu and Guney 2007).

Kriging interpolation data can illustrate where high values of nitrate do exist and extrapolate concentrations in areas where no data were collected. However, sampling size and locations do matter in kriged interpolation layers. In a controlled, hypothetical study (Luzzadder- Beach 1995) a 15% sampling density was shown to be sufficient to capture larger trends – this equaled about 5 wells per California township. However, studies are limited to the data that are available. Though a water monitoring program must be designed with a certain goal in mind to be useful, monitoring well selection is often limited when working with a set of currently existing wells (Luzzadder-Beach 1992).

Delaunay triangulation is another way to create a derived surface and interpolate data values. This method creates a triangulated irregular network (TIN) which is a form of digital terrain modeling. Digital terrain models (DTMs) are information systems that store, manipulate and display information about terrain and the dominant componenet is the surface structure as opposed to coverate (Peucker 1979). Modeling terrain is an important component of spatial analysis and has a long history of scientific research within the community. As early as the late 1950s, civil engineers started to use computers to calculate terrain profiles across highway trasses (Peucker 1979). Problems with traditional terrain representations were recognized as early as 1967 (Peucker 1979). Non-stationary topographic surfaces force a regular grid to be adjusted to the roughest terrain in the model which makes the surface highly redundant in smooth terrain. An accurate and efficient model would was needed to model these surfaces and the DTM system should contain those features which were the natural units of analysis for the "real world" problems to be solved (Peucker et al 1979). During the 1970s large amounts of theortetical and applications-based research was taking place at the Harvard Laboratory for Computer Graphics and Spatial Analysis and in 1975 Poiker and Chrisman published what is probably the first mention of the TIN structure that is common today in *The American Geographer*. Poiker (or Peucker) published a number of the early articles on TIN data structures and is noted as defining the TIN as an irregular point structure capable of containing the minimal amount of data that can define a surface and where the neighbors of every point are found by a triangulation of the point set (Plews 1989).

TINs are now widely used to display natural or derived data surfaces in GIS software. This was not always the case – earlier in the history of GIS software only a few packages were able to deal fully with a third dimension of data (Kraak 1993). A basic definition of a TIN would call it a list of points and their coordinates that are stored with a corresponding file containing information about the topology of the network (Clarke 2003). TINs are a form of vector-based digital geographic data and are created by triangulating the set of points in the system – the vertices are connected with a series of edges to form a network of triangles. A TIN is a flexible way to represent highly variable surfaces (such as rough terrain) because the method of construction allows the nodes to be placed irregularly over a surface (ESRI 2010).

METHODS

Ideally, a groundwater model could be used to simulate flow through a watershed using data including groundwater depth, nutrient concentration, soil conductivity (based on soil type), and precipitation patterns. A stronger model would include surface flow and incorporate land use/land cover data which would capture areas of potential nonpoint source flow as well as registered point sources. See Figure 2 for an example of how these data could work together to form a model of nutrient flow. Using a model such as this it would be possible to gather information on where in the watershed nitrate concentrations would be highest. Physical properties of the watershed used in the model would be parameters affecting nitrate concentration. If these parameters were known it is possible that they could become indicators of high nitrate concentrations in other areas – this would be useful for watershed planning efforts and local water quality monitoring activities. Nitrates can have serious effects on local populations if ingested in large quantities. These effects include methemoglobinemia also called “blue-baby” syndrome. This is a condition in wich there is a reduction in the oxygen-carrying capacity of the blood. In the absence of a mathematical model, a different analytical approach must be undertaken to identify parameters that would indicate possible nitrate contamination zones.

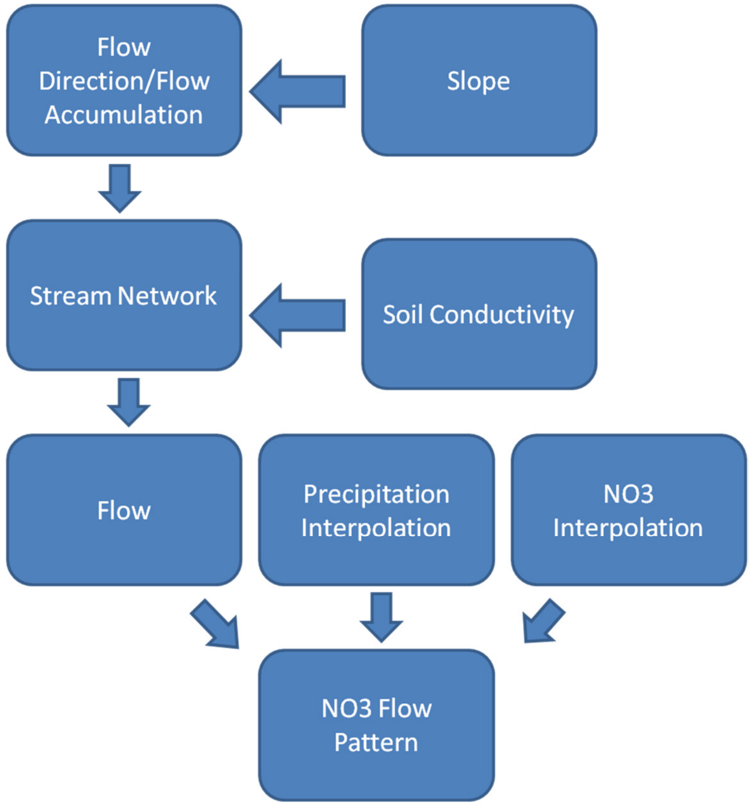


Figure 2: Theoretical Groundwater Model

Data and Scale

In absence of a full data model an interpolation method based on sufficient data points and secondary data including groundwater basins, land use, soil types, and proximity to known sources of NO^3 could be used to identify areas of concern for nutrient pollution. Through California's GeoTracker GAMA data for NO^3 concentrations were collected for 2006 for both for water supply wells and environmental monitoring wells. Many data points for the environmental monitoring wells are well above the 45 mg/L MCL allowed by California's Code of Regulation. A number of the water supply wells exhibit concentrations greater than the MCL as well.

This work looked at a large and complex area where many factors influence nutrient flow through groundwater. It is difficult to model a complex system over large distances – too many variables are present that can affect the outcome. However, locating areas of concern and analyzing the patterns of local conditions can help identify parameters of that may help in identification of possible areas of high nitrate concentration. Areas can be identified using general parameters and field sampling can confirm or deny nitrate pollution.

For this project, all nitrate concentration data comes from wells drilled in the SHR in northern California. The largest dataset is of water supply wells in the SHR. This data comes from a number of different types of wells and from different agencies. USGS provided data from water that is typically treated, disinfected, or blended with other waters after withdrawal to maintain acceptable water quality. The California Department of Water Resources provided data from irrigation, stock or domestic wells through a program that monitors groundwater basins in Northern California to determine water quality and related factors affecting beneficial uses. A number of wells were monitored by the California Department of Health Services. The smaller set of data came from environmental monitoring wells at regulated facilities that in many cases have identified contamination. The environmental monitoring well positions are geographically accurate according to the California Waterboards website, but the public water supply wells are only accurate to within 0.5 miles (SWRCB 2008). All data were collected from January 1, 2006 through December 31, 2006. This year was chosen when a ten-year block of data were identified and both sets of wells showed incidences of levels of nitrate higher than the MCL.

Data points for this process were limited to what was publically available within the SHR. Water quality monitoring data are costly and time consuming to collect and often what is available is limited by funding and availability of existing monitoring programs. In a larger watershed like the SHR this can result in an uneven spread of data (see the figure illustrating well locations). Geographic distribution of analysis data points should be as uniform as possible so that results are a fair representation of the study area. However sometimes data are simply unavailable – this means that analysis must proceed even under data-limited conditions. This is an unfortunate reality faced by the public sector – data are often limited and yet the project must move forward.

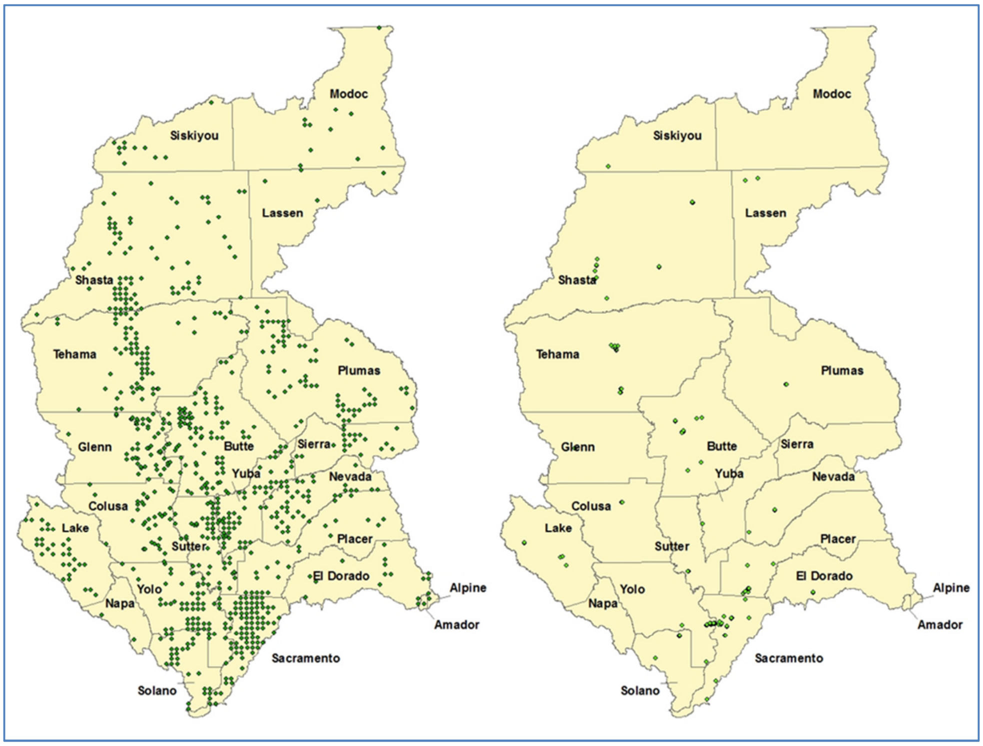


Figure 3: Left - Water Supply Wells, Right- Environmental Management Wells

With limited data and lack of a groundwater model it is important to look at other aspects of local geography that could indicate high nitrate concentrations. As noted above a number of factors have been linked to nitrate concentration levels. These include groundwater basin characteristics as shown in California studies, land use/land cover activites, and soil type and particle sizes. Seasonality may play a role, too, with planting and water seasons contributing nitrates from the agricultural sector, and possible precipitation patterns affecting the local landscape. Proximity to areas where high nitrate concentrations have already been identified and monitored may also contribute to conditions in local groundwater wells. A listing of possible characteristics currently found in zones of high nitrate concentration could be useful for future watershed studies.

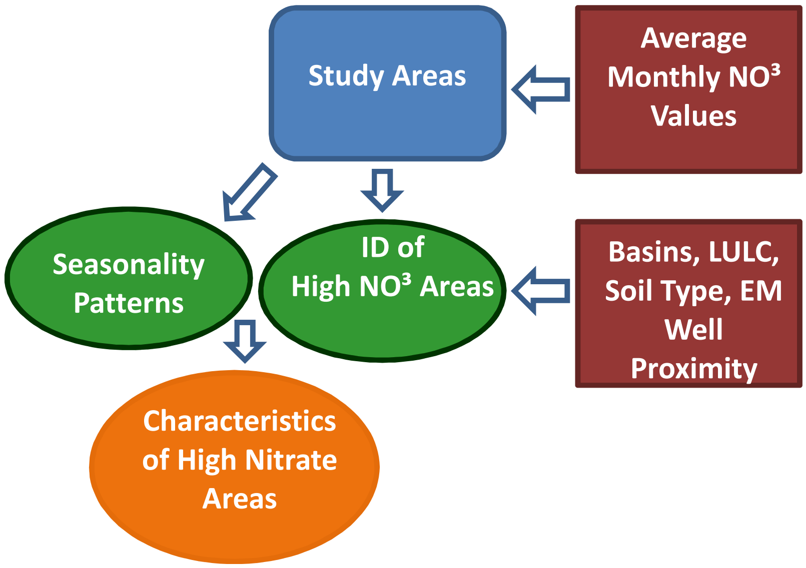


Figure 4: Project Flow Model

To identify characteristics that could indicate zones of high nitrate concentration it was necessary to create a set of areas with high nitrate concentrations based on the available data. Each nitrate value in the dataset has a longitude and a latitude coordinate so the data value is set in space. Using the nitrate concentration as a "z" value a 3D surface can be created. This is similar to using heights to create a digital elevation model – only the elevation component is nitrate value. This is a hypothetical surface derived from the data but useful for identifying study areas.

The intended method to create the surface was using the kriging interpolation process. Kriging has a long history in water quality studies and is used in numerous other spatial studies. However, when the kriging was tested with the data given no areas of contamination levels above the MCL of 45 mg/L were identified. Data were broken out into the following categories and all kriging trials resulted in the same outcome: all data for 2006, data by month for 2006, and a total of five years of data for the month of June (2002 – 2006). No areas of contamination were identified by the kriging methodology so an alternate form was selected – Delauny triangulation.

The software used for this anaylsis is ArcGIS 10 and this package supports Delaunay triangulation. This particular method of triangulation requires that each triangle's circumscribing circle contains no points from the dataset in its interior. This creates a surface where the minimum interior angle of all triangles is maximized and long, thin triangles are avoided as much as possible (ESRI 2010). TIN layers were created for the data belonging to each month. The z value used was the nitrate concentration for each datapoint. Once the TIN layers were created for each month the data were given two classes – below the MCL of 45 mg/L and above the MCL of 45 mg/L. The outlines of the values above 45 mg/L were used as the zones of contamination. Some areas identified by month overlapped with other months and all areas of interest identified by this exercise were located in the southern half of the watershed.

Data for this exercise was split into months for 2006 for interpolation. This was to capture any possible seasonal patterns that might arise when looking at the data – these would not be apparent in data that was analyzed by year. Each month had a finite number of samples and some of these samples came from the same well. The spatial distribution of the data were similar throughout the year. To get a baseline, all analysis was also run with the entire year's worth of data.

Delauny triangulation was applied to the nitrate concentration data to identify zones of possible nitrate concentration. Once these zones were identified each data layer of interest – groundwater basin, land use/land cover, soil particle size, and environmental monitoring well locations – were clipped to the zones of interest and the data inside the zones was analyzed. The characteristics of the data within the zones of interest are likely to be contributing factors to high nitrate concentration samples.

Once the zones of high nitrate concentrations were identified they were used with other data layers to generate lists of parameters based on supplementary datasets. Data sets included groundwater basins, land use/land cover classifications, soil particle size, and environmental management well locations. Seasonal trends were captured by breaking nitrate zones into monthly layers and analyzing data captured using those deliniations.

RESULTS

Data Characterization

Initial Data Set

The data from each of the counties was clipped to the SHR. Each record contained one sampling event at one well at one discrete point in time. Some wells had multiple samples taken in a month and so the number of samples was larger than the number of wells. The table below shows the sample and number of wells by month for the original data set of all wells in 2006. The total number of samples in the entire data set for 2006 was 2,518 and the total number of wells was 1,823.

Table 1: Datapoints by Month

Month	Samples	Wells	Samples Above MCL	Counties
January	241	239	4	Lake, Sutter, Yolo, Yuba
February	195	191	2	Lake, Yolo
March	176	175	3	Sutter, Yuba
April	166	164	8	Lake, Placer, Sutter, Yolo
May	184	174	4	Yolo
June	224	213	5	Sutter, Yolo, Yuba
July	334	328	5	Butte, Sutter, Yolo
August	303	292	7	Sutter, Yolo, Yuba
September	165	159	6	Placer, Yolo, Yuba
October	176	168	9	Sutter, Yolo, Yuba
November	147	143	2	Yolo
December	207	200	6	Placer, Sutter, Yuba

The spatial distribution of the data were heavily weighted towards the lower part of the watershed. Most samples were returned from the southern part of the watershed – the counties shown below contributed 65% of all raw data to the project. The middle region contributed 25% and the upper region contributed 10%. In the table below a value of 0% contribution is due to rounding error.

Table 2: Datapoints by County

County	Count	Percentage
Sacramento	607	24%
Yolo	343	14%
Butte	261	10%
Shasta	212	8%
Sutter	149	6%
Tehama	143	6%
Yuba	141	6%
Solano	128	5%
Plumas	107	4%
Glenn	101	4%
Nevada	71	3%
Lake	69	3%
Colusa	49	2%
Placer	39	2%
Sierra	25	1%
El Dorado	22	1%
Modoc	21	1%
Siskiyou	15	1%
Lassen	5	0%
Alpine	4	0%
Napa	4	0%
Amador	2	0%
Total	**2518**	**100%**

Not all counties in the original data set returned nitrate values above the MCL of 45 mg/L. Counties that did contain these values included Butte, Lake, Placer, Sutter, Yolo, and Yuba. Yolo County had almost 50% of the samples returned above the MCL while Sutter County had 26%, Yuba County had 11%, and the rest provided less than 10% of the total number of samples. The sample data ranged from 45.2 mg/L up to 100 mg/L in these water supply wells. The highest values in the 70s and above were found in Sutter and Yolo counties. The mean of these data were 57, the median 54 and the mode 56.

Table 3: Data Points Above MCL

County	Samples	Percentage	Sample Months
Yolo	30	49%	April, May, June, July, August, September, October, November
Sutter	16	26%	January, March, April, June, July, August, October, December
Yuba	7	11%	January, March, June, September, December
Placer	4	7%	April, September, December
Lake	3	5%	January, February, April
Butte	1	2%	July
Total	61	100%	

2006 Data

The Delaunay triangulation method was applied to the entire data set to create zones of interest based on nitrate values. These are shown in the map below. These were the study areas for the entire year's worth of data. Because of the small size of the areas none of the original sample data points were captured within this data set. However, a visual analysis shows that these areas lie within Yolo, Yuba, Butte and very small part of Sutter County.

