Spatial and Temporal Trends in Nitrate Contamination of Groundwater in the Salinas Valley

A Capstone Project

Presented to the Faculty of Earth Systems Science and Policy

in the

Center for Science, Technology, and Information Resources

at

California State University, Monterey Bay

in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science

By

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May 31, 2001

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Acknowledgement

I would like to express special thanks to the Monterey County Water Resources Agency. Without their resources, historical data, and cooperation, this project would not have been possible.

Abstract

As the Earth's population grows, we must work harder to find new fresh water sources and to protect existing ones. This Capstone focuses on the contributions of nitrate contamination to groundwater in the Salinas Valley. How is the spatial distribution of nitrate contamination changing over time, and should we be more concerned about some areas than others? I sampled wells throughout the Salinas Valley in Summer 2000 and combined that data with historical data provided by the Monterey County Water Resources Agency. Agricultural and domestic wells from Castroville to San Ardo were included in the survey. The Monterey County Consolidated Chemistry Laboratory analyzed the samples for nitrate, chloride, and conductivity. I prepared a GIS model of the data to examine patterns in space and time. I found nitrate concentrations to be increasing across the Salinas Valley, with the most serious rates in the Eastside and Forebay. Nitrate appears to move by diffusion in all areas but the Pressure subarea, where it advances laterally due to lack of overhead recharge.

Introduction

Groundwater is used for agricultural, commercial, and domestic purposes in the Salinas Valley. Infiltration and recharge in agricultural areas introduces nitrate from fertilizer into the aquifer. The EPA has set a maximum contaminant level for nitrate in drinking water of 45 mg/L (Nolan and Stoner 2000). When nitrate is consumed in drinking water, it creates a host of health problems including blue-baby syndrome, cancers of many organ systems, spontaneous abortions, and non-Hodgkin's lymphoma (Nolan and Stoner, 2000; Canter, 1996).

There are ecological effects as well. It is possible for nitrate-laden groundwater to reach surface reservoirs. The increased nutrient concentration would cause algae populations to soar. As the algae die, they are consumed by decomposing bacteria. The bacteria's respiration depletes the water of dissolved oxygen, a process known as eutrophication. The oxygen poor water can cause fish mortality (Driscoll, 1986; Cook, 1991). Ruminant animals can be "seriously affected" by ingesting nitrates from birth through adulthood. Nitrate in stock water can cause loss of milk production, aborted calves, and other problems (Canter, 1996).

Groundwater/Nitrate Interaction

The application of nitrogen-based fertilizers is the most widespread human source of nitrate in groundwater systems (Antonakos and Lambrakis, 2000). Groundwater pollution is related to overfertilization of cropland that is in an aquifer's recharge area (Guimera, 1998). Where nitrate concentrations are high, they are generally associated with intensive agricultural production since World War II (Cook, 1991). Leaching is enhanced in irrigated systems (Ray and Kelly, 1999). Irrigation contributes to ground water pollution in two ways: transport of contaminants through soil and, through malfunction or lack of back-siphoning valves, may permit back flow to the well of chemicals applied through the irrigation system (Massey, 1986). The general conclusion of investigators studying nitrate movement in irrigated areas has been that irrigation must be properly scheduled to prevent excessive losses of nitrate through the soil zone (Ray and Kelly, 1999).

Because deeper groundwater is typically older than shallow, it is less likely to show effects from recent land use (Nolan and Stoner 2000). The chemical characteristics of the nitrate anion allow it to easily move in water. Once it is introduced into the aquifer, it flows along with the groundwater. It percolates downward through the unsaturated vadose zone until it reaches the saturated zone, where it begins to flow laterally (Chen et al 1998). Stratification of nitrate with depth has been reported by many investigators, with high nitrate concentrations typical near the water table, decreasing with depth (Ray and Kelly, 1999).

Nitrogen occurs in the environment in several different forms. Under aerobic (oxygenated) conditions, nitrate (NO_3^-) is the end product of N transformation regardless of the source of N applied. If it is not taken up by crop roots, it is subject to downward transport in the soil profile along with the water front (Paramasivam et. al., 1999). Under anaerobic conditions and in the presence of denitrifying bacteria and a readily available carbon source, nitrate is chemically reduced to less harmful N_2O or N_2 gases, a process termed as denitrification (Paramasivam et. al., 1999). Denitrification by microbes increases with bacterial population and with water filled pore space, and tends to be most productive at the soil/groundwater interface (Paramasivam et. al., 1999). Thus; denitrification potential increases with depth down to the water table, then drops off (Fryar et al., 2000; Antonakos and Lambrakis, 2000; Paramasivam et. al., 1999).

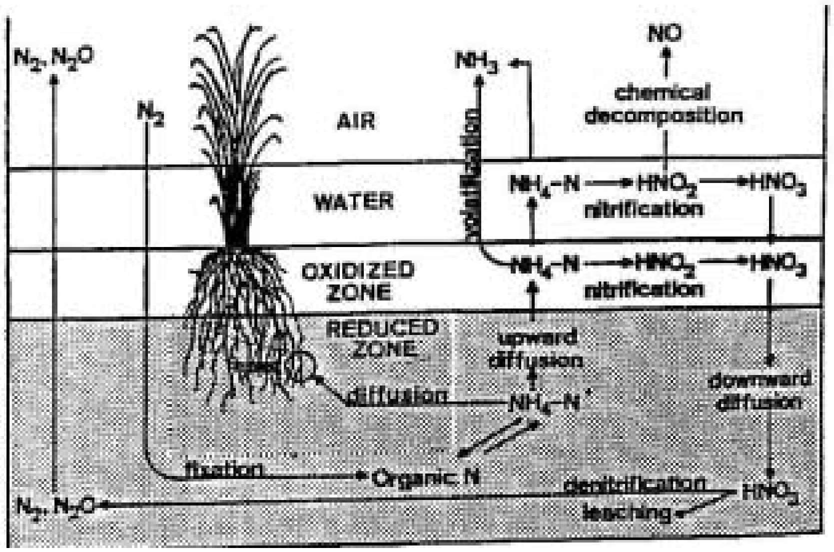


Figure 1 Nitrogen Cycle in the Subsurface Environment (Canter, 1997)

Not all areas are equally susceptible to nitrate infiltration. Soil susceptibility to nitrate leaching depends upon profile texture, drainage and soil thickness. Heavier-textured and thicker soils have greater opportunities for denitrification because of slower infiltration, typically more available carbon, and longer residence times. Low water tables make it take longer for contaminants to get there and natural attenuation may occur along the way (Yanggen, 1986; Cook, 1991). Shallow and well-drained soils are more likely to leach nitrate to groundwater. High infiltration rates provide contaminants access to groundwater (Yanggen, 1986; Cook, 1991). In one study, the most vulnerable land was associated with valleys and areas of low or reduced topography, which reduce the distance between the land surface and the water table. (Cook, 1991).

Salinas Valley Hydrogeology

The Salinas Valley can be divided into four hydrogeologic subareas: the Upper Valley, the Forebay, the East Side, and the Pressure area. The Upper Valley extends from the San Luis Obispo County line northward almost to Greenfield. The Forebay begins at the boundary with the Upper Valley and extends northward along the Salinas River to Gonzales. These two areas consist mostly of alluvial deposits and are the sites of active aquifer recharge. Northward of the Forebay, the valley is divided roughly along Hwy 101 into the Pressure area on the Marina side and the East Side in the Castroville area. The pressure area is divided stratigraphically by three marine clay aquicludes, dividing the aquifer into segments at 180’, 400’, and 900’ below MSL. Fresh subsurface water is under pressure from flow coming northward down the valley toward the coastline. This pressure is lessened by well pumping, which has resulted in saltwater intrusion in the Castroville and Marina areas. Because of the aquicludes, no recharge occurs in this area. The East Side is characterized by its inconsistency. It most likely was formed by a series of alluvial fans as well as non-contiguous clays laid down by marine transgressions. Depth to water varies greatly, and communication between subsurface and surface water probably does as well.