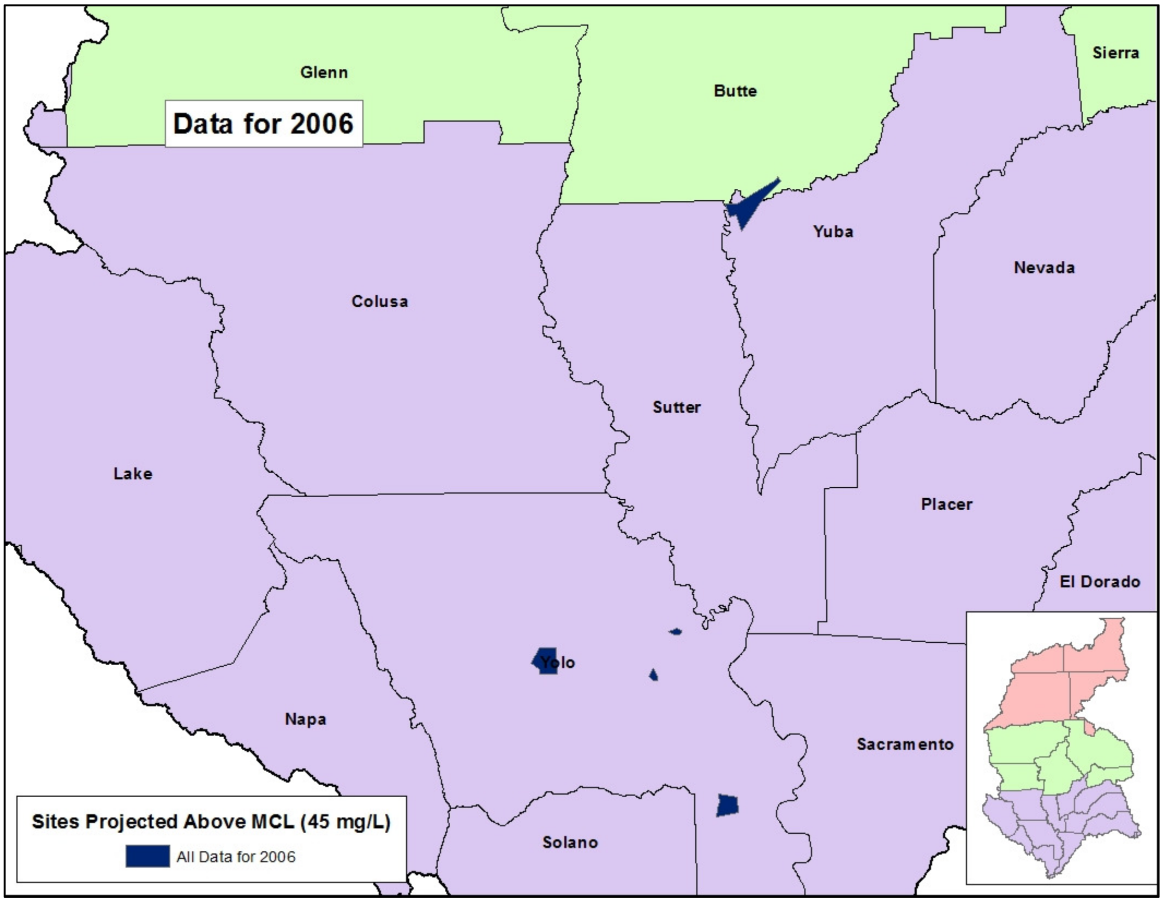


Figure 5: 2006 Data Zones of Interest

Data by Month

Data for this exercise was also broken out into months. This was to capture any possible seasonal patterns that might arise when looking at the data – these would not be apparent in data that was analyzed by year. Original samples in the zones of interest were extracted for each month. The data for each month had a finite number of samples and some of these samples came from the same well. A total of 37 samples were identified by the triangulation process as being within zones of interest – these included samples captured by each month's Delaunay triangulation run. These samples came from a total of 19 individual wells. The highest number of samples returned was 5 and this number was found in both August and October. The highest number of wells was also 5 and this number was found in October. The average number of wells was 3, the median number of wells was 3.5 and the mode of the wells was 4.

Table 4: Wells and Samples by Month

Month	Samples	Wells	Counties
January	2	2	Butte*, Lake, Yuba
February	1	1	Colusa*, Glenn*, Lake
March	1	1	Sutter
April	4	4	Lake, Placer, Yolo
May	2	2	Solano*, Yolo
June	3	3	Sacramento*, Solano*, Sutter*, Yuba, Yolo
July	4	4	Butte, Sutter, Yolo
August	5	4	Sutter, Yolo
September	4	4	Butte*, Placer, Sutter*, Yuba, Yolo
October	5	5	Sutter, Yolo
November	2	2	Yolo
December	4	4	Butte*, Placer, Sutter, Yuba

*From visual survey of maps in Appendix B

Each month had a different set of counties represented in the total data set. No single county was identified in each month. Of the total number of samples identified by month, the most were identified in Yolo County. Yolo County samples were found in eight of twelve calendar months and represented nearly half of all samples identified as lying within the zones of contamination.

Table 5: Samples by County

County	Samples	Percentage
Yolo	18	49%
Sutter	6	16%
Yuba	5	14%
Placer	4	11%
Lake	3	8%
Butte	1	3%
Total	37	100%

Most of the counties represented by the zones of interest are in the southern part of the watershed. Three additional counties are represented by the zones of contamination: Glen, Solano, and Sacramento. The area represented by Sacramento is very small.

Data Presentation

For each of the data sections below, data were analyized for the entire 2006 data set and was split into each month and analyzed separately. Maps for monthly data are presented as "fused" data sets – all of the polygons are combined to show all the areas covered by the maps. This is to give a better visual representation of the data tables presented as results. See Appendix B for images of each month's zones of interest illustrated separately. See Appendix A for images of each month's original set of water safety wells used in this study.

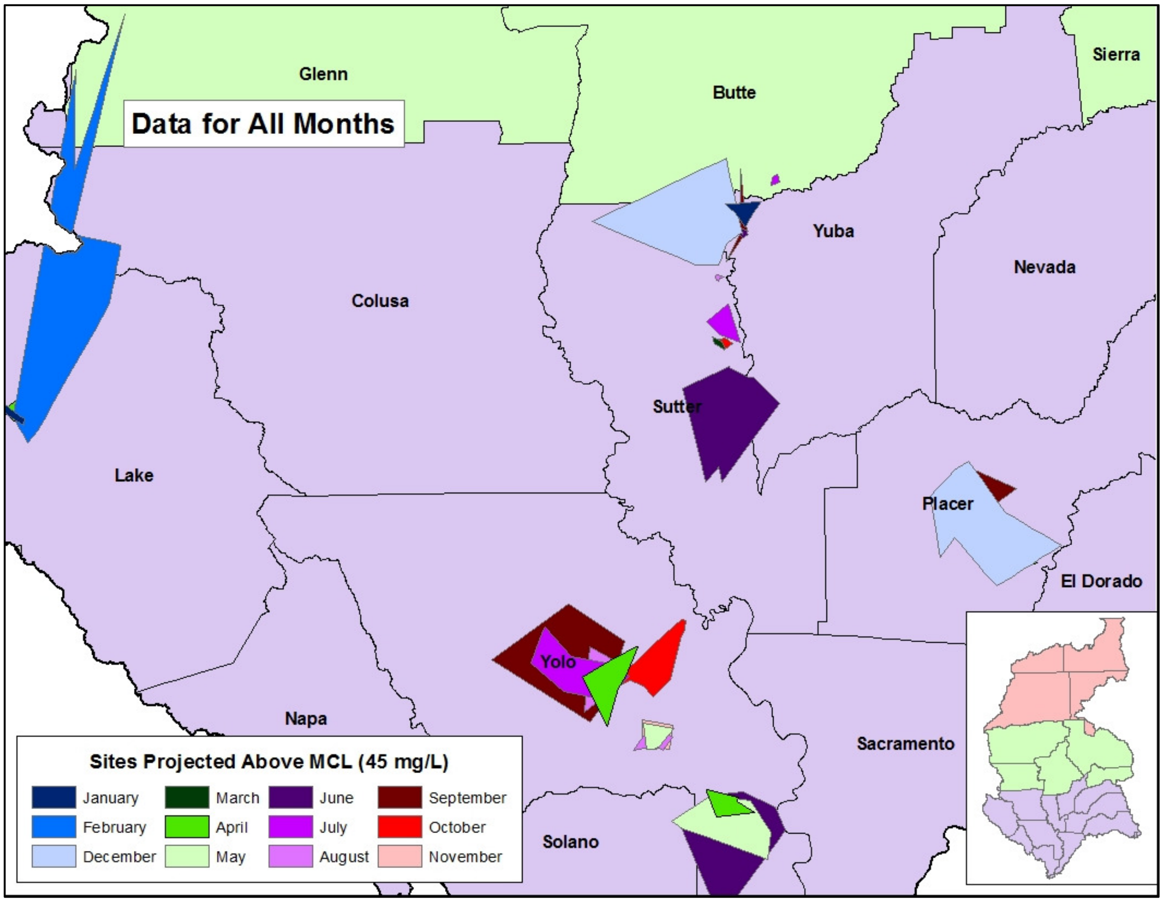


Figure 6: Map of All Contamination Zones

Proximity to Environmental Management Wells

One of the primary concerns of this project was to evaluate if environmental management wells were within a short distance of the zones of interest identified by the Delaunay triangulation. These monitoring wells are separate from the water supply wells and are used solely to monitor pollutants of concern – these are not wells providing potable water to residents. However, these wells do lie in the same geographic areas as the water supply wells and contamination measured at these wells could possibly contribute nitrate contamination to water supply wells in the same areas.

The maps below illustrate the buffer zones considered including 1 mile, 5 miles, and 10 miles. The data for each month was buffered separately but the map below uses a fused dataset to illustrate the buffer zones considered for the monthly analysis. These buffer areas were used to capture samples taken from environmental monitoring wells.

The environmental management well dataset is composed of water samples taken at discrete points in time from a number of different wells within the watershed. These wells have a precise geographic location unlike the water supply wells where the geographic location provided by the dataset is accurate within a half mile of the well's actual physical location.

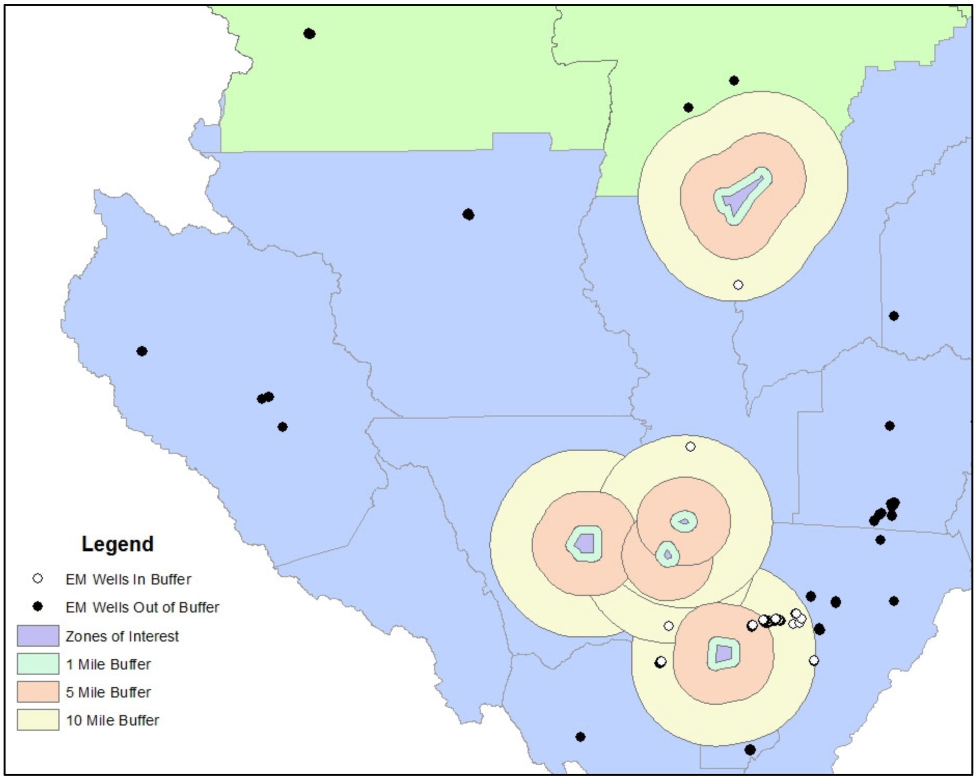


Figure 7: Buffer Zones for 2006 Data and EM Wells

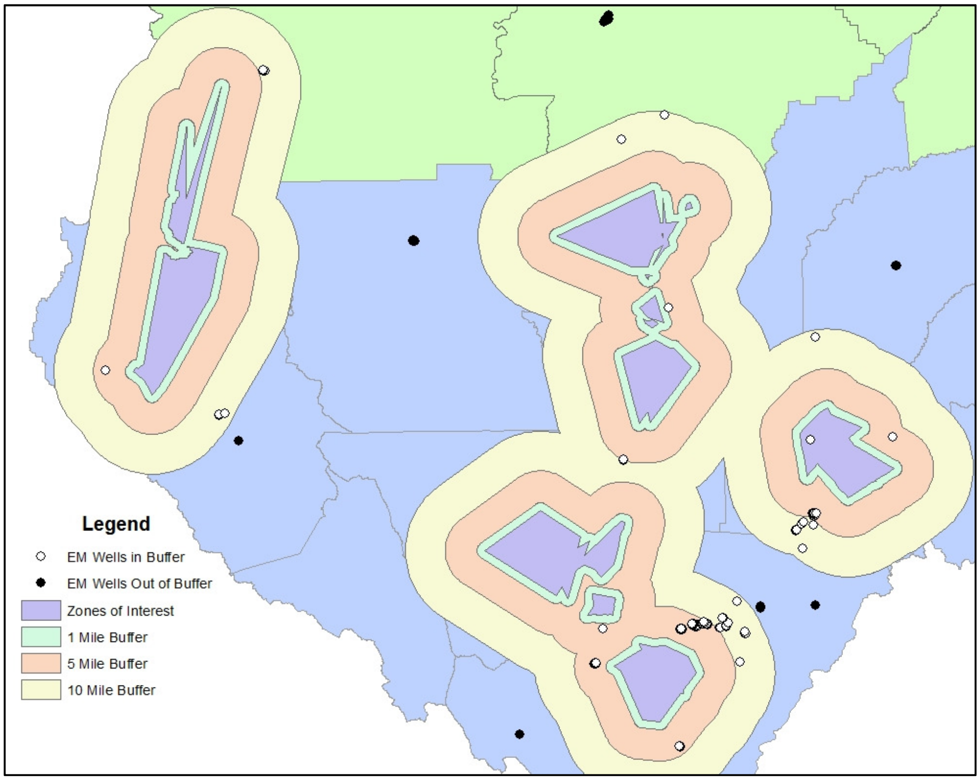


Figure 8: Buffers for All Months and EM Wells

2006 Data

The zones of interest for the entire 2006 dataset were very small in area. So the area covered by the buffers was also small. However, though no wells were found within the buffers for 1 mile, there were wells in both the 5 and 10 mile buffers. A count of samples and wells is listed below along with the counties in which the environmental management wells lay.

Table 6: EM Wells in Buffers for 2006 Data

Buffer Zone (miles)	Number of Samples	Number of Wells	Counties
1	0	0	NA

5	54	25	Yolo
10	286	85	Sacramento, Solano, Sutter, Yolo, Yuba

Timing of the samples in each of the buffer areas was captured in the table below. The green cells represent months in which the data samples captured by the buffer areas were taken. Months with no samples are white.

Table 7: Months Where Data Samples Captured for 2006 Data

2006 Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 Mile												
5 Miles			(green)	(green)			(green)	(green)	(green)			
10 Miles	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)

Data by Month

Data were broken out by month and buffers created at 1 mile, 5 miles, and 10 miles. September and October had environmental monitoring wells within one mile of their zones of interest. All months had environmental monitoring wells within 5 miles and 10 miles of their zones of interest. Some months captured more data samples and wells than others.

Table 8: EM Wells in Buffers for Monthly Data

Month	Buffer Zone (miles)	Number of Samples	Number of Wells	Counties
January	1	0	0	NA
	5	15	14	Lake

	10	18	16	Lake, Yuba
February	1	0	0	NA
	5	14	14	Lake
	10	40	14	Glenn, Lake
March	1	0	0	NA
	5	5	2	Yuba
	10	5	2	Yuba
April	1	0	0	NA
	5	106	41	Lake, Placer, Yolo
	10	381	95	Lake, Placer, Sacramento, Solano, Yolo
May	1	0	0	NA
	5	178	61	Solano, Yolo
	10	329	90	Sacramento, Solano
June	1	0	0	NA
	5	227	82	Sacramento, Solano, Yolo, Yuba
	10	353	97	Sacramento, Solano, Sutter, Yolo, Yuba
July	1	0	0	NA
	5	2	2	Yuba
	10	7	7	Yolo, Yuba
August	1	0	0	NA
	5	43	16	Solano, Yolo, Yuba
	10	217	75	Sacramento, Solano, Yolo, Yuba
September	1	1	1	Placer
	5	11	5	Placer, Yolo
	10	147	56	Nevada, Placer, Solano, Yolo, Yuba
October	1	0	0	NA
	5	2	2	Yuba
	10	13	8	Sutter, Yolo, Yuba
November	1	0	0	NA
	5	5	5	Yolo
	10	92	36	Solano, Yolo
December	1	1	1	Placer
	5	32	16	Placer
	10	60	29	Butte, Nevada, Placer, Sacramento, Yuba

Timing of the samples in each of the buffer areas for each month was captured in the table below. The green cells represent months in which the data samples captured by the buffer areas were taken. Months with no samples are white.

Table 9: Months Where Data Samples Captured for Monthly Data at 1 Mile

1 Mile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
January												
February												
March												
April												
May												
June												
July												
August												
September												
October												
November												
December												

Table 10: Months Where Data Samples Captured for Monthly Data at 5 Miles

5 Miles	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
January												
February												
March												
April												
May												
June												
July												
August												
September												
October												

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
November		■										
December				■	■			■		■		

Table 11: Months Where Data Samples Captured for Monthly Data at 10 Miles

10 Miles	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
January												■
February	■		■					■	■			■
March											■	
April	■	■	■	■	■	■	■	■	■	■	■	■
May	■	■	■	■	■	■	■	■	■	■	■	■
June	■	■	■	■	■	■	■	■	■	■	■	■
July		■									■	
August		■	■	■	■		■	■	■	■	■	
September	■	■	■	■	■	■	■	■		■	■	■
October		■	■								■	
November		■	■	■	■			■				
December	■	■	■	■	■	■	■	■	■	■	■	■

Groundwater Sub-basins

Analysis Methods

One part of this analysis involves using the zones of interest created by the Delaunay triangulation and overlaying them with the original water supply well dataset. Wells lying within one of the zones of interest may have metadata associated with them that will assist in the analysis of groundwater sub-basin characteristics. General visual surveys are also used to log the sub-basins within the zones of interest and the characteristics of these basins will also be analyzed.