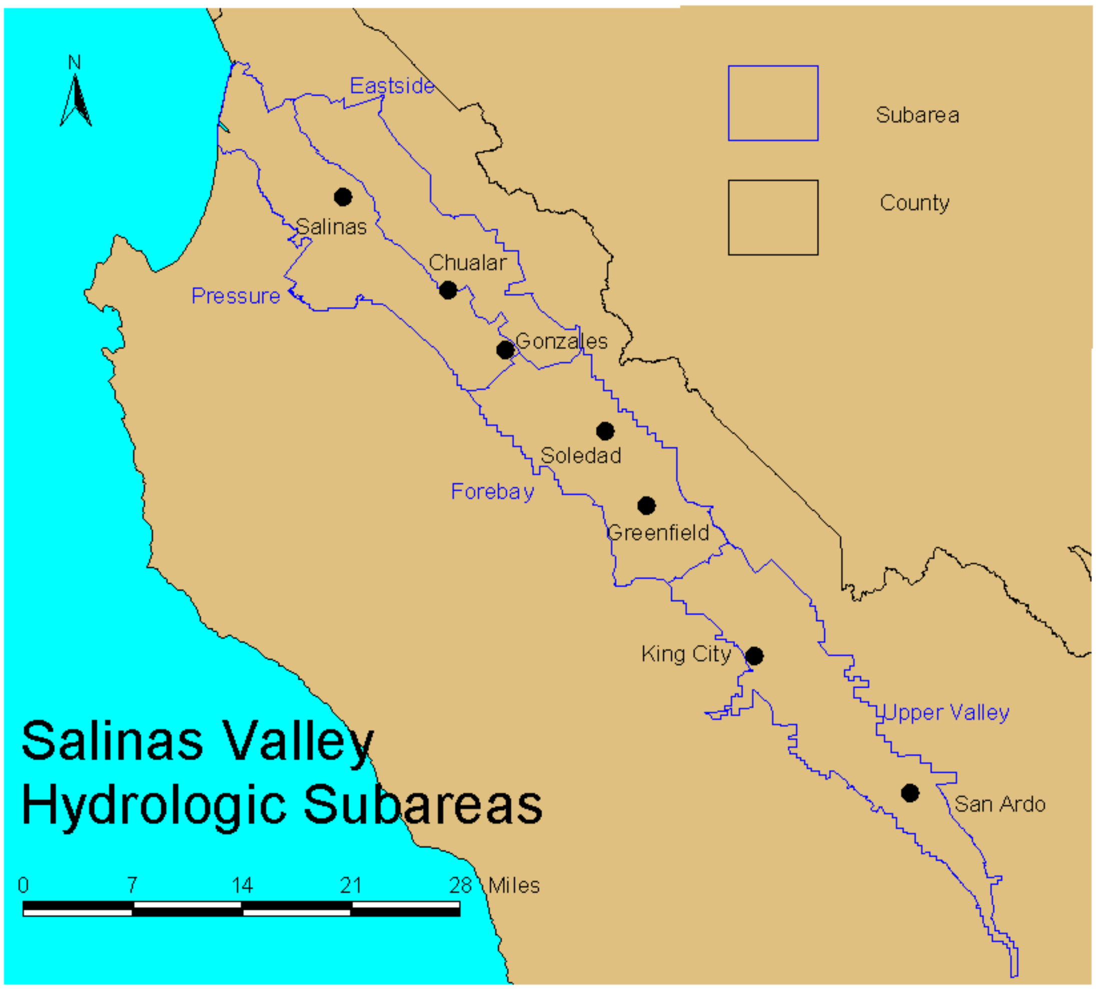


Figure 2 Lower Salinas Valley Subareas

In an effort to maintain plentiful supplies of groundwater, MCWRA makes carefully timed releases from the Nacimiento and San Antonio Reservoirs into the Salinas River. Studies have shown that the Salinas River bed effectively recharges the aquifer from its headwaters near the San Luis Obispo County line until a point about six miles west of Chualar. At that point, the marine clay layers become continuous and prevent recharge. Releases are calculated to keep the river bed wet in the recharge region during the dry season, which effectively moves water storage from the reservoirs to the ground. These releases also aid groundwater quality through dilution.

Relevant Groundwater Use and Protection Policies

The distribution of groundwater has received much more legislative attention than its protection. Surface water legislation is much more comprehensive because it has only been in the last 40 years that pumps have existed to extract groundwater in quantities sufficient to create widespread conflict. The hand-dug, windmill powered wells in use before that never extracted enough water to seriously deplete water supplies (Gould, 1986). Groundwater hydrology is a relatively young science (Anderson, 1987), and legislators have "either ignored the groundwater implications of pollution control policies or devised systems that reflect the limits of scientific knowledge" (Henderson, 1987).

Groundwater Pumping and Use Policies

Federal

Our laws for water use originally came from the English common law, also called the English "rule of capture" or the "absolute ownership rule." Under this system, a person whose property lies above or adjacent to water resources has unlimited use of the available water, regardless of injury caused to other users (Driscoll, 1986). This rule operated for many years with few changes in states east of the Mississippi, but shortcomings became apparent when it was applied to more arid western states. It was modified to allow only "reasonable use" of water resources and only to the extent that use does not harm the wells and springs of others. This was known as the "American" or "reasonable use rule" (Henderson, 1987). This is built upon by the "correlative rights rule," also known as the "California rule," which provides equal access to aquifers during times of drought (Henderson, 1987). In wet years, the converse of the California rule allows excess water to be appropriated and used on property that is not adjacent to or overlying the water source.

State

Individual states are free to use any combination of these approaches for administering the allocation of their water resources. Two states, California and Texas, have no statewide groundwater management plan (Hall, 1995; Saracino, 1995). According to the California State Water Code, "All water within the State is the property of the people of the State, but the right to the use of water may be acquired by appropriation in the manner provided by law" (California State Legislature, Section 102). The water code does not authorize the State of California to manage groundwater. It does provide for programs formed on an "ad hoc basis" based on local needs, or management by certain existing local governments (DWR, 1996). In the event of a dispute between landowners over how much groundwater can rightfully be extracted, the courts arrive at a distribution that guarantees each user a proportionate share of the groundwater that is available each year. The court also appoints a "Watermaster" who ensures that the basin is managed according to the court's orders (DWR 2000).

Local

The Salinas Valley groundwater basin is not adjudicated. Users of wells are allowed to pump their correlative share of the groundwater, which is undefined. Essentially, use is unlimited until overdrafting has already occurred and shortage causes someone's use to be curtailed. Only if adjudication were to occur would a regulatory agency be able to control how much extraction occurs and manage the amount of extraction to preserve groundwater quality and quantity. The Monterey County Water Resources Agency monitors the volume of pumping from high-capacity wells, performs water quality testing, and measures groundwater levels. Well owners are legally obliged to report their pumping, but not required to limit it in any way.

Pollution Prevention

Prevention of groundwater contamination is clearly a more feasible goal than remediation because of the limited self-cleansing capability of groundwater (Mac Donnell and Guy, 1991). Unlike surface water, where many of the toxic chemicals can be removed or neutralized quickly, aquifer restoration takes a very long time and can be prohibitively expensive.

Federal

Many agencies are charged with preventing contamination of groundwater resources, and under a patchwork of legislation. However, no single piece of legislation was designed to deal with it comprehensively on the federal level or relate it to the laws and policies of the states (Massey, 1986).

- *Pre-Legislation:* Historically, groundwater pollution was addressed largely through the enforcement of private remedies. Well owners claiming their rights to groundwater were affected by another's polluting activities typically invoked tort concepts of negligence, strict liability, trespass and nuisance. These remedies have generally been inadequate. (Massey, 1986) Winning a suit in one of these ways requires a plaintiff to prove a causal connection between the contamination and an action of the defendant, which is very difficult to do (Henderson, 1987).

- *Clean Water Act:* The federal government began to protect groundwater with amendments to the Federal Water Pollution Control Act, now known as the Clean Water Act. It primarily deals with surface water but protects groundwater in a tangential fashion. It was designed to regulate point source pollution, which it defines as "any discernible, confined and discrete conveyance." A 1977 amendment to the Act specifically excluded return flows from irrigated agriculture from the definition (Wood, 1988;

Massey, 1986). Because of the exclusion, it isn't possible to use the Clean Water Act to protect the Salinas Valley aquifer from agricultural nitrate.

- *Court Precedent:* The Tenth Circuit court in *United States v. Earth Sciences* defined nonpoint source pollution as, "disparate runoff caused primarily by rainfall around activities that employ or cause pollutants." The court went on to say," because nonpoint sources of pollution, … are virtually impossible to isolate to one polluter, no permit or regulatory system was established as to them" (Wood, 1988). The Clean Water Act put agricultural runoff into the nonpoint source category and because of the Tenth Circuit Court decision, nitrate pollution such as that examined in this study slips the net of federal regulation.

- *The Safe Drinking Water Act* regulates underground disposal of contaminants through injection into deep wells (MacDonnell and Guy, 1991). It protects underground sources of drinking water and recharge zones of aquifers that are the principal source of drinking water for an area from exceeding certain federally set drinking water standards (Massey, 1986). The Act protects municipal supply wells only, and fails to reach aquifers that supply only private wells (Wood, 1988). This legislation might be used in areas of the Salinas Valley surrounding wells used by water purveyors such as Cal Water, but does not help rural residents who use their own supply wells.

- *The Resource Conservation and Recovery Act* requires that hazardous waste disposal performed by waste disposal facilities be done in a manner that protects groundwater (MacDonnell and Guy, 1991; Wood, 1988). It sets design criteria for solid waste facilities and requires accounting of hazardous materials from the place they are generated to the place where they are finally disposed (Massey, 1986). It requires permitted disposal sites to clean up groundwater contaminated by leaking storage sites when leaks are discovered through monitoring (Henderson, 1987). The RCRA only regulates licensed waste disposal facilities, not any other kind of activity.

- *The Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA or Superfund) is the premier groundwater cleanup program (Henderson, 1987). It is directed towards sites of past hazardous waste disposal and lacks any provisions regulating current polluting activities (Wood, 1988). CERCLA is aimed at cleanup, but does not address pollution prevention.

State

California has identified over 394 groundwater basins, which makes it hard to tailor one law that will fill the needs of all basins (Wickersham, 1981).

- The Porter-Cologne Water Quality Control Act establishes water quality permits. This statute sets up waste discharge requirements to control disposal of pollutants into wells. Discharge may be subject to monitoring by the State Water Resources Control Board or the Regional Water Quality Control Board (Wickersham, 1981).

- The Water Code contains a chapter on enforcement that gives the Regional Boards the authority to lien properties of businesses who fail to obey the cease and desist or cleanup orders issued by the Boards (Mac Donnell and Guy, 1991).

- The Water Code also requires the California Department of Water Resources to develop well standards to protect groundwater quality. They regulate the construction, maintenance, alteration, and destruction of production wells, monitoring wells, and cathodic protection wells (DWR, 1992).