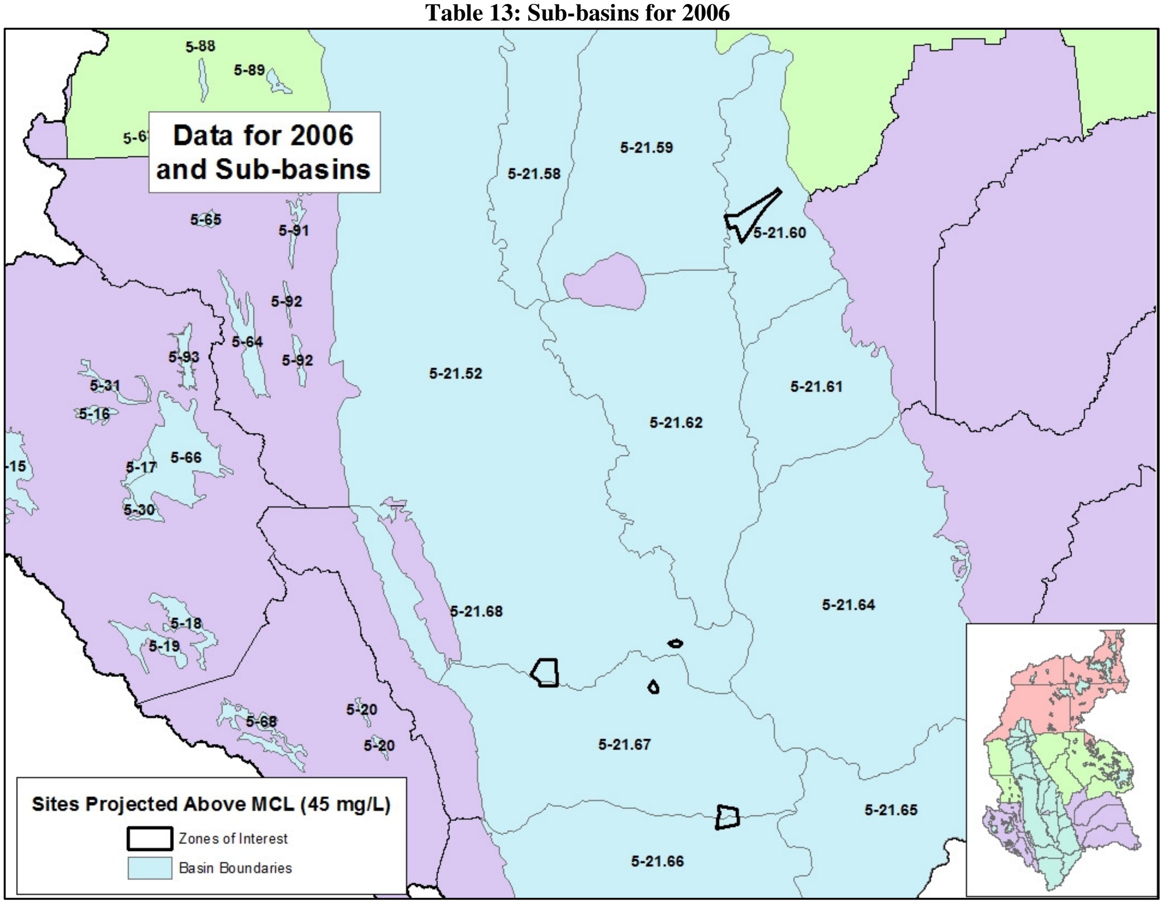
2006 Data

No wells were identified by the zones of interest for the 2006 data set – no points lay within the zones. However, a visual analysis identified 4 sub-basins that contained zones of possible nitrate contamination. These basins were all contained within the larger set that was identified when analyzing data by month.

Table 12: Visual Survey: 2006 Sub-basins

Sub-Basin
Sacramento Valley - Colusa (5-21.52)
Sacramento Valley - North Yuba (5-21.60)
Sacramento Valley - Solano (5-21.66)
Sacramento Valley - Yolo (5-21.67)

Table 13: Sub-basins for 2006



Data by Month

Using the wells lying within the zones of interest for each month, a total of 7 groundwater sub-basins were identified. All sub-basins were located within the main Sacramento Valley Basin. As seen in the table below, 8 wells (or 22% of the samples) had no associated basin within the raw data provided by GeoTracker GAMA. 32% of the samples came from the Yolo sub-basin (5-21.67), 14% came from the Sutter sub-basin (5-21.62), 11% came from each of the North Yuba and Solano sub-basins (5.21.60 and 5-21.66, respectively). The Colusa sub-basin (5-21.52) made up 5% of the sample while East Butte and South Yuba (5-21.59 and 5.21.61, respectively) both contributed 3%.

Table 14: Wells by Basin

Basin Name	Individual Wells	Samples
Sacramento Valley - Yolo (5-21.67)	4	12
Unknown	4	8
Sacramento Valley - Sutter (5-21.62)	3	5
Sacramento Valley - North Yuba (5-21.60)	2	4
Sacramento Valley - Solano (5-21.66)	2	4
Sacramento Valley - Colusa (5-21.52)	2	2
Sacramento Valley - East Butte (5-21.59)	1	1
Sacramento Valley - South Yuba (5-21.61)	1	1

Table 15: Wells by Name

Well Name	Samples	County	Basin
5700827-001	6	Yolo	Sacramento Valley - Yolo (5-21.67)
5700541-001	4	Yolo	Sacramento Valley - Yolo (5-21.67)
1700677-001	3	Lake	Unknown
5700546-001	3	Yolo	Sacramento Valley - Solano (5-21.66)
5800025-001	3	Yuba	Sacramento Valley - North Yuba (5-21.60)
3103259-002	2	Placer	Unknown

3104509-001	2	Placer	Unknown
5102009-001	2	Sutter	Sacramento Valley - Sutter (5-21.62)
5110003-013	2	Sutter	Sacramento Valley - Sutter (5-21.62)
3.84214e+14*	1	Yolo	Sacramento Valley - Colusa (5-21.52)
5103303-001	1	Sutter	Sacramento Valley - Sutter (5-21.62)
5103335-001	1	Sutter	Sacramento Valley - East Butte (5-21.59)
5700723-001	1	Yolo	Sacramento Valley - Colusa (5-21.52)
5700745-001	1	Yolo	Sacramento Valley - Yolo (5-21.67)
5700757-001	1	Yolo	Sacramento Valley - Solano (5-21.66)
5700769-001	1	Yolo	Sacramento Valley - Yolo (5-21.67)
5800201-001	1	Yuba	Sacramento Valley - North Yuba (5-21.60)
5800851-001	1	Yuba	Sacramento Valley - South Yuba (5-21.61)
ESAC-22	1	Butte	Unknown

* Well name: 384214000000000

No data were available for these wells. GeoTracker GAMA does provide depth to water, depth to water change, and groundwater elevation for some wells. However, for the water supply wells listed in this study no data are available. From research done in the database it appears that most of this auxiliary information is available for the environmental monitoring wells and not for water supply wells.

A visual survey was also used to identify the different sub-basins captured by the zones of contamination. There were 11 sub-basins identified over the twelve month period. These 11 sub-basins included all of the basins that were identified by the data point exercise as well as some that were not.

Table 16: Visual Survey: Sub-Basins Identified

Sub-Basin	Samples
Sacramento Valley - Yolo (5-21.67)	8
Sacramento Valley - Sutter (5-21.62)	7
Sacramento Valley - Colusa (5-21.52)	6

Sacramento Valley - North Yuba (5-21.60)	5
Big Valley (5-15)	3
Sacramento Valley - Solano (5-21.66)	3
Sacramento Valley - North American (5-21.64)	2
Sacramento Valley - East Butte (5-21.59)	1
Sacramento Valley - South Yuba (5-21.61)	1
Sacramento Valley - South American (5-21.65)	1
Long Valley (5-31)	1

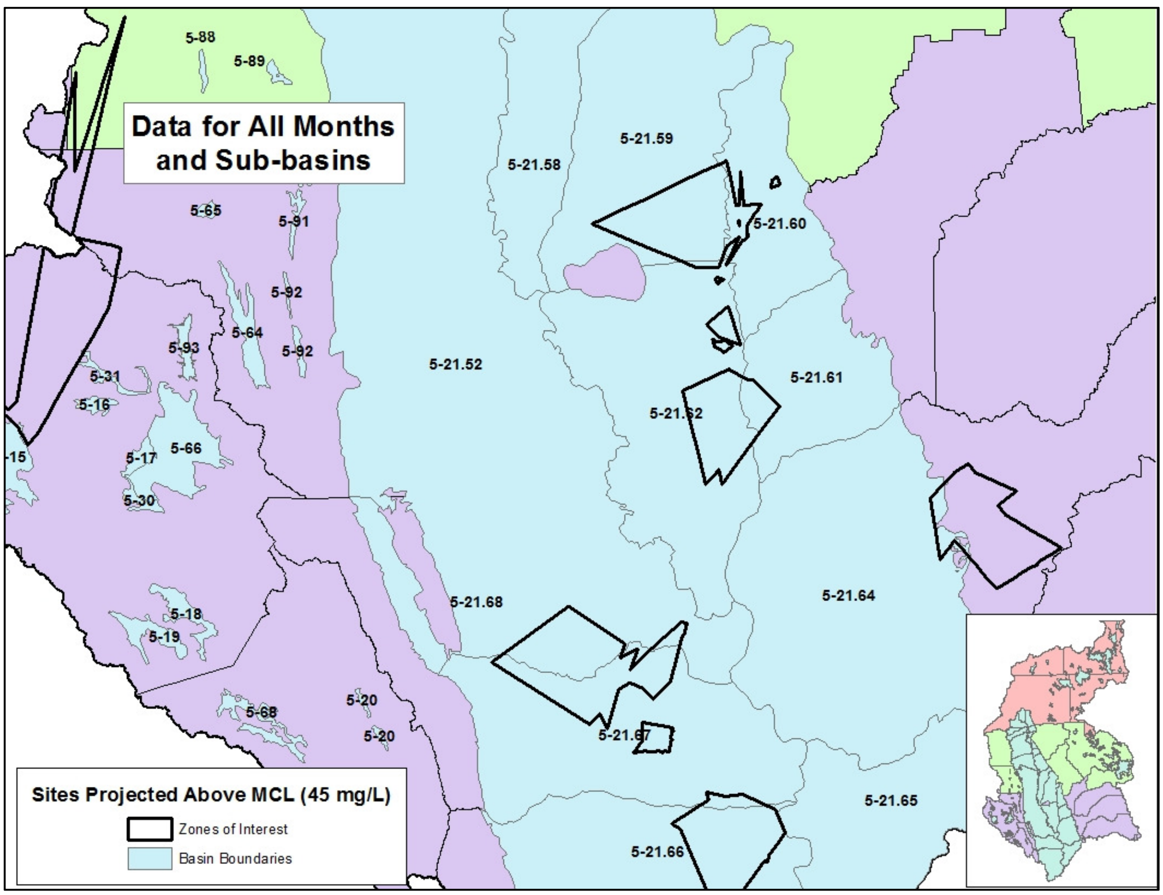


Figure 9: Sub-basin Data for All Months

Sub-basins were analyzed by month. Each month had a different number of sub-basins noted with June having the most at 6 and September having the second most at 5. The spring months had the fewest number of sub-basins noted while the fall months had the greatest number of sub-basins noted.

Table 17: Visual Survey: Winter Sub-Basins

Month	Sub-Basin
January	Big Valley (5-15)
	Sacramento Valley - North Yuba (5-21.60)
February	Big Valley (5-15)
	Long Valley (5-31)
December	Sacramento Valley - East Butte (5-21.59)
	Sacramento Valley - North Yuba (5-21.60)
	Sacramento Valley - Sutter (5-21.62)
	Sacramento Valley - North American (5-21.64)

Table 18: Visual Survey: Spring Sub-Basins

Month	Sub-Basin
March	Sacramento Valley - Sutter (5-21.62)
April	Sacramento Valley - Solano (5-21.66)
	Big Valley (5-15)
	Sacramento Valley - Colusa (5-21.52)
	Sacramento Valley - Yolo (5-21.67)
May	Sacramento Valley - Solano (5-21.66)
	Sacramento Valley - Yolo (5-21.67)

Table 19: Visual Survey: Summer Sub-Basins

Month	Sub-Basin
June	Sacramento Valley - North Yuba (5-21.60)
	Sacramento Valley - South Yuba (5-21.61)
	Sacramento Valley - Sutter (5-21.62)
	Sacramento Valley - South American (5-21.65)

	Sacramento Valley - Solano (5-21.66)
	Sacramento Valley - Yolo (5-21.67)
July	Sacramento Valley - Colusa (5-21.52)
	Sacramento Valley - North Yuba (5-21.60)
	Sacramento Valley - Sutter (5-21.62)
	Sacramento Valley - Yolo (5-21.67)
August	Sacramento Valley - Colusa (5-21.52)
	Sacramento Valley - Sutter (5-21.62)
	Sacramento Valley - Yolo (5-21.67)

Table 20: Visual Survey: Fall Sub-Basins

Month	Sub-Basin
September	Sacramento Valley - Colusa (5-21.52)
	Sacramento Valley - North Yuba (5-21.60)
	Sacramento Valley - Sutter (5-21.62)
	Sacramento Valley - North American (5-21.64)
	Sacramento Valley - Yolo (5-21.67)
October	Sacramento Valley - Colusa (5-21.52)
	Sacramento Valley - Sutter (5-21.62)
	Sacramento Valley - Yolo (5-21.67)
November	Sacramento Valley - Colusa (5-21.52)
	Sacramento Valley - Yolo (5-21.67)

Land Use / Land Cover

Land use classes can be tied to nitrate pollution through contribution of nitrates to local areas but also through impacts to local soil conditions. Agricultural activities have the possibility to add nitrates to local systems through crop fertilizations but they can also impact soil compaction and soil composition which can change the way water flows through these areas and possibly affect the way nutrients flow through the systems.

Common land use classes were examined using data from the 2006 National Land Cover Database (NLCD). NLCD 2006 raster layers were built from Landsat Enhanced

Thematic Mapper+ data collected throughout 2006. The 16-class land cover classification scheme was applied consistently across the coterminous United States at a spatial resolution of 30 meters. Layer values are based primarily on the unsupervised classification of the collected data (Fry 2011). 15 land classes were found when looking at all the areas identified as possible zones of high nitrate concentration the only class lacking was "Perennial Ice/Snow". Types of land classes found included barren land, agriculture, forest, developed areas, water/wetlands, and grass/scrub covered areas. Overall the landcover class most captured by the areas was developed open space, grassland/herbaceous cover followed that and evergreen and deciduous forest areas tied for third greatest type of landcover. When areas were measured seasonally the Fall, Spring, and Winter seasons all included all 15 land cover classes but the Summer sampling included only 12 – evergreen and mixed forest were excluded as well as shrub/scrub land.

2006 Data

Data for 2006 was analyzed for the LULC context. It showed heavy percentages in disturbed areas – developments and cultivated crops. It also showed wetlands as being a significant area of concern.

Table 21: Land Uses from 2006 Data

LULC	Percentage
Developed, Open Space	34%
Cultivated Crops	16%
Emergent Herbaceous Wetlands	11%
Grassland/Herbaceous	9%

Developed, Low Intensity	7%
Woody Wetlands	7%
Developed, Medium Intensity	6%
Barren Land	3%
Developed High Intensity	3%
Hay/Pasture	3%
Open Water	2%
Total	100%

The map below illustrates where in the watershed land use classes were captured. Some areas are quite small but the number of land use classes captured was very high – 11 out of 15 classes were returned for these zones.

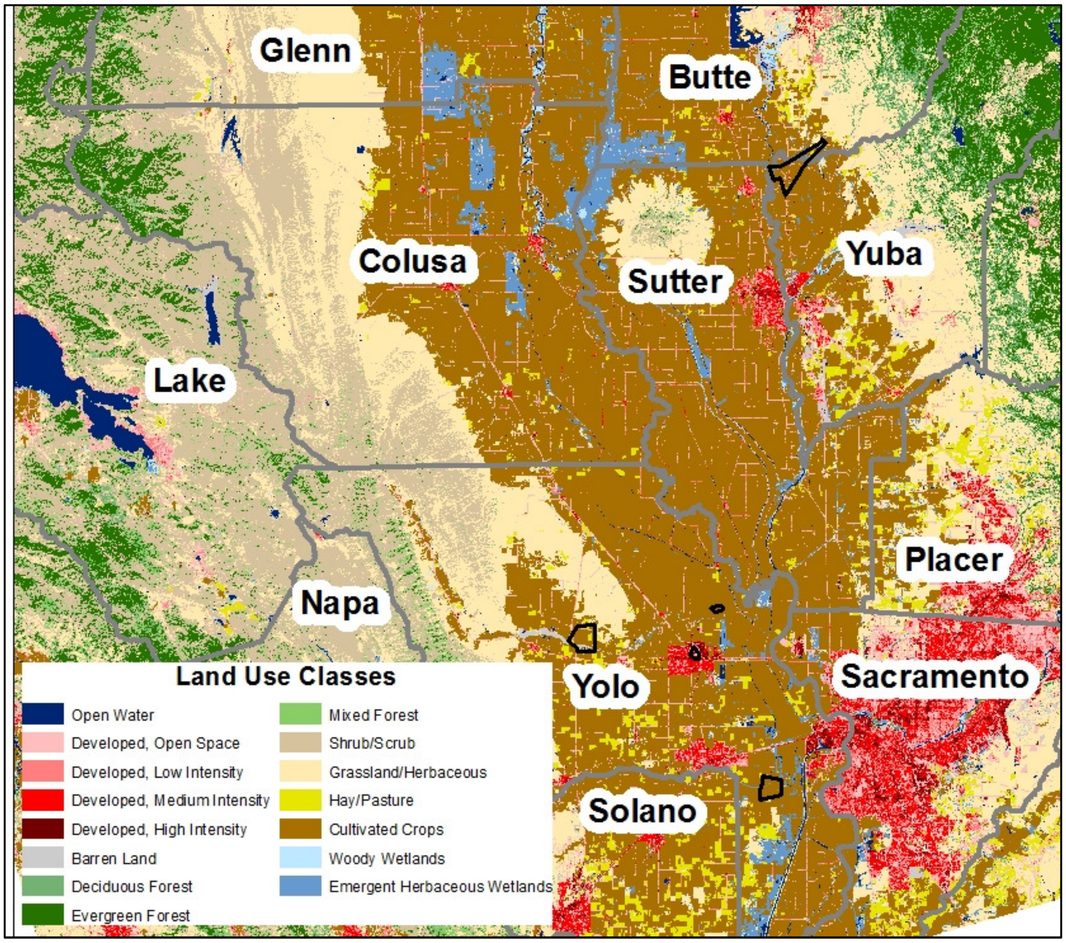


Figure 10: Land Use Classes Captured by Zones of Interest from 2006 Data

Data by Month

Data by month showed an overall trend of developed land and forests or grasslands. Cultivated crops did not show as highly as they did when using zones of contamination created from all 2006 data. Developed land and forest land were in the top 5 represented land cover types for each season.

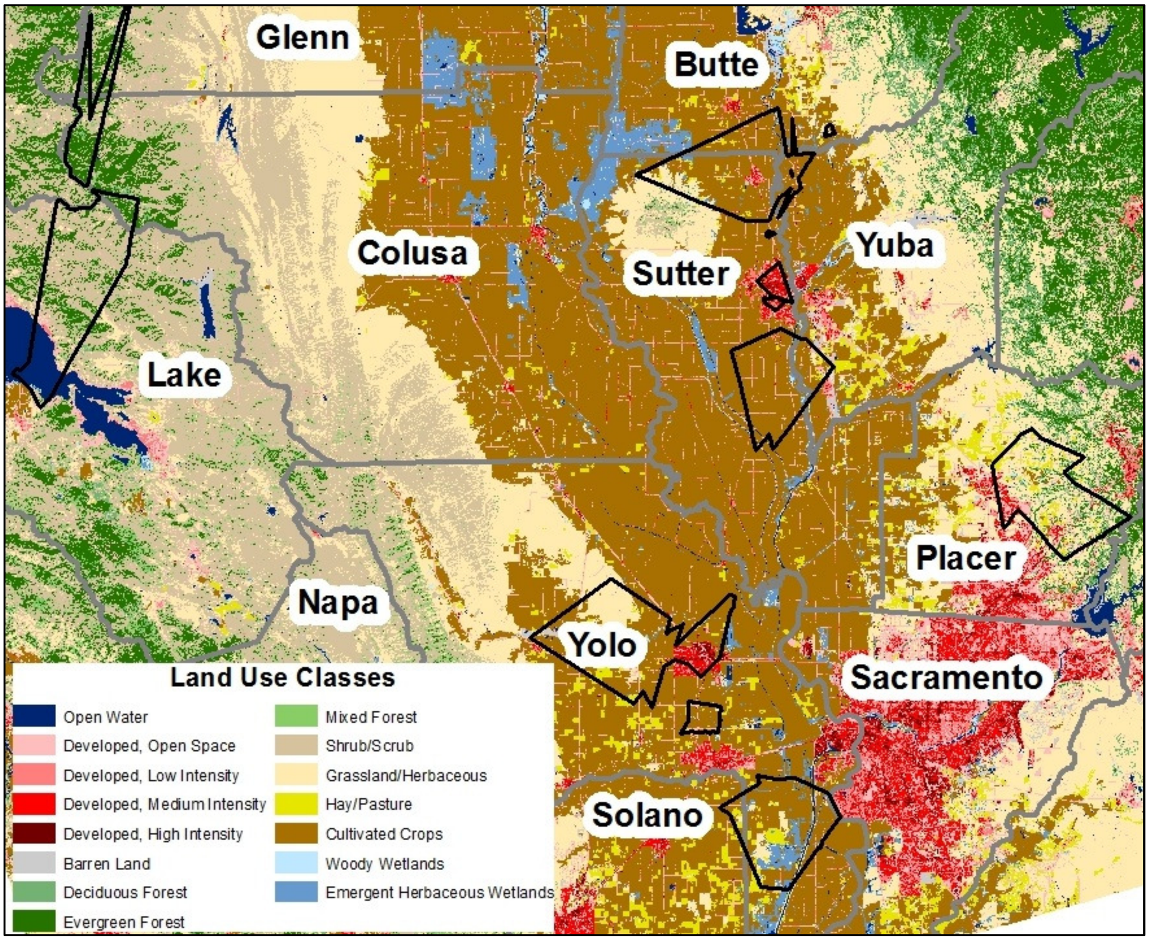


Figure 11: Land Use Classes Captured by Zones of Interest from Monthly Data

The data for all months was combined to look at what kinds of land use classes were returned by that dataset. In the table below classes that made up over 10% of the total data set included those for developed open space, grasslands, and two types of forest. Additionally, low intensity developed land, cultivated crops, mixed forest, shrublands and emergent herbaceous wetlands all made up between 5% and 10% of all data samples. This is very mixed and does not include the medium and high intensity developed areas. Hay and pastureland area also comes in below 5% of all samples. In the tables below colors represent general land use class types: red represents developed land, green represents forest, orange represents cultivated land, brown represents grassland, grey represents barren land, and blue represents water features.

Table 22: Overall Land Use Classifications

Land Use Class	Percentage Total
Developed, Open Space	19%
Grassland/Herbaceous	13%
Evergreen Forest	11%
Deciduous Forest	11%
Developed, Low Intensity	8%
Cultivated Crops	7%
Mixed Forest	7%
Shrub/Scrub	6%
Emergent Herbaceous Wetlands	5%
Developed, Medium Intensity	4%
Hay/Pasture	3%
Woody Wetlands	3%
Barren Land	2%
Developed, High Intensity	1%
Open Water	1%
Total	**100%**

Data were analyzed by seasonal month sets to capture seasonal patterns. The tables below illustrate the percentage of total area represented by land use class. Data were also analyzed by month and these tables can be found in Appendix C.

Table 23: Land Use Classifications for Winter

Land Use Class	Percentage Total
Evergreen Forest	18%
Developed, Open Space	15%
Deciduous Forest	15%
Mixed Forest	12%
Grassland/Herbaceous	11%
Shrub/Scrub	11%
Developed, Low Intensity	5%
Woody Wetlands	3%
Cultivated Crops	2%
Developed, Medium Intensity	2%
Hay/Pasture	2%
Emergent Herbaceous Wetlands	2%
Developed, High Intensity	0%
Open Water	0%
Barren Land	0%
Total	**100%**

Table 24: Land Use Classifications for Spring

Land Use Class	Percentage Total
Developed, Open Space	21%
Grassland/Herbaceous	15%
Deciduous Forest	13%
Evergreen Forest	10%
Cultivated Crops	8%
Emergent Herbaceous Wetlands	8%
Developed, Low Intensity	6%
Hay/Pasture	4%
Mixed Forest	4%
Developed, Medium Intensity	4%
Shrub/Scrub	3%
Woody Wetlands	2%
Barren Land	1%
Open Water	1%
Developed, High Intensity	1%
Total	**100%**

Table 25: Land Use Classifications for Summer

Land Use Class	Percentage Total
Developed, Open Space	23%
Cultivated Crops	16%
Emergent Herbaceous Wetlands	14%
Grassland/Herbaceous	13%
Developed, Low Intensity	12%
Developed, Medium Intensity	5%
Hay/Pasture	5%
Woody Wetlands	4%
Barren Land	4%
Open Water	2%
Developed, High Intensity	2%
Deciduous Forest	1%
Total	**100%**

Table 26: Land Use Classifications for Fall

Land Use Class	Percentage Total
Developed, Open Space	24%
Grassland/Herbaceous	15%
Developed, Low Intensity	12%
Deciduous Forest	9%
Cultivated Crops	9%
Developed, Medium Intensity	7%
Hay/Pasture	5%
Evergreen Forest	5%
Emergent Herbaceous Wetlands	4%
Woody Wetlands	4%
Barren Land	3%
Developed, High Intensity	2%
Shrub/Scrub	1%
Mixed Forest	0%
Open Water	0%
Total	**100%**

Soil Types

According to Ward and Trimble, a soil is the unconsolidated minerals and material on the immediate surface of the earth that serves as a natural medium for the growth of plants. Soil texture is the classification of soil by the relative proportions of sand, silt, and clay present. They define infiltration as the passage of water through the surface of the soil via pores or small openings into the soil profile (Ward and Trimble, 2004). Infiltration of surface water – stormwater runoff, lakes and rivers, overland runoff – is one way chemicals such as nitrates can find their way into groundwater sources. Infiltration is a very complicated process that can be affected by a number of soil factors. Some affecting factors include soil texture, bulk density, heterogeneity, cracks, and surface conditions. Soils also have a hydraulic conductivity which is the ability of a soil to transmit water under a unit hydraulic gradient – this is often called permeability and is a function of soil suction and soil water content. Computations of soil-water storage or flow commonly require soil-water potential (measure of the energy status of the soil water reported as a negative pressure) and hydraulic conductivity – but these vary widely and nonlinearly with water content for different soil textures (Saxton et al, 1986). As such for larger watershed-scale studies these kinds of measurements could be difficult and costly to obtain. One substitute for more cost intensive methods of considering infiltration rates is to look at soil texture. Soil texture predominately determines the water-holding characteristics of most agricultural soils (Saxton et al 1986). This relationship likely holds for non agricultural soils as well.

Soil data were procured from the USDA-NRCS SSURGO soils database. The data came as both spatial and tabular data allowing for map units identified by the

Delaunay triangulation to be used to identify individual soil series within the areas of interest. SSURGO data are returned in map units that are made up of one or more soil series dominant to a specific area. Through the USDA NRCS Soil Series Classification Database a soil series report was downloaded that included more information about most soil series type. One component included in this data were the particle-size or substitute class (USDA NRCS 2010). This particle size was used in the analysis.

Particle-size class is used to characterize the grain-size composition of the soil. This excludes any organic matter and salts more soluble than gypsum. Particle size classifications can differ across professions and this taxonomy is specifically concerned with the limit between sand and silt. Two classification systems were taken into consideration: engineering classifications (limit set at 74 microns) and pedologic classifications (50 or 20 microns). The differences are based on the assumptions made in the classifications which differ between the two disciplines. This taxonomy provides 2 generalized and 11 more narrowly defined classes – this permits distinctions between families of soils for which particle size is important and provides broader groupings for soils where fine distinction could produce undesirable separations.

USDA NRCS classifies soil types by the percentage of sand, silt, and clay particles in each soil. These represent the “fine earth” particles in soils and particle sizes are defined below in millimeters. Infiltration rate in soils is dependent on the percentage of sand, silt, and clay in the soil as well as clay mineralogy. Water will move more quickly through the larger pore spaces in a sandy soil than a clayey soil. An estimate of infiltration from USDA NRCS is greater than 0.8 inches per hour for sands, between 0.2

and 0.4 inches per hour for loams, and between only 0.04 and 0.21 inches per hour for clays (USDA NRCS 2008). Fine earth concentrations can provide other types of drainage patterns that affect contaminant concentrations. California's Imperial Valley contains clay soils with very low infiltration rates in half of its agricultural areas. When these soils dry they form cracks and water runs through these cracks in the soil instead of filtering through them resulting in excessive soil salinity. A number of methods have been tried to leach salts out of the soils with varying degrees of success (Grismer and Khaled 1996).

Soil Separates

The United States Department of Agriculture uses the following size separates for the <2 mm mineral material:

Very coarse sand:	2.0-1.0 mm
Coarse sand:	1.0-0.5 mm
Medium sand:	0.5-0.25 mm
Fine sand:	0.25-0.10 mm
Very fine sand:	0.10-0.05 mm
Silt:	0.05-0.002 mm
Clay:	< 0.002 mm

Figure 12: Fine Earth Size (USDA NRCS)

The data from the SSURGO soil dataset returned a variety of soil types. All returned types had significant components of the soil being in the fine earth category. The definitions of the soil classes follow below – some pertaining to "shallow families" mean those soils which are Oxisols that are less than 100 cm deep (from the mineral soil surface) to a root-limiting layer and are not in a Lithic subgroup, other mineral soils and Folistels that are less than 50 cm deep (from the mineral soil surface) to a root-limiting layer and are not in a Lithic subgroup, or other Histels that are less than 50 cm deep to a rootlimiting layer.

All the observed soil classifications are mineral soils that, in the thickest part of the control section (if part of the control section has a substitute for particle-size class and is not in one of the strongly contrasting particle-sizes), or in a part of the control section that qualifies as an element in one of the strongly contrasting particle-size classes, or throughout the control section, meet one of the following sets of particle-size class criteria:

- **Clayey** - Have 35 percent or more (by weight) clay (more than 30 percent in Vertisols) and are in a shallow family or in a Lithic, Arenic, or Grossarenic subgroup, or the layer is an element in a strongly contrasting particle-size class.
- **Coarse-Loamy** - Have, in the fraction less than 75 mm in diameter, 15 percent or more (by weight) particles with diameters of 0.1 to 75 mm (fine sand or coarser, including rock fragments up to 7.5 cm in diameter) and, in the fine-earth fraction, less than 18 percent (by weight) clay.
- **Fine** - Have (by weighted average) less than 60 percent (by weight) clay in the fine-earth fraction.
- **Fine-Loamy** - Have, in the fraction less than 75 mm in diameter, 15 percent or more (by weight) particles with diameters of 0.1 to 75 mm (fine sand or coarser, including rock fragments up to 7.5 cm in diameter) and 18 to 35 percent (by weight) clay (Vertisols are excluded).

- **Fine-Silty** - Have, in the fraction less than 75 mm in diameter, less than 15 percent (by weight) particles with diameters of 0.1 to 75 mm (fine sand or coarser, including rock fragments up to 7.5 cm in diameter) and, in the fine-earth fraction, 18 to 35 percent (by weight) clay (Vertisols are excluded).
- **Loamy** - Have a texture of loamy very fine sand, very fine sand, or finer, including less than 35 percent (by weight) clay in the fine-earth fraction (excluding Vertisols), and are in a shallow family or in a Lithic, Arenic, or Grossarenic subgroup, or the layer is an element in a strongly contrasting particle-size class (listed below) and the layer is the lower element or the other element is a substitute for particle-size class.
- **Loamy-Skeletal** - Have 35 percent or more (by volume) rock fragments and less than 35 percent (by weight) clay.
- **Very-Fine** -Have 60 percent or more clay.

2006 Data

The 2006 dataset showed the following distribution of particle-size classes:

Table 27: Soil Particle Size for 2006 Data

All 2006 Data – Soil Types			
Map Unit	Particle Size	Count	Percentage
Yolo-Tehama-Rincon family-Marvin (s882)	Fine Silty - Fine Silty - Fine - Fine	4	40%
Redding-Corning (s821)	Fine - Fine	1	10%
Stockton-Clear Lake-Capay (s824)	Fine - Fine - Fine	1	10%
Sycamore-Shanghai-Nueva-Columbia (s855)	Fine Silty - Fine Silty - Fine Loamy -	1	10%

	Coarse Loamy		
Tisdale-Kilaga-Conejo (s870)	Fine Loamy - Fine - Fine Loamy	1	10%
Willows-Solano-Pescadero (s886)	Fine - Fine Loamy - Fine	1	10%
Yolo-Sycamore-Brentwood-Artois (s883)	Fine Silty - Fine Silty - Fine - Fine	1	10%
Total		10	100%

SSURGO data returns multiple soil types per map unit – this is due to the scale of the dataset. Each of the soil types for the 2006 dataset is made up of multiple soils – some particle sizes are unknown.

Data by Month

The types of soil within each month varied very little. Data were better shown by combining the months into seasons. Three months were assigned to each season: Winter – December, January, February; Spring – March, April, May; Summer – June, July, August; and Fall – September, October, November. The monthly data set showed the following distribution of particle-size classes:

Table 28: Soils for Winter Months

Winter Data - Soil Types			
Map Unit	Particle Size	Count	Percentage
Maymen-Etsel (s704)	Loamy - Loamy Skeletal	8	12%
Sheetiron-Rubble land-Neuns (s706)	Loamy Skeletal - Unknown - Loamy Skeletal	8	12%
Yollabolly-Rock outcrop (s707)	Loamy Skeletal - Unknown	8	12%
Parrish-Maymen-Los Gatos-Etsel (s617)	Fine - Loamy - Fine Loamy - Loamy Skeletal	6	9%

Speaker-Sanhedrin-Kekawaka-Hopland (s705)	Fine Loamy - Fine Loamy - Fine - Fine Loamy	4	6%
Cole (s699)	Fine	2	3%
Parrish-Los Gatos-Hulls-Goulding (s628)	Fine - Fine Loamy - Fine Loamy - Loamy Skeletal	2	3%
Sheetiron-Millich-Goulding (s616)	Loamy Skeletal - Clayey - Loamy Skeletal	2	3%
Skyhigh-Millsholm-Bressa (s703)	Fine - Loamy - Fine Loamy	2	3%
Sobrante-Hambright (s709)	Fine Loamy - Loamy Skeletal	2	3%
Sodabay-Konocti-Benridge (s710)	Fine Loamy - Loamy Skeletal - Fine	2	3%
Tisdale-Kilaga-Conejo (s870)	Fine Loamy - Fine - Fine Loamy	2	3%
Toomes-Supan (s622)	Loamy - Fine Loamy	2	3%
Water (s8369)	None	2	3%
Wolfcreek-Still-Lupoyoma-Kelsey (s700)	Fine Loamy - Fine Loamy - Fine Silty - Coarse Loamy	2	3%
Landlow-Clear Lake (s630)	Fine - Fine	1	2%
Olashes (s875)	Fine Loamy	1	2%
Redding-Corning (s821)	Fine - Fine	1	2%
San Joaquin-Rocklin-Redding-Montpellier-Cometa (s876)	Fine - Fine Loamy - Fine - Fine Loamy - Fine	1	2%
Sierra-Caperton-Andregg (s817)	Fine Loamy - Loamy - Coarse Loamy	1	2%
Sobrante-Rock outcrop-Auburn (s840)	Fine Loamy - Unknown - Loamy	1	2%
Stohlman-Palls (s871)	Loamy - Coarse Loamy	1	2%
Subaco-Oswald-Gridley (s856)	Fine - Fine - Fine	1	2%
Sycamore-Shanghai-Nueva-Columbia (s855)	Fine Silty - Fine Silty - Fine Loamy - Coarse Loamy	1	2%
Vina-Brentwood (s642)	Coarse Loamy - Fine	1	2%
Xerofluvents-Ramona-Kilaga-Cometa (s839)	Unknown - Fine Loamy - Fine - Fine	1	2%
Total		65	100%

Table 29: Soils for Spring Months

Spring Data - Soil Types			
Map Unit	Particle Size	Count	Percentage
Yolo-Tehama-Rincon family-Marvin (s882)	Fine Silty - Fine Silty - Fine - Fine	8	24%

Stockton-Clear Lake-Capay (s824)	Fine - Fine - Fine	4	12%
Yolo-Sycamore-Brentwood-Artois (s883)	Fine Silty - Fine Silty - Fine - Fine	4	12%
Hillgate-Corning (s885)	Fine - Fine	2	6%
Maymen-Etsel (s704)	Loamy - Loamy Skeletal	2	6%
Sacramento-Ryde-Egbert (s881)	Very Fine - Fine Loamy - Fine	2	6%
Cole (s699)	Fine	1	3%
Sheetiron-Rubble land-Neuns (s706)	Loamy Skeletal - Unknown - Loamy Skeletal	1	3%
Sierra-Caperton-Andregg (s817)	Fine Loamy - Loamy - Coarse Loamy	1	3%
Skyhigh-Millsholm-Bressa (s703)	Fine - Loamy - Fine Loamy	1	3%
Sobrante-Hambright (s709)	Fine Loamy - Loamy skeletal	1	3%
Sodabay-Konocti-Benridge (s710)	Fine Loamy - Loamy Skeletal - Fine	1	3%
Speaker-Sanhedrin-Kekawaka-Hopland (s705)	Fine Loamy - Fine Loamy - Fine - Fine Loamy	1	3%
Sycamore-Sailboat-Egbert (s853)	Fine Silty - Fine Loamy - Fine	1	3%
Tisdale-Kilaga-Conejo (s870)	Fine Loamy - Fine - Fine Loamy	1	3%
Toomes-Supan (s622)	Loamy - Fine Loamy	1	3%
Water (s8369)	None	1	3%
Willows-Solano-Pescadero (s886)	Fine - Fine Loamy - Fine	1	3%
Total		34	100%