- Although the Water Code does not specifically grant the Watermaster of an adjudicated basin the authority to regulate extraction to protect groundwater quality, Watermasters are recognizing that quality and quantity are inseparable. Court decisions in 1991 and 1993 granted Watermasters authority to limit extractions to help prevent the spread of contaminants and to expedite remediation (DWR, 1996).

Local

The condition of the aquifer in the Salinas Valley hasn't gotten bad enough to warrant adjudication. Local agencies and growers are working to make sure it stays that way. Voluntary programs are in place to reduce groundwater contamination. These efforts include "field days" held on local ranches, where speakers from government agencies, academia, and the farming community share strategies for controlling runoff, reducing leaching, minimizing fertilizer applications, and other management practices. The USDA has a mobile lab that will visit ranches free of charge to test the soil for nitrogen and make recommendations for making irrigation and fertilization more efficient. If these efforts do not prove successful, it's possible that the State Water Board or EPA might step in and begin mandatory measures. This threat is the farmers' only incentive to address the nitrate problem. Nobody wants to be regulated.

Research Question/Hypothesis

It is not understood exactly how the distribution of nitrate in the Salinas Valley works. It isn't clear how long it takes changes in surface activities to be reflected in samples taken from wells. It isn't clear how long it takes contamination to move from one part of the aquifer to another.

I hypothesize that inland nitrate concentrations will tend to be higher than coastal nitrate concentrations for several reasons: inland soils are not as fertile and require more fertilizer application; and the aquifer is unconfined east of Spreckles which allows more nitrate contamination from above. I expect time trends will show increasing nitrate contamination in all areas, but most drastically in the inland areas. I expect to find a time lag between increased nitrate concentrations in the unconfined and those in the confined portions of the aquifer because nitrate contributions are limited to those from lateral flows.

Materials and Methods

Groundwater Wells

A sample set of wells was selected over forty years ago by the County's flood control agency, MCWRA's predecessor. In the 1980's, MCWRA expanded the network to over 250 wells. This list of wells, with additions of new wells and deletion of destroyed wells, has been sampled annually ever since. Wells included in the survey must have well logs on file with the Agency. They are screened at a known depth and, if in the Pressure area, cannot have perforations in more than one layer of the aquifer. The goal is to have a network of wells spaced densely enough to make contaminants moving through the aquifer apparent. In recent years, the sample set has been decreased due to budget and staff constraints.

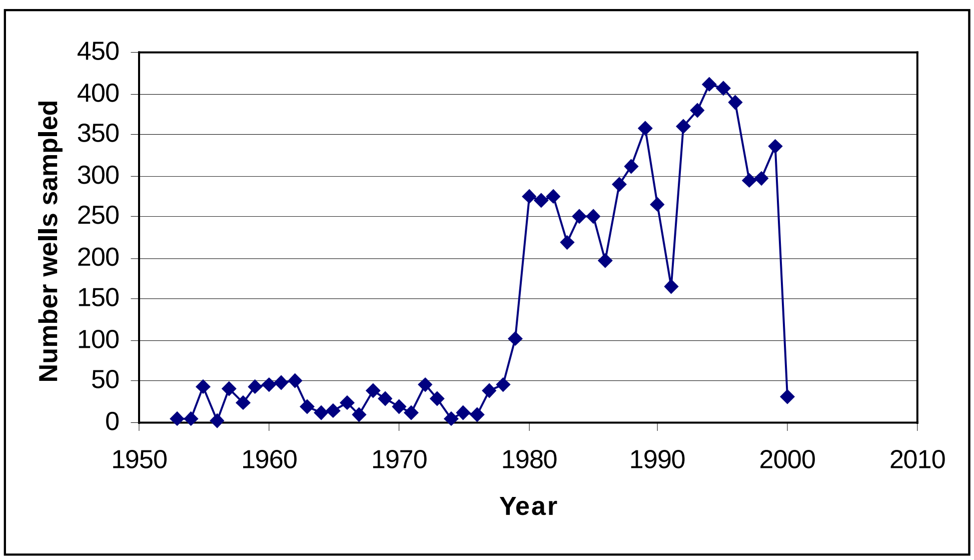


Figure 3: Sample set size

Water Sampling Method

Well sampling follows standard operating procedures established by the MCWRA. An effort is made to sample each well every summer. The wells must be running for a sample to be drawn. These agricultural wells are quite large and produce a significant volume of water. The Agency does not ask growers to turn the wells on for the sampler because of the water and power that would be wasted and to prevent upsetting the very specific irrigation schedules that the growers use. If a well is not running when the sampler visits, two more attempts are made. It isn't a perfect process, and each well doesn't get sampled each year. At the beginning of the sampling season, the Agency mails letters to each well owner whose well is on the survey to tell them to expect the sampler.