Table 30: Soils for Summer Months

Summer Data - Soil Types			
Map Unit	Particle Size	Count	Percentage
Yolo-Tehama-Rincon family-Marvin (s882)	Fine Silty - Fine Silty - Fine - Fine	8	20%
Tisdale-Kilaga-Conejo (s870)	Fine Loamy - Fine - Fine Loamy	6	15%
Yolo-Sycamore-Brentwood-Artois (s883)	Fine Silty - Fine Silty - Fine - Fine	5	13%
Stockton-Clear Lake-Capay (s824)	Fine - Fine - Fine	4	10%
Hillgate-Corning (s885)	Fine - Fine	3	8%
Willows-Solano-Pescadero (s886)	Fine - Fine Loamy - Fine	3	8%
Sacramento-Ryde-Egbert (s881)	Very Fine - Fine Loamy - Fine	2	5%

San Joaquin (s825)	Fine	2	5%
Sehorn-Diablo-Balcom-Alo (s887)	Fine - Fine - Fine Loamy - Fine	2	5%
Sycamore-Shanghai-Nueva-Columbia (s855)	Fine Silty - Fine Silty - Fine Loamy - Coarse Loamy	2	5%
Redding-Corning (s821)	Fine - Fine	1	3%
Subaco-Oswald-Gridley (s856)	Fine - Fine - Fine	1	3%
Sycamore-Sailboat-Egbert (s853)	Fine Silty - Fine Loamy - Fine	1	3%
Total		40	100%

Table 31: Soils for Fall Months

Fall Data - Soil Types			
Map Unit	Particle Size	Count	Percentage
Yolo-Tehama-Rincon family-Marvin (s882)	Fine Silty - Fine Silty - Fine - Fine	11	24%
Stockton-Clear Lake-Capay (s824)	Fine - Fine - Fine	7	16%
Hillgate-Corning (s885)	Fine - Fine	6	13%
Yolo-Sycamore-Brentwood-Artois (s883)	Fine Silty - Fine Silty - Fine - Fine	6	13%
Sehorn-Diablo-Balcom-Alo (s887)	Fine - Fine - Fine Loamy - Fine	3	7%
Willows-Solano-Pescadero (s886)	Fine - Fine Loamy - Fine	3	7%
Tisdale-Kilaga-Conejo (s870)	Fine Loamy - Fine - Fine Loamy	2	4%
Redding-Corning (s821)	Fine - Fine	1	2%
San Joaquin-Rocklin-Redding-Montpellier-Cometa (s876)	Fine - Fine Loamy - Fine - Fine Loamy - Fine	1	2%
Sierra-Caperton-Andregg (s817)	Fine Loamy - Loamy - Coarse Loamy	1	2%
Sobrante-Rock outcrop-Auburn (s840)	Fine Loamy - Unknown - Loamy	1	2%
Sycamore-Shanghai-Nueva-Columbia (s855)	Fine Silty - Fine Silty - Fine Loamy - Coarse Loamy	1	2%
Toomes-Supan (s622)	Loamy - Fine Loamy	1	2%
Xerofluvents-Ramona-Kilaga-Cometa (s839)	Unknown - Fine Loamy - Fine - Fine	1	2%
Total		45	100%

DISCUSSION

Geographic Locations

2006 Data

Zones of interest created by using the entire set of data from 2006 returned areas in Butte, Sutter, Yolo and Yuba counties. These are four of the six counties that returned data above the MCL from the original data set with the missing counties being Placer and Lake. These areas are generally smaller than those in the monthly data sets and are situated roughly down the center of the lower part of the SHR. Butte County is contained within the middle zone but the classification of upper/middle/lower part of the region are arbitrary and only meant to aid in visualizing analysis data. There is no scientific reason that the small parts of the middle zone should be any different in characteristics than the lower zone.

However, all the zones of interest do lie in the southern part of the watershed – this is also where the greatest number of data samples were found (see Appendix A). From the studies by Luzzader-Beach it has been illustrated that the number of data samples does affect the patterns of data returned by interpolation processes. The number of data samples in this case may have been insufficient to accurately capture the entire watershed but was heavily weighted enough in the southern part of the watershed to return reliable results. Based on the data returned by each of the studied characteristics (proximity to environmental management wells, sub-basins, land use / land cover, and soil types) it does seem like the zones of interest are at least somewhat appropriate in their boundaries.

Monthly Data

The data are concentrated in the southern part of the SHR. None of the zones of interest were identified in the upper part of the region and only a few of the zones entered into the middle of the region. The areas identified by the zones of interest did show a spatial pattern. Overall the areas fell roughly down the center of the southern section with some zones to the west and east of this area. Winter season data stuck toward the northern boarder of the area with some parts extending briefly into the middle zone. Spring areas tended towards the lower part of the region. Summer areas were primarily located along the center of the zone. Fall zones also stayed on the center line but did extend west and east briefly over the season.

Some counties were more represented by the zones of interest than others. Lake, Placer, Yolo, and Sutter counties saw the greatest area both when viewed by month – the larger zones of interest covered more area in these counties than others, and when viewed overall – each of these counties included zones created from multiple months worth of data in many different sizes. With so many of the zones centered on these counties and within their general area it seems like these would be hot spots of nitrate pollution.

From a visual observation of the zones of interest returned, Lake and Placer counties are not as well represented as Yolo and Sutter counties. Lake data were only returned in February and January while Placer data are returned in April, September, and December. Both of these counties also had fewer original well samples than both Yolo and Sutter, Lake ranking 12 and Placer ranking 14 out a total of 22 counties that contained well data in 2006. In terms of total samples of the original data set – Lake provided 3% and Placer provided 3%. Yolo County has zones of interest returned April through November and Sutter County has zones of interest returned in March and then June through October. Both these counties also had a higher number of initial well samples with Yolo ranking second and Sutter ranking fifth out of 22 counties that returned data. In percentage terms, Yolo provided 14% of the well samples and Sutter provided 6%. Lake and Placer also had fewer samples that were above the MCL which may also contribute to the size and shape of the zones of interest.

Original Data Points and Locations of Zones of Interest

The zones of interest created by the Delaunay triangulation method represented the data that it was based upon well. There were 61 samples out of the entire original water supply well dataset that were above the MCL of 45 mg/L. These data were observed in six counties over the entire year of 2006. Using the entire data set three of these counties were well represented with an additional county being very nearly tangentially in the zones of interest identified. Yolo County had multiple areas identified, Yuba and Butte Counties shared a contiguous area that also just barely touched Sutter County. Yolo County had the greatest number of samples over the MCL and had the greatest representation in the zone of interest. Sutter had the second highest but barely made it into the data set. Yuba County had more area with in the zone of interest but Butte County shared around ⅓ of the zone despite only having a single data point above the MCL. Sutter County, despite being second only to Yolo County in number of samples and returning over ¼ of the samples in the data above the MCL, barely made it into the zones highlighted by the triangulation method. Sample size does seem to affect the areas represented but it is possible the number of surrounding samples or lack thereof affect the interpolation process and can create unexpected results.

When viewing the data by month a few more suprising patterns show up. Some of the counties with datas above the MCL did not contain zones of interest in all of the months for which they returned samples above the MCL. These include Sutter County in January and April and Yuba County in March. Additionally the March data set is an extremely small portion of Sutter County. Logically it would seem that the Yuba County value would not be competing with nearby values and should be within the dataset.

Some months contained zones of interest even though there were no original data samples above the MCL within that month. Sutter County did not have samples in September but did contain part of a zone of interest. Butte County had only one sample above the MCL in July (and did contain a zone of interest in that month) however it also partially contained zones of interest in December and September.

Some counties in the watershed did not return samples of well water with nitrate concentrations higher than the MCL. However these counties did end up containing pieces of the zones of interest. These counties included Colusa, Glenn, Sacramento (a very small piece of one), and Solano Counties. These counties did not contain entire zones of interest – many of these areas spanned a number of counties.

Effects of Original Data on Zones of Interest

It is clear from the monthly data that the number of samples above the MCL do affect the creation of the zones of interest. No zones of interest are created solely within any areas that do not originally have samples with appropriate nitrate values. The Delaunay triangulation method cannot create something from nothing if there is no data to support it. Likewise, it seems from the examination of the zones and numbers that the greater the number of samples the greater the likelihood of more zones of interest and larger zones of interest. However, the complete set of nitrate values above the MCL was not contained within the zones of interest.

The number of wells contained by the zones of interest over all of the months was only 37. Comparing the number of samples identified each month by the areas of interest and the original number of samples above the MCL for each month you can see that the zones of interest did not include all of the samples over the MCL. This means that not all of the geographic areas with observed levels of nitrate in water supply wells are represented by the Delaunay triangulation method. The months of the first half of the year, January to June, tended to have only about 50% of their samples above the MCL within the zones of interest. The second half of the year, from July through December, had a better percentage (with November using both of its samples). The percentages of the total number of samples was roughly the same – for example Yolo County returned 49% of the samples out both the data points contained within the zones of interest and 49% of the data points within the original 61 data points above the MCL. Sutter County was the only county to have significantly fewer data points contained within the zones of interest – dropping from 16 to 6 – and contributing 26% of the original data set to only 16% of the data set identified by the zones of interest.

For the entire set of 2006 data none of the original sample wells were contained within the zones of interest. Despite that, the areas were still created within the counties that had data above the MCL. However not all of the counties with original data points above the MCL contained zones of interest.

It is clear that the surrounding data points do have an effect on the zones of interest created. The availability of data points and the values affect how the triangulation process creates boundaries. For this study zones of interest were created in the appropriate counties and the geographic locations of some of the original data points (where there are actual, observed instances of nitrate values above the MCL) were included in the zones created by triangulation. Not all were included meaning that the method is not simply drawing lines around areas arbitrarily – this method may bear more investigation for use in further nitrate prediction simulations.

Proximity to Environmental Management Wells

2006 Data

Even the relatively small areas created using the entire 2006 data set showed environmental management wells within five- or ten-mile buffers of the study areas. The five-mile buffer picked up 25 wells – some within a cluster – in Yolo County. The ten-mile buffer captured 85 and included the data from the five-mile buffer but also wells in Sacramento, Solano, and Yuba Counties. Sacramento and Solano are not within the original data set so the buffering process may help to expand study areas where data are scarce.

Environmental management well data that was included in the buffer area was collected in Yolo County mostly in months that the original high nitrate values were collected. Some samples of the data were collected in March but water safety wells in this data set did not show high values of nitrate in March. It would be interesting to look at data in March from nearby wells outside of the original data set to see if those wells also have high levels of nitrate. If so, the five-mile buffer would add valuable data for watershed planning and groundwater monitoring efforts. The ten-mile buffer returned environmental management well data from the entire year – this may be due to the clusters of wells being high in number. Further study would be needed to see if there were correlations between spikes in nitrate data from the environmental management wells and other wells within the ten-mile buffer zones. Another method of predicting danger to local groundwater would be to buffer clusters of environmental management wells and to look at whether or not water supply wells within buffer zones had instances of nitrate higher than the MCL.

Data by Month

Two months captured environmental management well data within 1 miles of the original zone of interest. Both September and December had one sample found in Placer County in the one-mile buffer zone. All months had wells within the five-mile buffer zone and the ten-mile buffer zone. The number of wells was greater in the April to June timeframe, though August also provided high number of wells and samples captured by the buffers.

Environmental management well data are more interesting to look at by month because the environmental management well data set was taken as a whole, some of the data returned by the buffers do not seem likely to affect water supply well data. For example, environmental management wells found within the January, February, and March five-mile buffer zones all had data collected in the November and December timeframe. It seems unlikely that these areas would be affected by well data that is nearly a year distant from the zone creation month. However, it would be interesting to look at 2005 environmental management well data to see if nitrate data collected from these particular wells came at a different time. For the five-mile buffer zones, the months with larger sample numbers, April to June, all had data collected within the months of February through May and July through October and both of the months that had data within one mile of the area of interest returned a data collection month of October. This information seems more easy to analyze. Data collected April through June could be affected by environmental management well values from earlier in the year, although values from later in the year will not necessarily be useful.

The timeframes for the ten-mile buffer data are so wide, due to the number of wells collected, that it is unlikely the nitrate value data would be useful in any analysis. However, it is possible that examining the characteristics of the land within the buffer zones (one-, five-, and ten-mile areas could be used for this) could provide insight as to whether or not there is danger of future contamination. It is also possible to use data from past or future years to see if the environmental management wells within the buffers ever seem to have an effect on the local water supply wells.

Groundwater Basins

2006 Data

Though there were only a few zones of interest created when using the entire dataset for 2006 there were still a total of four groundwater basins identified in these areas. In fact, all of the 2006 zones of interest occurred within one of the four sub-basins – Colusa, North Yuba, Solano, or Yolo. Three zones of interest out of a total of five lay totally or partially within the Yolo sub-basin. Two of five zones of interest lay within the Colusa sub-basin. These are still the areas that had the greatest number of well data samples above the MCL.

Data by Season

A total of 11 sub-basins were identified by visual survey of the seasonal data. Over the entirety of 2006, 38 instances of the basins were identified (adding up each set of basins observed in each month). Nearly 70% of these observances took place in 4 out of 11 basins: Yolo, Sutter, Colusa, or North Yuba sub-basins. Yolo had the greatest number of observances, followed by Sutter, Colusa, and North Yuba. Nearly 70% of the data returned by mapping the zones of interest came from less than 40% of the total dataset.

Though ranking second, Sutter sub-basin did show up in each of the seasons at least once. Yolo, Colusa, and Sutter showed up in all of the seasons except for the winter season. North Yuba sub-basin in all seasons except for the spring season. The spring season identified the fewest total number of sub-basins while the fall season identified the most. Most of the returned sub-basins were within the Sacramento Valley Basin – only winter and spring showed Big Valley and Long Valley which are separate entities from Sacramento Valley Basin.

All of the sub-basins have water bearing formations from roughly the same geological time periods. Yolo and Colusa sub-basins deposits consist partly of the Tehama formation. All contain a lot of alluvial materials and sedimentary rocks (CDWR 2003).

Groundwater level trends for available data are the same for all four of the highest count subbasins. The groundwater levels overall remain relatively constant. Hydrograph data for Yolo and Colusa do show decreases during dry years but recover during "wet" or post-drought years. Sutter subbasin groundwater recharge is indicated as stream percolation, deep percolation of rainwater, and percolation of irrigation water. North Yuba sub-basin has stream channel and floodplain deposits along the Yuba River, Feather River, and Honcut Creek that are highly permeable and provide for large amounts of groundwater recharge. Artificial recharge potential is low due to soil types overlying recharge areas. Yolo and North Yuba sub-basins have a groundwater budget of Type C while Sutter and Colusa sub-basins have Type B. Type B indicates that enough data are available to estimate the groundwater extraction to meet local water use needs. Type C indicates a low level of knowledge of any of the budget components for the area (CDWR 2003).

Land Use / Land Cover

2006 Data

Land use class data were somewhat surprising – developed land returned more results than cultivated cropland or grassland areas. When looking at the classes returned by the full year of data the greatest part was returned by developed lands – these including all the subcategories including open space and low – high intensity. Cultivated Crops and pasturelands also made an appearance along with a small part being grassland and herbaceous areas. Developed areas can contribute many different kinds of pollutants to the local watersheds from sources including lawn and pet waste, stormwater runoff, and permitted point sources including wastewater treatment plants. Agricultural land in general contribute nitrates from fertilization. 18% of the land uses captured in the yearly data areas are wetlands. Another 2% is classed as open water. This seems to speak to runoff from surface areas which given the other major classes are developed land and cultivated crops seems reasonable.

Data by Month and Season

Nitrate data were analyzed both by season and by month. The winter season saw most of its land uses being within the forest and shrubland categories. When viewing all the monthly data together these natural areas represented the bulk of the areas with high projected nitrate values. However, when breaking out data by month, the patterns were different. January showed 60% of the area in developed land (Developed, Open Space is the top contending type in all categories.) 20% of the data were in wetland or water areas and 5% was in cultivated crop or pasture land. Shrubland and forest represented less than 1% of all the data for the month. February returned 60% of the data in forest land with

30% in shrub and grassland. Only 5% of the data from this month comes from developed land and about 1% comes from water features such as wetlands and less than 1% was shown to be in lands classified as “barren”. December, counted in the winter months, returns about35% developed, about 30% forest, 18% shrublands and 7% of both water features and pasture. It seems that the February data might be skewing the percentages for the winter months graph –which seems accurate given the relative area compared to the other months in the winter category.

The spring category showed the bulk of its samples in the developed areas with 32%, forested areas coming second with 27%, grass and shrubland having 18%, cultivated lands having 12%, water areas having 11% and barren land showing at 1%. Breaking these out by months showed a similar pattern. March had 96% of its samples returned in the developed category with the rest being in cultivated areas. April showed 35% forested areas, 30% developed areas, 20% grasslands, 7% in cultivated lands, about 3% in water features, and less than 1% in barren land. May had 35% of its samples in water features, 26% in cultivated lands, 22% in developed areas, 15% in grasslands and 3% in barren lands. These categories seem to be better represented in the seasonal percentages – most of the major groups are well represented in each month and no single month skews the results.

Summer totals again showed developed areas first with 39%, cultivated areas with 21%, water features with 20%, grasslands with 13%, barren lands with 4% and forests with only 1%. Looking by month, these values are again well represented. June had 34% developed land, 27% water features, 22% cropland, 13% grassland, 4% barren land and

1% forest. July had 60% developed lands, 18% cropland, 13% grassland, around 5% as water features, 4% barren land and less than 1% forest land. August had 38% developed land, 22%, cultivated land, around 17% water features, 16% grasslands, 4% barren land and again less than 1% forest.

Out of all the land classes captured by the zones of interest in the fall seasons, 45% developed lands, 16% grasslands, around 14% forest land, around 8% water features and 3% barren land. By month the data were again well represented. September saw 35% developed land, 21% forest, 19% grassland, 15% cropland, 8% water and 3% being barren land. October had 73% being developed land, 11% cropland, 7% grasslands, 7% water, 3% baren land and less than 1% forest land. November had 36% developed land, 26% water features, 21% cultivated land, 11% grassland and 4% as barren land.

Land Uses Represented by Zones of Interest

All the months and seasons commonly have three categories being top contenders for areas of nitrate contamination – developed land (with the category of Developed, Open Space being the greatest number of samples), cultivated areas including crop and pasture lands, and water features. Developed areas in this area of California could be contributing nitrates via septic systems – indeed this is one of the main contributors of nitrates to groundwater noted in the supporting literature. There is also a possible surface water component from storm water runoff.

Cultivated areas can contribute nitrates through surface water runoff during planting seasons. Proper fertilization practices can help to decrease the amount of nutrients enter local groundwater stores but the growing, planting, and harvesting seasons of crops can create a rolling season of nutrient inflow. California in 2006 accounted for 46% of the US fruit and nut production and 63% of the national value of fruit and nut crops. Grapes are another large part of the agriculture sector with Napa County (Agricultural District 4) even receiving the highest average price of $3,046.13 per ton. A number of the counties identified either by the zones of interest or buffer zones had cash crops including tomatoes and grapes (including wine grapes). Counties that included these fruits in their top commodities included Sutter, Sacramento, Colusa, and Yolo (tomatoes are one of the top commodities in this county.) Grapes have crop seasons from January through mid-June and tomatoes run from mid-May through December (CDFA 2007). These crop seasons in the cultivated areas that have been shown to be major players in the zones of interest could be contributing nitrate to groundwater stores.

California is also the leading state in alfalfa hay production (and consumption) as well as cotton, rice, sorghum for grain, wheat, and potatoes. Counties of interest that have alfalfa hay as a top commodity include Sutter, Yolo, Gelnn, Sacramento, Solano and Colusa. Record rainfall in March and April delayed the 2006 alfalfa hay season and the crop load was severly affected by heavy July rains. Rice is another field crop represented by the counties of interest including Butte, Glenn, Sutter, Yolo and Yuba. In 2006 the planting season was delayed due to rain during late March and early April. Rice planting continued through to mid-June this year (CDFA 2007). These areas and time periods of cultivation could have contributed to high observed nitrate values in water supply wells.

Soils

2006 Data

General particle characteristics for 2006 data tended towards the fine types of soil. Fine soils composed 54% of the different specific soil types with fine silty soils being 21% and fine loamy soils being 13%. Others included coarse loamy and silty soil types.

For the entire year's worth of data the only soil map unit shown returned more than once within the zones of interest (for nitrate concentrations above the MCL) was Yolo-Tehama-Rincon family-Marvin. These soil types ranged from fine silty to fine. These categories were also found within the other soil map unit component soils found in the 2006 zones of interest. Other categories of particle size included both fine loamy and coarse loamy soils. Yolo soils show up in another map unit within this area. The soils from this most observed class have specific characteristics that may be useful in defining parameters of areas that are sensitive to nitrate concentrations.

Yolo soils exist on nearly level to moderately sloping alluvial fans and formed in fine-loamy alluvium derived from sedimentary formations. They are well drained with slow to medium runoff and moderate permeability. They are used for intensive ow/field/orchard crops and the original vegetation was annual grasses, forbs, and some scattered Oak. The series is extensive in California. Tehama soils are on terraces and fans and have slopes of 0 to 15%. They formed in mixed alluvium and are geographically associated with Yolo soils. Tehama soils are well or moderately-well drained and have medium runoff and slow permeability. With irrigation the soils support row crops, pasture, and a few orchards. If the soils are formed dry they support small grains and pasture. Tehama soils are moderately extensive. Rincon series soils consist of deep, well drained soils that formed in alluvium from sedimentary rock. They are on old alluvial fans and both stream and marine terraces. They have slopes of 0% to 30%. The soils are extensive and found in the intermountain valleys of the Coast Range and along the west side of the lower Sacramento and Upper San Joaquin Valleys. Rincon Series soils are well drained with slow to rapid runoff and slow permeability. They are used for irrigated citrus, deciduous fruits, row crops, and alfalfa. Some are dry farmed for grain and pasture. Natural vegetation included annual grasses and forbs. Marvin soils are associated with Rincon soils. They are on nearly level flood plains at elevations of 10 to 100 feet under annual grasses and forbs. They formed in fine textured alluvium from mixed sources. They are moderately well to somewhat poorly drained, runoff is slow and permeability is slow.

Seasonal Data

Data by month did not give enough incidences of map units for a reasonable analysis so the data were combined into seasons. January, February and December of 2006 were used as the winter season, March through May was the spring season, June through August was the summer season and September through November was the fall Season. Within these seasonal tables the same map unit grouping that showed the most times in the 2006 dataset – Yolo-Tehama-Rincon family-Marvin, showed up in the spring (24% of the samples and the greatest number of samples), summer (20% of samples and the greatest number of samples), and fall (24% of the samples and the greatest number of samples). The series did not show up in the winter season at all. Broken down by month, this soil type occurs every month between April and November of 2006. This specific SSURGO map unit seems like a very likely candidate for high nitrate levels.

The top winter map unit grouping was tied between Maymen-Etsel, Sheetiron-rubble land-Neuns, and Yollabolly-Rock Outcrop. All of these soils exist in mountainous areas with slopes ranging between 5 and 100 percent. Maymen soils exist between a range of 400 and 4,250 feet, Etsel soils exists at 1,000 to 6,000 feet, Sheetiron soils exist at 2,400 to 5,500 feet, Neuns soils at 2,200 to 6,000 feet and Yollabolly at 5,000 to 8,000 feet. None of these soils are used for agriculture but Sheetiron and Nuens are used for timber and Yollabolly has some incidental timber harvesting in its area.

Maymen soil is somewhat excessively drained, has high to very high runoff, and moderate to moderately rapid permeability. Etsel soils are somewhat excessively drained, have low to high runoff, and are moderate to moderately rapidly permeable. Sheetiron soils are well drained, have medium to very rapid runoof and are moderate to moderately rapid permeability. Neuns soils are well drained, have low to high runoff and are moderately permeable. Yollabolly soils are excessively drained, have rapid and very rapid runoff and are moderately permeable. The bulk of the winter soils are obviously from mountainous areas and are more well drained than the soils in the rest of the year. However, it is interesting to note that the winter soils have the same reported types of particle size as the other seasonal soil types. This seems to indicate that SSURGO reported particle size classifications are not the proper indicator from soil data to narrow down areas of possible nitrate contamination.

Each map unit is composed of a series of soils – but these map units share soils between them. A full listing of occurrences and the percentage total can be found in Appendix D. The Yolo soil type was that most observed comprising 7% of all soils within the zones of interests over the four seasons. Marvin, Rincon family soils, and Tehama were all 5% of the total samples over the four seasons and Sycamore came in at 4%. Aside from Yolo, Sycamore was the only other soil type to come up twice within the 2006 data set – both Yolo and Sycamore came up twice. Sycamore soil was found in one map unit group in the winter data set – it appeared one time in the map unit group of Sycamore-Shanghai-Nueva-Columbia. Sycamore is a competing series with Yolo. They are found on nearly level flood plains at elevations of 10 to 100 feet. The soils formed in mixed sedimentary alluvium. Sycamore soils are formed under poorly drained conditions and exist with some areas drained. Surface runoff varies from slow to very slow and permeability varies from moderate to moderately slow. The soils are used for orchard, row, truck and field crops excluding rice. Natural vegetation consists of annual grasses and oak.

Characteristics

There are two types of characteristics that emerge as important when considering the soils dataset. The first is what characteristics to use for each soil type and soil type map unit to indicate areas where there may be high nitrate concentrations. The reported particle size data does not seem to be appropriate because the different soil types represented by the winter dataset verses the spring, summer, and fall datasets did not have radically different particle size descriptions. Types of soils seem to be a better fit along with the drainage, permeability, runoff, and general soil usage characteristics. Soils here in the winter seem to be those found in high altitudes with very quick draining, high permeability and quick runoff times. Soils in the other seasons seem to be those that are slower to drain, have lower permeability and slow surface runoff. Yolo and Sycamore soils seem to be very likely candidates for high nitrate values in groundwater (others may be applicable – see Appendix D for the complete listing of soil type incidences) and the soil map unit of Yolo-Tehama-Rincon family-Marvin (S883) is a good indicator as well.

Seasonality

Looking at the initial data it is difficult to pull out any seasonal trends in nitrate levels. The initial data are so weighted to the southern part of the SHR that any analysis makes it difiicult to say that this is truly the area that needs the only concern. This holds true through the dataset – this project captures the characteristics of the southern part of the region much more accureately than the middle or northern parts of the region. Seasonal trends would be affected by the data collected – numbers of samples and times of sampling. It is impossible to say that a greater number of samples above the MCL are captured in one season because there is definitely a seasonal trend – it may simply be that there is more data available for that season and thus higher values of nitrates are more likely to be captured. Likewise for the number of environmental management wells captured by the buffers – the fact that wells are within the buffer zones notes that the wells are certainlyh possible of passing high nitrate concentrations to other groundwater sources but the number of samples counted in each buffer zone does not necessarily reflect patterns by season.

However, there are patterns seen when looking at other data from the study – these are shown through the tables for each characteristic. The winter season overall returned land use land cover classes highly representative of forested areas and grasslands. The only month of the grouping (January, February, and December) to have a different configuration was January – and this zone of interest was very small compared to the other two zones and possibly not as representative of larger patterns due to its size. January as well as February and December do have in their top representative land use land cover classes many of the developed classes. The Developed, Open Space class appears in all three of these months and is the second highest representative class in the season when taken as a whole.

Major soils for the winter season (those that were returned most when analyzing soil types captured by the zones of interest) all existed withn mountainous areas and on high slopes. These areas would seem to correlate with land use values in that the zones of interest identified are likely in rocky, sloped areas with developed land intermittently spread throughout. It is possible that the most at-risk areas in the winter are those that are in forested areas with sparse development around them. Sub-basins were also different in the winter with fewer incidences of the Sacramento Valley basins being seen. Winter is different for three characteristics studied in this paper and this seems to point to different patterns in groundwater nitrate concentrations in winter months.

The spring season also kept Developed, Open Space as the top contentder – match ing that for all seaons. Spring also had high percentages of forest and grassland in its land use land cover classifications – although it had cultivated crops coming in higher than the winter percentages (but lower than summer and fall). March is a very small area and so likely its ultra-developed areas get lost in the data samples for April and May. April included Developed, Open Space as its top type but followed it with a wetlands category. May showed a trend toward increasing incidences of cropland while keeping open space. These trends seem to be moving from the winter versions through to the summer versions.

The top soil for spring was the Yolo - Tehama - Rincon family - Marvin group – the same as both summer and fall data. However, it does have a high incidence of Maymen - Etsel at 6% - which is one of the important winter soils but does not appear in either summer or fall soil types. This soil type also seems to indicate that spring is a transition period between the winter conditions in the zones of interest to the summer and fall conditions. The spring patterns also capture the Big Valley sub-basin that is seen in the winter but neither in summer nor fall.

Summer and fall season data are very similar in terms of soils and sub-basin representation. Land use land cover data are where more of a progression through seasons can be seen. Both seasons have a similar set of sub-basins with all observed basins lying in the Sacramento Valley region. Summer does have more basins that any other season, including fall, and is more varied than the spring. The fall season has fewer sub-basins but only one (Scaramento Valley – North American) is not found in the summer grouping. The Yolo - Tehama - Rincon family - Marvin soil group is also the top observation for the summer and fall seasons as it was in the spring season. These two later seasons are more similar to each other than winter is to spring or spring is to them.

13 soil map unit types are found in the summer seasons and nine of these are found within the 14 soil map unit types of the fall season set. The ordering by percentage observation is fairly similar in both of these groups as well.

Summer land use land cover still has Developed, Open Space as the top observed type for each of its component months. June has the same land use type for its second most observed percentage as the month of May – Emergent Herbaceous Wetlands and cultivated crops and grasslands come in after that. July has three types of developed land in the top three spots – Low, Open Space, and Medium. Grassland and cultivated crops follow those. August has cultivated crops after Developed, Open Space and then grasslands and wetlands. It seems that during the early parts of the growing season the land uses observed are similar to spring and as the season turns and more crops grow, are fertilized, and begin to be harvested observed land classes turn more towards cultivated areas.

Fall trends keep Developed, Open Space on top for all months. Grasslands and forest are higher in September than cultivated crops – but these come before all other types of land use classes. October has three types of developed land in the first three spots – Low, Open Space, and Mediaum (the same pattern as the month of July). November has another incidence of Emergent Herbaceous Wetlands in the number two spot with cultivated crops and grasslands following that.

It seems that land use classes follow a typical planting, growning and harvesting season. There is a lot of developed land in the zones of interest but a great deal of it is open space instead of heavily developed areas. Observed sub-basins change throughout the years with spring being the transitional time between the colder months and the summer and fall seasons being more similar to each other. Soils seem to follow the same pattern though like land use land cover patterns the top observation remains the same throughout the set.

CONCLUSIONS

Methodology Effectiveness

The method of identifying zones of interest for possible high nitrate concentrations using the Delauney triangulation method is predictive only where incidences of interest occur. This method needs the values above the MCL to be able to create the zones of interest – it cannot create something from nothing. However, it does turn point data into polygon data. Where once there was only a single well with a high concentration, applying the Delauney triangulation method will generate an area for water quality specialists to search for other wells that may have groundwater with high nitrate concentrations. This is especially important if there are other wells in the vicinity that provide water to local residents that may not be aware of nitrate levels in the area.

The method is supported by the data found using the various data layers including the land use/land cover data for the area, the soil particle size data, and the groundwater sub-basin characteristics. Background research supports the results that were found being legitimate – the soil particle size seems accurate based on previous studies, the land use/land cover is similar to some particular studies cited in the introduction, and similarities are found in the sub-basins that are identified by some of the zones of interest. The conditions seem favorable for subsurface flow and the proximity of the environmental management wells indicates that there could be some flow-through contamination.

More data samples would improve the accuracy of the method. These results are heavily weighted to the geographic areas that have more original well data than those that have fewer data samples – even if some of those samples are above the MCL. It is possible that averaging the samples for each well in a month could give better results – or a more conservative effort that wanted the largest zone of interest could simply throw out all the values except for the highest. There are a number of ways to use future data that could help define the method for future users.

Environmental Management Well Proximity

Buffering the zones of interest even at one mile (for some areas) captured environmental management wells. Both the five- and ten-mile buffers returned quite a few of these wells, too. There is an indication that the zones of interest and the water supply wells with high levels of nitrate are located within areas that could be affected by groundwater from the monitored wells. Timing is important, though as the further out the buffer the longer the timeline that the environmental management well data comes from. If the zone of interest was created from data returned in March, samples from environmental management wells returned from months after March will have no bearing on the water supply wells in question.

The larger buffers could possibly return unhelpful results – and it would be interesting to look at environmental monitoring well data to see when the nitrate “spikes” occurred and correlate these with zones of interest created for each month from water supply well data. A large spike in enivonrmental management well nitrate levels could affect the size and shape of nearby water supply well zones of interest. Looking at data over more than a single year would help to identify any true patterns.

A study of the local characteristics of the “buffer zones” is advisible. If conditions are favorable for groundwater flow-thorugh it is more likely that environmental management wells are affecting local water supply wells. If favorable conditions are found it would show that the Delauny triangulation method is a good way to begin to study groundwater flow and nitrate transmission through local groundwater.

Groundwater Sub-basins

Data from this analysis would be more useful if there was data about the depth of the wells and the water depth at the time of sampling. If this method were used again it would be important that this supplementary data are recorded and made available to the public. Unfortunately datasets are often limited and archival datasets such as this one that was collected in 2006 are difficult to supplement. It is possible that the local conditions in the sub-basins do have an affect on nitrate transport through groundwater. They all had some similar characteristics and based on previous work done in California it is interesting to note that the recharge areas are highly permable in natural areas but that artificial recharge potential is low (and related to soil types).

Land Use/Land Cover

Land Use/Land Cover categories seem to reflect the agricultural seasons and the urban nature of the local environment. The highly represented category for all seasons and overall was land classed as Developed, Open Space. This is not the high density urban clustering that we might think of but more open spaces that may have local nitrate contributions including lawn and garden fertilizers and leaking septic systems. This type of area was found in the Nantucket study mentioned earlier and could be home to human-induced nitrate pollution as mentioned in the introduction section of the paper. This category being so highly represented and supported by evidence does lend credence to the utility of the Delauny triangulation method of detecting zones likely to have high nitrate concentrations.

Cropland is still one of the higher represented categories – it has fewer subcategories but still stays on top in the months of the summer and fall seasons. This could be due to crop fertilization and crop harvesting during these times of years. Agricultural data seems to support the legitimancy of these findings.

The winter season sees the zones of interest capturing mostly forestlands. Though the counties that are represented by these months are not in the top five timber harvesting counties, other counties in the SHR are – Shasta, Siskiyou, and Plumas being third, fourth, and fifth highest respectively (CDFA 2007). The conditions that make those counties good for timber harvest may hold true for the winter zones of interest and further study would benefit the analysis.

Weather conditions by month could yield clues about land use land cover patterns. High precipitation could flush crop nutrients into groundwater and take time to filter into water supply wells due to soil permeability and drainage conditions. Using data from the agricultural report and the local areas around the zones of interest would shed some light on possible patterns observed here and assist with the analysis of seasonality effects on local groundwater nitrate concentrations.

Soils

Soil type is a more useful indicator than particle size when using the SSURGO data set. Some of the soils that were found in this project occur together frequently so other soils that are associated with those that are found in this data could also indicate a possibility for high nitrate values. Many of the soils outside of the winter months are not highly permeable but are moderately well to well drained. Groundwater would not necessarily be traveling close to the surface so these soils may be good transmitters of water that is high in nitrate concentration. Local data would make a difference here. As in some of the studies mentioned in the background research, there could be other characteristics of these soils (such as fracturing and channelization) that would make it easier for groundwater to flow below the surface. A study of these local characteristics would add depth to what has been observed here.

Further Research

This study did provide some interesting results. The zones of interest generated are close to environmental monitoring wells – some are as close as 1 mile away. This makes it a useful method to know where private well owners may need to be warned if there is an incident of extremely high nitrate concentration. Additionally, it seems that areas with lots of developed open space and cropland are likely to have high nitrate concentrations and that some significant soil groupings may affect the areas, too. This information may be helpful to water quality managers in the future to help serve the public and to keep safe the citizens of the State of California. It is possible, too, that this method could be duplicated in other areas to assist more people with monitoring the health of their local water.

Some things could be changed in further studies. One very important part of the study is the amount and spatial distribution of the data. A larger number of samples from a smaller number of wells is likely to be less helpful in finding areas of concern than a dataset covering a lager percentage of the spatial area. And while it is very cost effective to use large, publically available datasets some local information would assist in determining the utility of the outcome of the studies. For example, local land use and local soil characteristics would be very helpful in validating the study areas. It is difficult to use very general parameters given by SSURGO and NLCD to make judgements about small areas with variable local conditions. The data returned by this study is a good starting point to create a general set of parameters that could pinpoint areas of higher nitrate concentration. However, more local data would make these results more accurate.

Running this process with other years of data – and possibly increasing the number of years used in a single run of the Delauny triangulation process – may yield better insight into patterns in the data. Looking at other years, and even 2006 again, and combining the data with supplementary information about local agriculture, growing seasons, precipitation patterns, and temperature flux may show other factors that can assist in narrowing down the types of areas that would be affected by high nitrate concentrations. This process provided a good general set of parameters and did show that environmental management wells were within the proximity to the waster supply wells and futher usage and refinement may yield a useful tool for watershed management professionals.