Before taking the sample, the sampler takes great care to make sure the well is the correct one. The sampling log includes information about the well such as the PG&E meter number and plant number, and might also include a flow meter number or engine serial number. Once the sampler is certain the well is the correct one, the sample can be taken.

The water sample is taken as close to the wellhead as possible. A visual inspection of the well setup must be made to make certain that amendments aren't inadvertently included in the sample. It is common practice for growers to inject fertilizer or other amendments into ports on the well's discharge line and samples must be taken "upstream" of these injections if they are present. The sample bottles used are plastic and usually a pint in volume. If the well to be sampled is also on the list of wells sampled for saltwater intrusion, a half gallon bottle is used instead. This provides the lab enough water to perform all necessary tests and eliminates the need to sample the well twice. The sampler rinses the bottle and lid with well water three times before filling, capping, and labeling it with the well number, date, time, and sampler's initials; and storing it in a cooler. This information is also recorded in the sampling log.

Figure 4: Typical agricultural irrigation well

Samples are taken to the Monterey County Consolidated Chemistry Laboratory for analysis. A chain of custody form is used to make sure all samples are accounted for and properly identified. Results are sent to the Water Resources Agency. Agency staff check these results against the sampling log for QA purposes.

I performed the sampling of the 2000 wells in June, July and August.

Data Analysis

I received a spreadsheet from MCWRA with 7,065 data points in it. 721 unique wells were represented. It included samples from 1953 to 2000.

I began by creating a GIS map of the sampled wells. The state well ID numbers, which give each well's township-range-section number, were used to calculate the positions of the wells relative to each other. I took GPS locations of three wells and used that information to tie the wells into a "real world" coordinate system. I selected wells that were easily accessible without a four wheel drive vehicle and not close to each other. I prepared an Arc View project showing the Salinas Valley with hydrogeologic subareas and the locations of the wells surveyed.

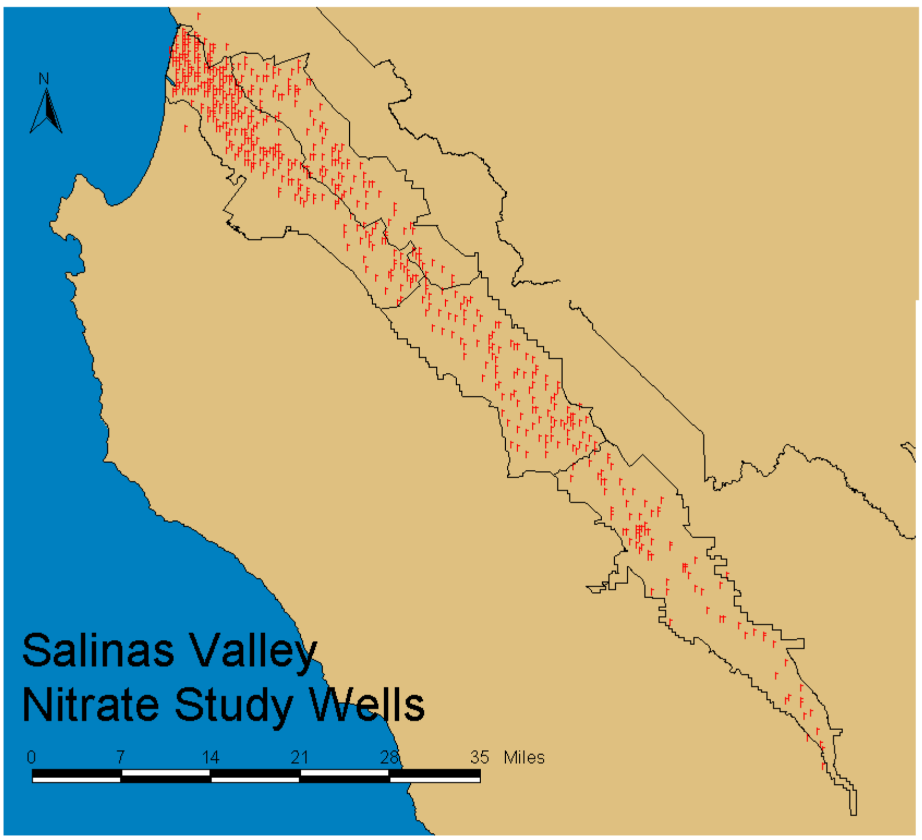


Figure 5 Full set of study wells

Because the sample set isn't exactly the same every year, there were holes in the data set. It was important to fill these gaps in the record to avoid confusing missing samples with fluctuating conditions. If a highly nitrate-laden well was missed one year, it might appear that nitrate in the aquifer had decreased overall, when in fact it had not

I used filtering and interpolation to fill these gaps. I limited the duration of my analysis to 1980-1999, due to small sample sizes outside of that time span. I restricted the study to wells that were surveyed at least 10 times between 1980 and 1999. Within this subset, any well missing four consecutive samples was eliminated. Any well missing the first three or last three years of the study was also eliminated Missing data at the beginning or end of the record were filled in by inserting the nitrate concentration from the closest available value. Other missing data were added by interpolating between preceding and subsequent years' measured nitrate concentrations. The data set contained 197 wells after the selection process. . In 1991, a small sample size made it necessary to extrapolate 53% of the concentrations from previous and subsequent measurements. With the exception of that year, at least 62% of the concentrations used in any given year were actual measurements.