APPENDIX A: ORIGINAL WATER SUPPLY WELL DATA BY MONTH

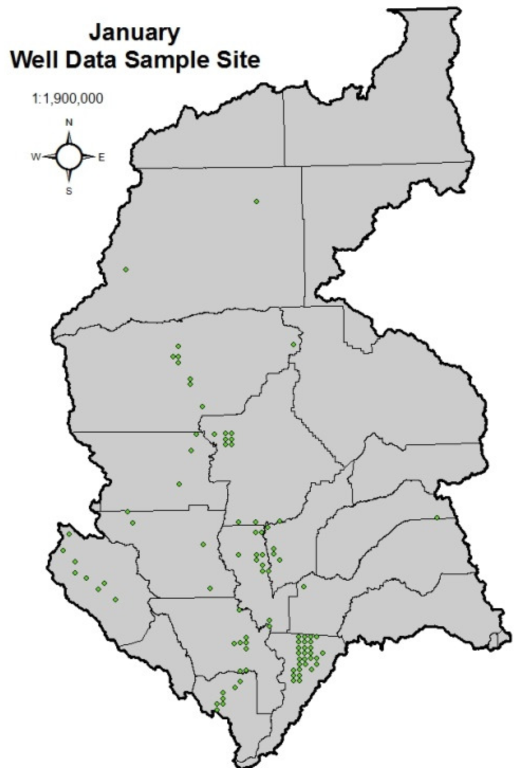


Figure 13: Sample Sites - January

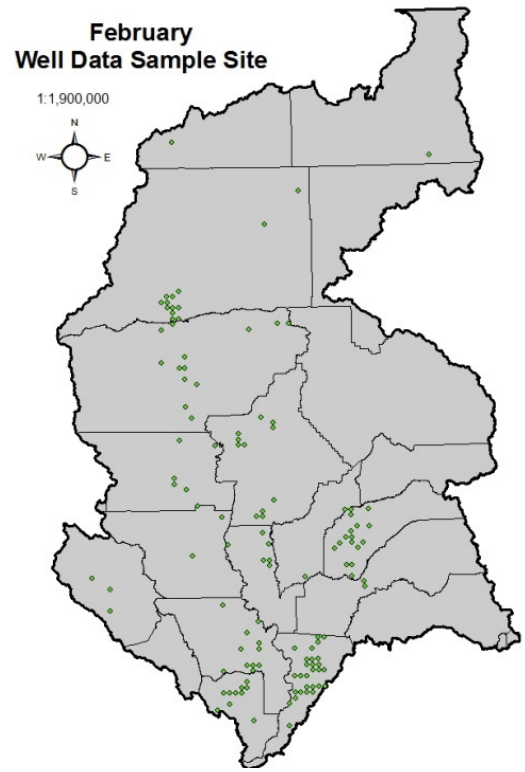


Figure 14: Sample Sites - February

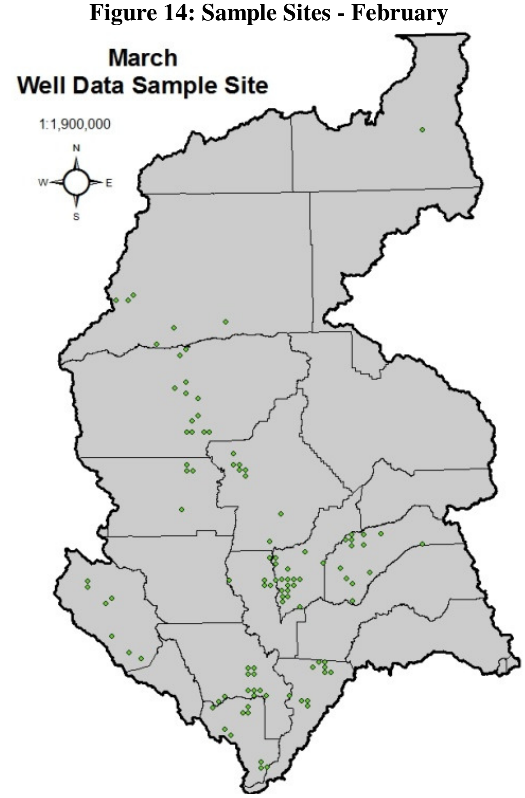


Figure 15: Sample Sites - March

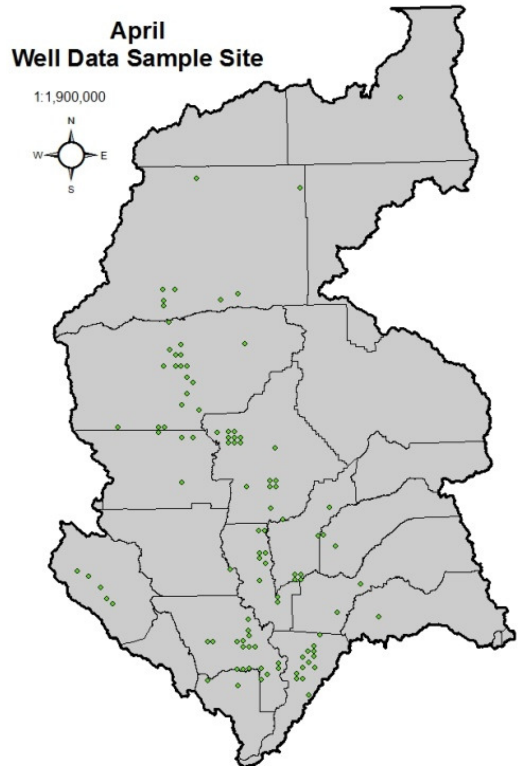


Figure 16: Sample Sites - April

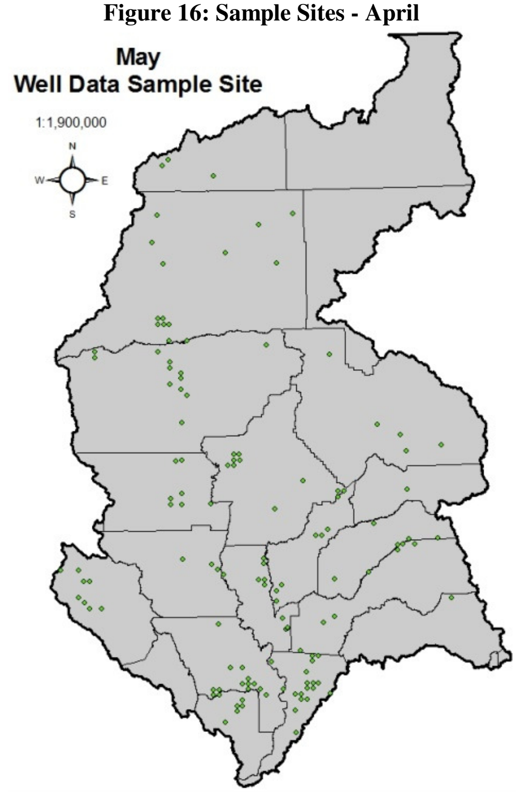


Figure 17: Sample Sites - May

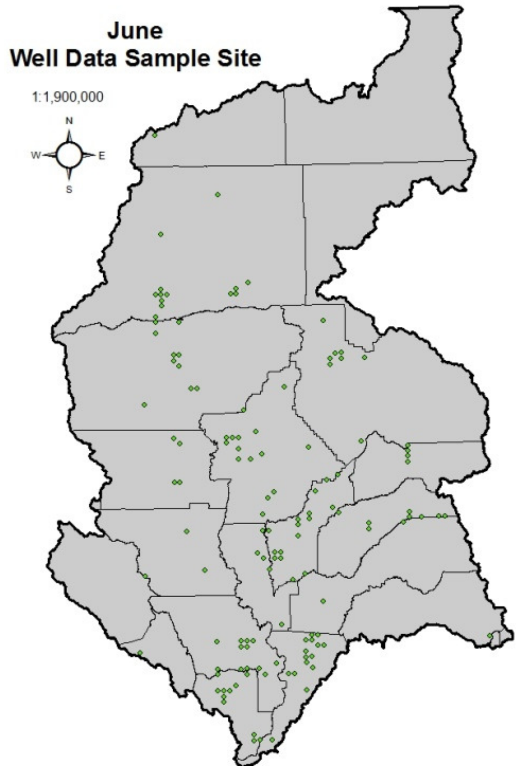


Figure 18: Sample Sites - June

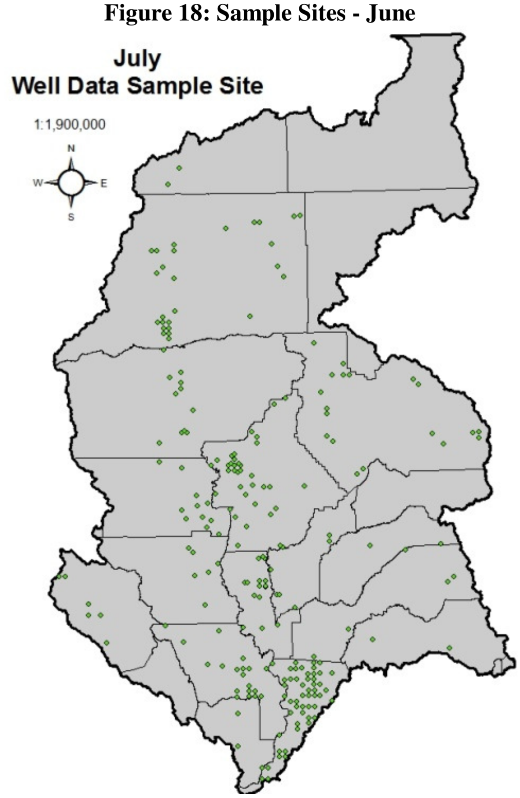


Figure 19: Sample Sites July

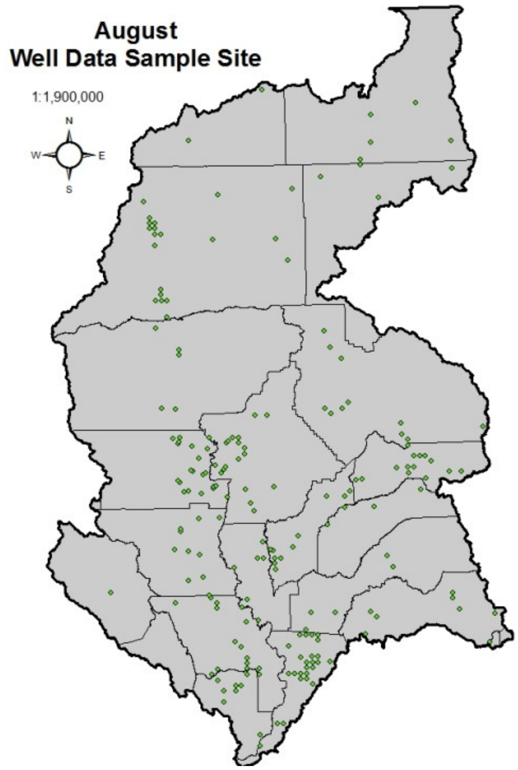


Figure 20: Sample Sites August

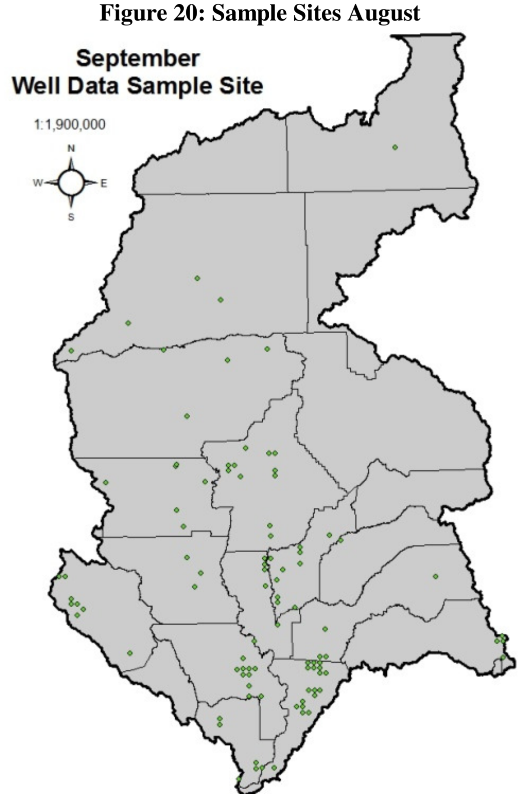


Figure 21: Sample Sites - September

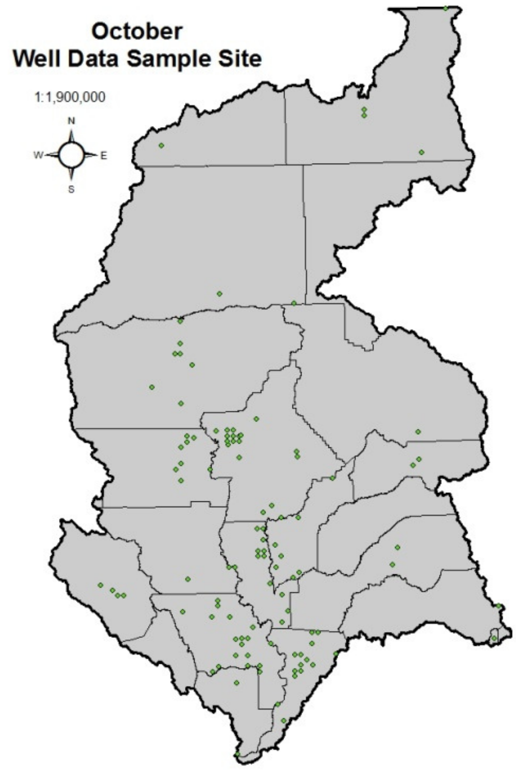


Figure 22: Sample Sites - October

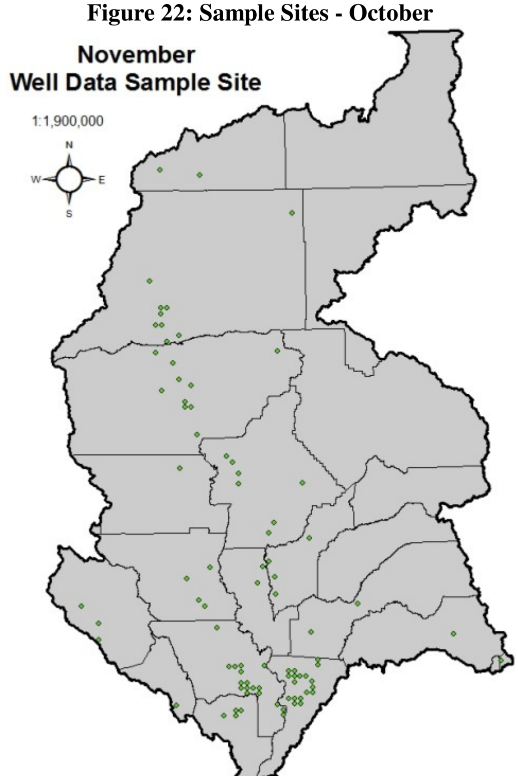


Figure 23: Sample Sites - November

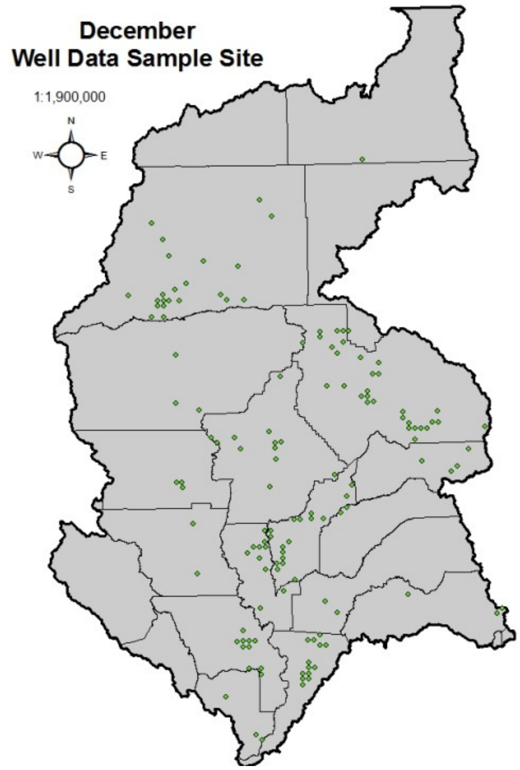


Figure 24: Sample Sites - December

APPENDIX B: CONTAMINATION ZONES BY MONTH AND SEASON

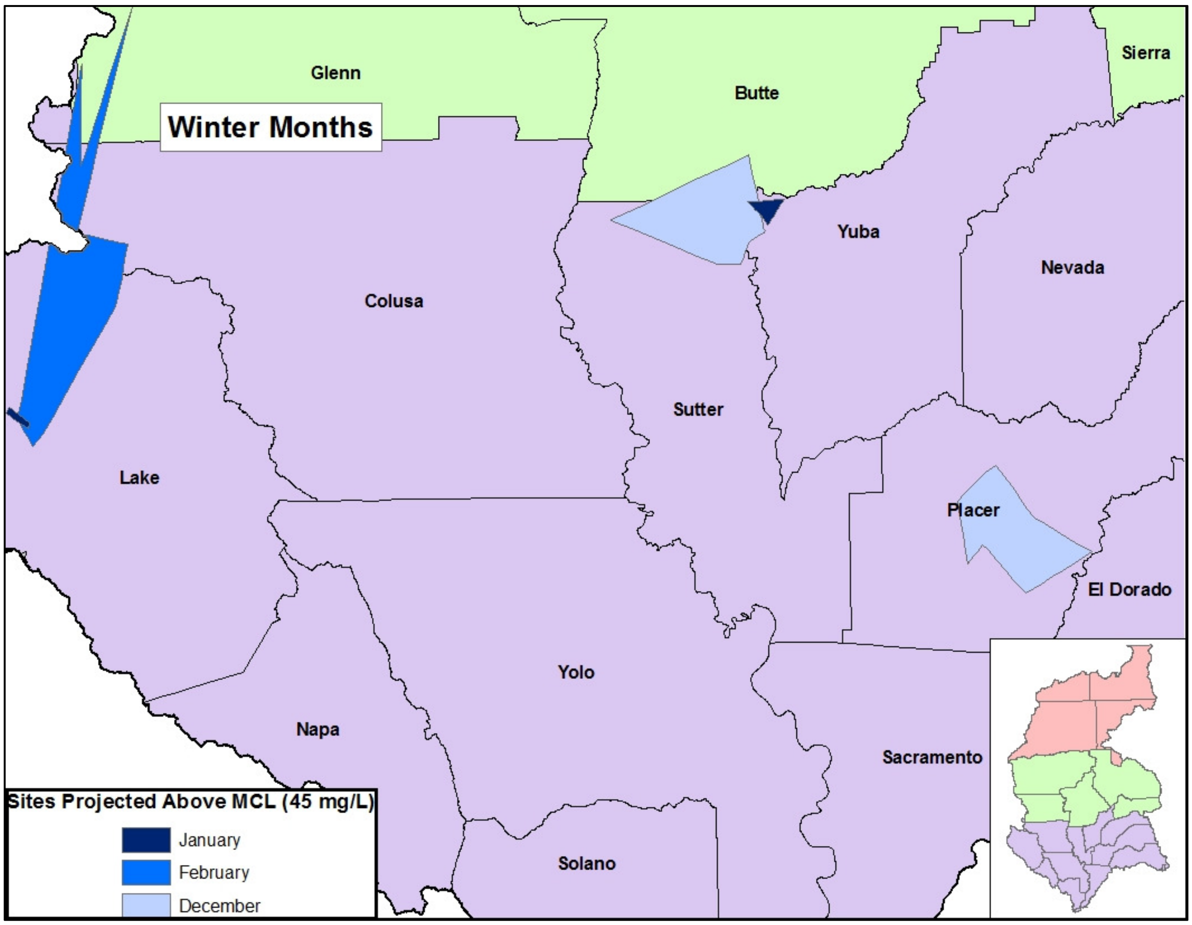


Figure 25: Map of Winter Contamination Zones

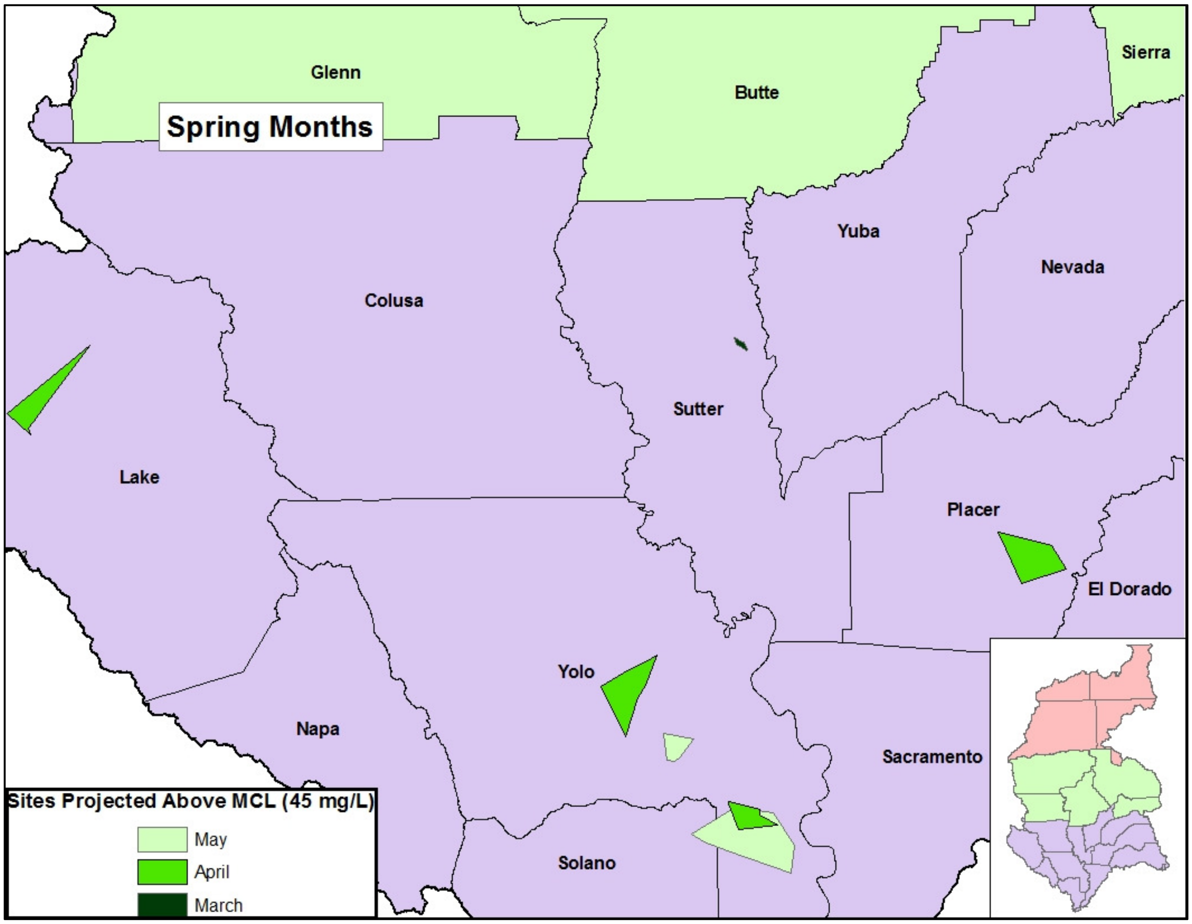


Figure 26: Map of Spring Contamination Zones

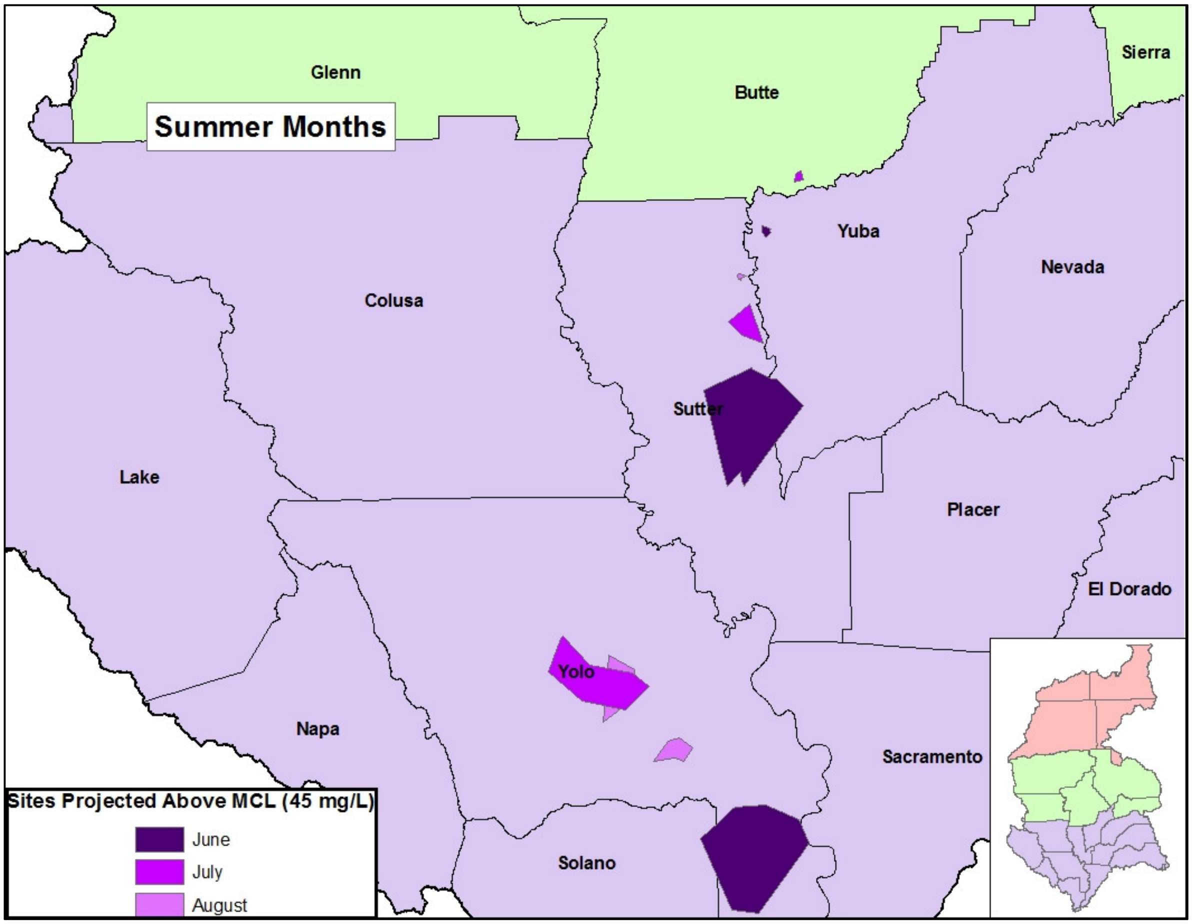


Figure 27: Map of Summer Contamination Zones

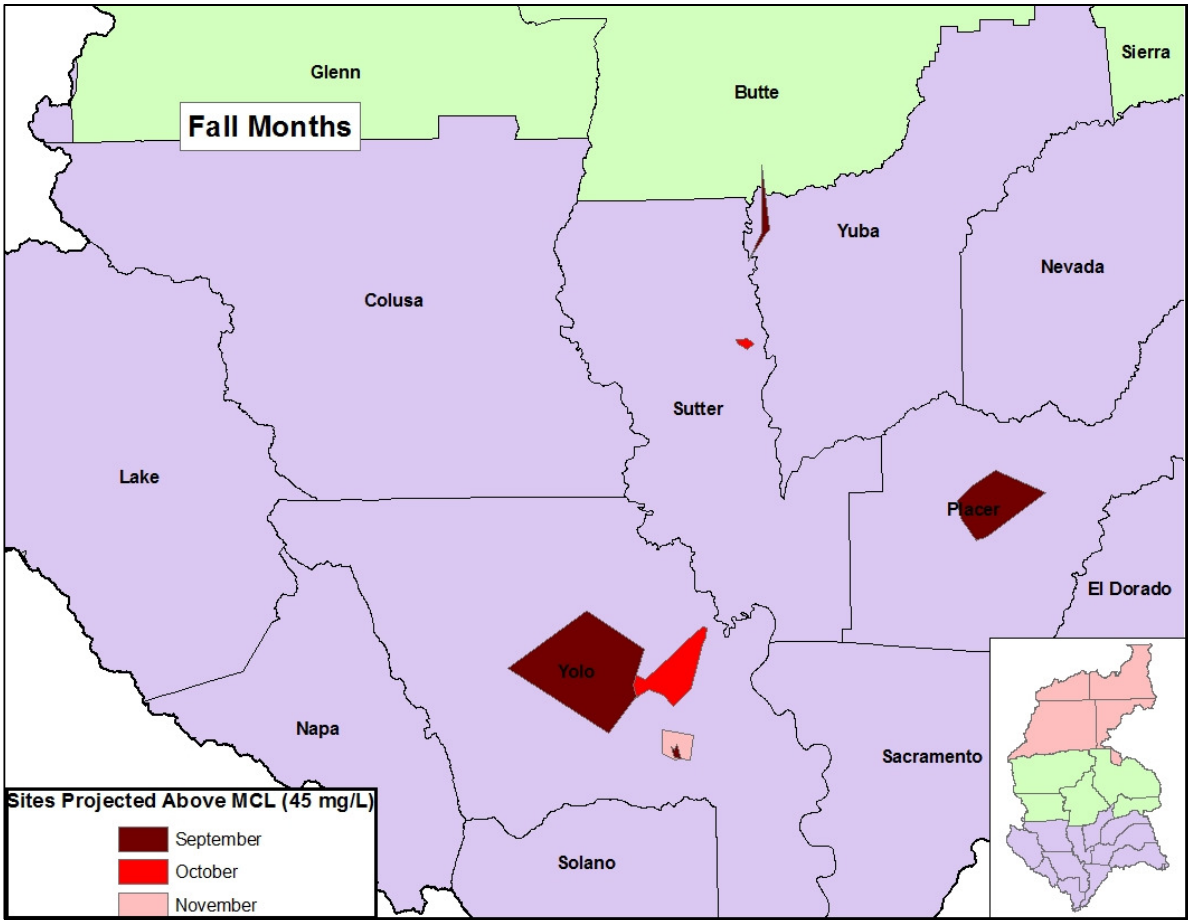


Figure 28: Map of Fall Contamination Zones

APPENDIX C: LAND USE DATA BY MONTH

Table 32: Land Use Classes for January

Land Use Class	Percentage Total
Developed, Open Space	54%
Emergent Herbaceous Wetlands	15%
Developed, Low Intensity	13%
Wood Wetlands	7%
Cultivated Crops	5%
Developed, Medium Intensity	2%
Developed, High Intensity	1%
Open Water	1%
Mixed Forest	1%
Shrub/Scrub	0%
Total	100%

Table 33: Land Use Classes for February

Land Use Class	Percentage Total
Evergreen Forest	29%
Mixed Forest	28%
Shrub/Scrub	23%
Grassland/Herbaceous	8%
Deciduous Forest	6%
Developed, Open Space	5%
Woody Wetlands	0%
Emergent Herbaceous Wetlands	0%
Developed, Low Intensity	0%
Barren Land	0%
Cultivated Crops	0%
Developed, Medium Intensity	0%
Open Water	0%
Total	100%

Table 34: Land Use Classes for March

Land Use Class	Percentage Total
Developed, Medium Intensity	37%
Developed, Low Intensity	36%
Developed, Open Space	21%
Cultivated Crops	4%
Developed, High Intensity	2%
Total	100%

Table 35: Land Use Classes for April

Land Use Class	Percentage total
Developed, Open Space	23%
Deciduous Forest	17%
Grassland/Herbaceous	15%
Evergreen Forest	13%
Developed, Low Intensity	6%
Mixed Forest	5%
Shrub/Scrub	5%
Cultivated Crops	5%
Developed, Medium Intensity	4%
Hay/Pasture	3%
Emergent Herbaceous Wetlands	2%
Woody Wetlands	1%
Developed, High Intensity	1%
Barren Land	0%
Open Water	0%
Total	100%

Table 36: Land Use Classes for May

Land Use Class	Percentage Total
Emergent Herbaceous Wetlands	26%
Cultivated Crops	20%
Developed, Open Space	15%
Grassland/Herbaceous	15%
Hay/Pasture	6%
Woody Wetlands	5%
Developed, Low Intensity	5%
Open Water	4%
Barren Land	3%
Developed, Medium Intensity	1%
Developed, High Intensity	1%
Total	100%

Table 37: Land Use Classes for June

Land Use Class	Percentage Total
Developed, Open Space	24%
Emergent Herbaceous Wetlands	19%
Cultivated Crops	17%
Grassland/Herbaceous	13%
Developed, Low Intensity	7%
Woody Wetlands	5%
Hay/Pasture	5%
Barren Land	4%
Open Water	3%
Developed, Medium Intensity	2%
Developed, High Intensity	1%
Decidous Forest	1%
Total	100%

Table 38: Land Use Classes for July

Land Use Class	Percentage Total
Developed, Low Intensity	24%
Developed, Open Space	18%
Developed, Medium Intensity	13%
Grassland/Herbaceous	13%
Cultivated Crops	13%
Developed, High Intensity	5%
Hay/Pasture	5%