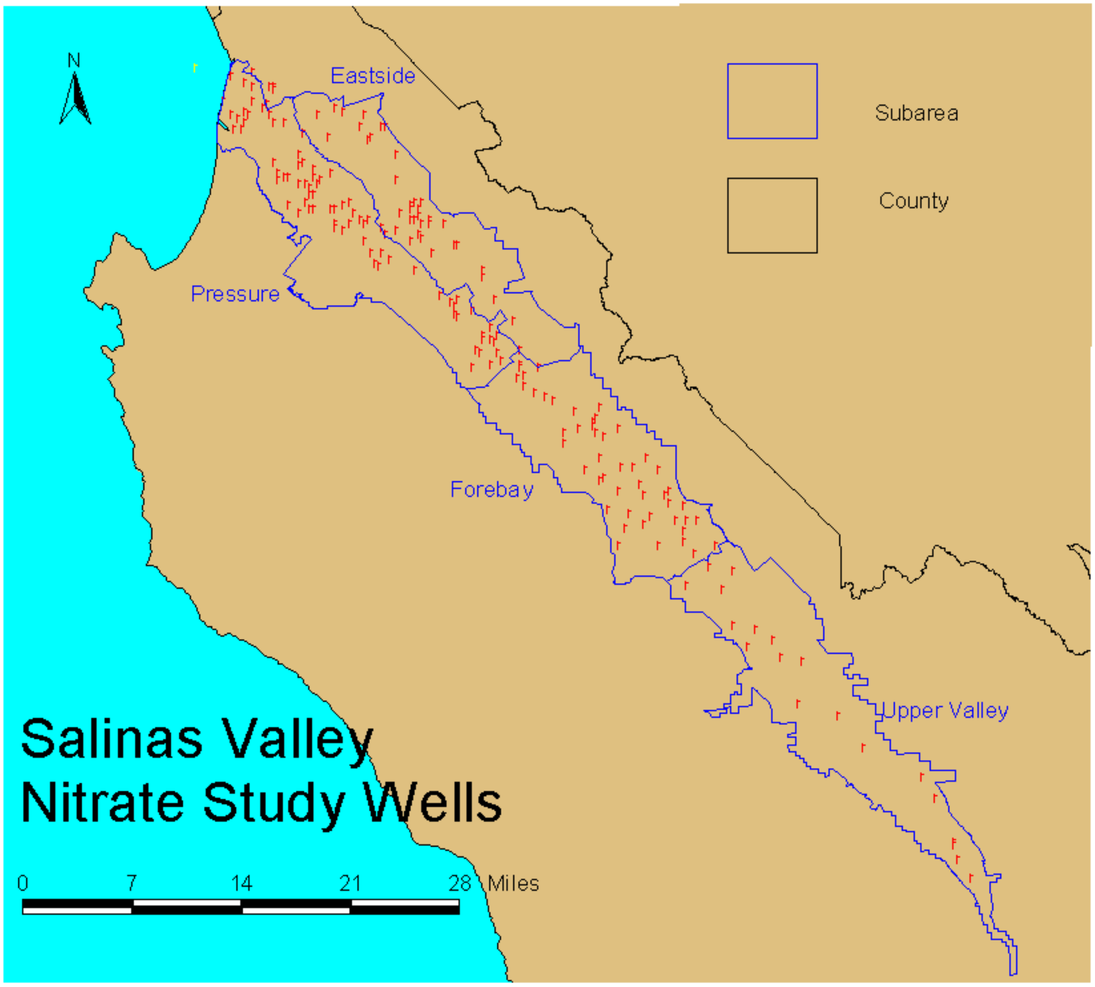
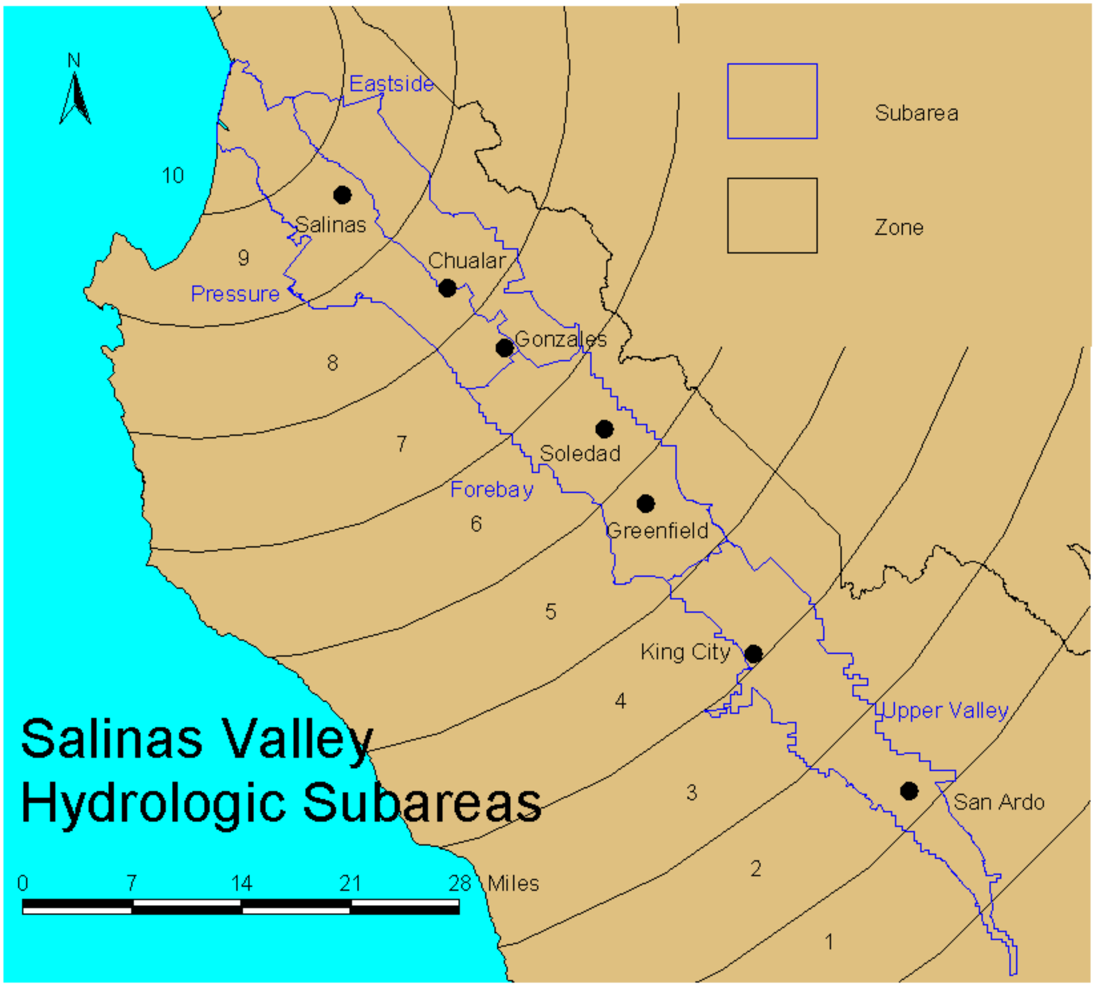