Barren Land	4%
Emergent Herbaceous Wetlands	3%
Woody Wetlands	2%
Open Water	0%
Deciduous Forest	0%
Total	100%

Table 39: Land Use Classes for August

Land Use Class	Percentage Total
Developed, Open Space	25%
Cultivated Crops	18%
Grassland/Herbaceous	16%
Emergent Herbaceous Wetlands	12%
Developed, Low Intensity	10%
Woody Wetlands	5%
Hay/Pasture	4%
Barren Land	4%
Developed, Medium Intensity	3%
Developed, High Intensity	1%
Deciduous Forest	1%
Open Water	0%
Total	100%

Table 40: Land Use Classes for September

Land Use Class	Percentage Total
Developed, Open Space	25%
Grassland/Herbaceous	18%
Deciduous Forest	13%
Cultivated Cros	9%
Evergreen Forest	7%
Hay/Pasture	6%
Developed, Low Intensity	6%
Woody Wetlands	4%
Barren Land	3%
Emergent Herbaceous Wetlands	3%
Developed, Medium Intensity	3%
Shrub/Scrub	1%
Mixed Forest	1%
Developed, High Intensity	1%
Open Water	1%
Total	100%

Table 41: Land Use Classes for October

Land Use Class	Percentage Total
Developed, Low Intensity	28%
Developed, Open Space	20%
Developed, Medium Intensity	18%
Cultivated Crops	9%
Grassland/Herbaceous	7%
Developed, High Intensity	7%
Emergent Herbaceous Wetlands	5%
Barren Land	3%
Hay/Pasture	2%
Woody Wetlands	2%
Open Water	0%
Deciduous Forest	0%
Total	100%

Table 42: Land Use Classes for November

Land Use Class	Percentage Total
Developed, Open space	19%
Emergent Herbaceous Wetlands	18%
Cultivated Crops	17%
Grassland/Herbaceous	11%
Developed, Low Intensity	9%
Woody Wetlands	8%
Developed, High Intensity	4%
Hay/Pasture	4%
Barren Land	4%
Developed, Medium Intensity	4%
Deciduous Forest	1%
Open Water	0%
Total	100%

Table 43: Land Use Classes for December

Land Use Class	Percentage Total
Developed, Open Space	22%
Deciduous Forest	20%
Grassland/Herbaceous	14%
Evergreen Forest	12%
Developed, Low Intensity	8%
Shrub/Scrub	4%
Cultivated Crops	4%
Wood Wetlands	4%
Developed, Medium Intensity	3%
Hay/Pasture	3%
Emergent Herbaceous Wetlands	3%
Mixed Forest	2%
Developed, High Intensity	1%
Open Water	0%
Barren Land	0%
Total	100%

APPENDIX D: SOIL OCCURRENCES

Table 44: Soil Occurrences for 2006 Data

Soil	Occurrences	Percentage Total
Sycamore	2	9%
Yolo	2	9%
Artois	1	4%
Brentwood	1	4%
Capay	1	4%
Clear Lake	1	4%
Columbia	1	4%
Conejo	1	4%
Corning	1	4%
Kilaga	1	4%
Marvin	1	4%
Nueva	1	4%
Pescadero	1	4%
Redding	1	4%
Rincon family	1	4%
Shanghai	1	4%
Solano	1	4%
Stockton	1	4%
Tehama	1	4%
Tisdale	1	4%
Willows	1	4%

Table 45: Soil Occurrences for Seasonal Data

Soil	Occurrences	Percentage Total
Yolo	42	7%
Marvin	27	5%
Rincon family	27	5%
Tehama	27	5%
Sycamore	21	4%
Etsel	16	3%
Maymen	16	3%
Artois	15	3%
Brentwood	15	3%
Capay	15	3%
Clear Lake	15	3%
Stockton	15	3%
Corning	14	2%
Kilaga	13	2%
Conejo	11	2%
Hillgate	11	2%
Sheetiron	11	2%
Tisdale	11	2%
Neuns	9	2%
Rubble land	9	2%
Los Gatos	8	1%
Parrish	8	1%
Rock outcrop	8	1%
Yollabolly	8	1%
Pescadero	7	1%
Solano	7	1%
Willows	7	1%
Egbert	6	1%
Alo	5	1%
Balcom	5	1%
Diablo	5	1%
Hopland	5	1%
Kekawaka	5	1%
Redding	5	1%
Sanhedrin	5	1%
Sehorn	5	1%
Sobrante	5	1%

Speaker	5	1%
Columbia	4	1%
Cometa	4	1%
Goulding	4	1%
Nueva	4	1%
Ryde	4	1%
Sacramento	4	1%
Shanghai	4	1%
Supan	4	1%
Toomes	4	1%
Andregg	3	1%
Benridge	3	1%
Bressa	3	1%
Caperton	3	1%
Cole	3	1%
Hambright	3	1%
Konocti	3	1%
Millsholm	3	1%
Sierra	3	1%
Skyhigh	3	1%
Sodabay	3	1%
Water	3	1%
Auburn	2	0%
Gridley	2	0%
Hulls	2	0%
Kelsey	2	0%
Lupoyoma	2	0%
Millich	2	0%
Montpellier	2	0%
Oswald	2	0%
Ramona	2	0%
Rock outcrop	2	0%
Rocklin	2	0%
Sailboat	2	0%
San Joaquin	2	0%
San Joaquin	2	0%
Still	2	0%
Subaco	2	0%
Wolfcreek	2	0%

Xerofluvents	2	0%
Brentwood	1	0%
Clear Lake	1	0%
Landlow	1	0%
Olashes	1	0%
Palls	1	0%
Stohlman	1	0%
Vina	1	0%

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