Figure 6 Filtered set of study wells

I sorted the wells into groups based on their hydrogeologic subarea and their distance from a datum in the Monterey Bay. The datum location was chosen by drawing a best fit line through the wells and choosing an arbitrary point on that line, past the westernmost well. I created ten zones of equal width and numbered them, beginning with zone one in the uppermost valley and continuing through zone ten at the coast. In cases where the groups had five or fewer wells, I merged groups within the same hydrologic subarea. No group contains wells in more than one hydrologic subarea, while some contain wells in more than one zone. This process resulted in fourteen well groupings. I calculated means and medians for each group in each annual survey and created a graph displaying how each well group changes with time.



For a more intuitive understanding of the spatial relationship, I created an animated map of each well's annual nitrate concentration. I used Arc View's "create TIN from features" command to generate concentration surfaces, one for each year between 1980 and 1999. Due to the limitations of the two-dimensional map view, I was able to map only one vertical layer of the Pressure subarea. I chose the P-180 because the data indicate it is the most susceptible to contamination. I displayed each year's concentration surface in a layout and exported it as a Windows Bitmap file. I imported all of the Bitmaps into Animation Shop and generated an animated .gif file.

Results and Discussion

Examining the graph of each group's mean annual nitrate concentration (Figure 3), four larger groups become apparent. At the bottom of the graph, the 900 and 400 foot layers of the Pressure area change very little over time and stay well under the drinking water standard of 45 mg/L NO_3^- . Above them, all three zones of the 180 foot layer of the Pressure area show more variation and a larger increase with time than their deeper counterparts, but they do remain under the DWS. The coastal zone of the East Side, the down-valley zone of the Forebay, and the uppermost Upper Valley form the next group, with their means all exceeding the DWS by the end of the study. The areas of highest concern are the inland zone of the East Side and the northern zone of the Upper Valley. These areas increased drastically over the twenty years examined.

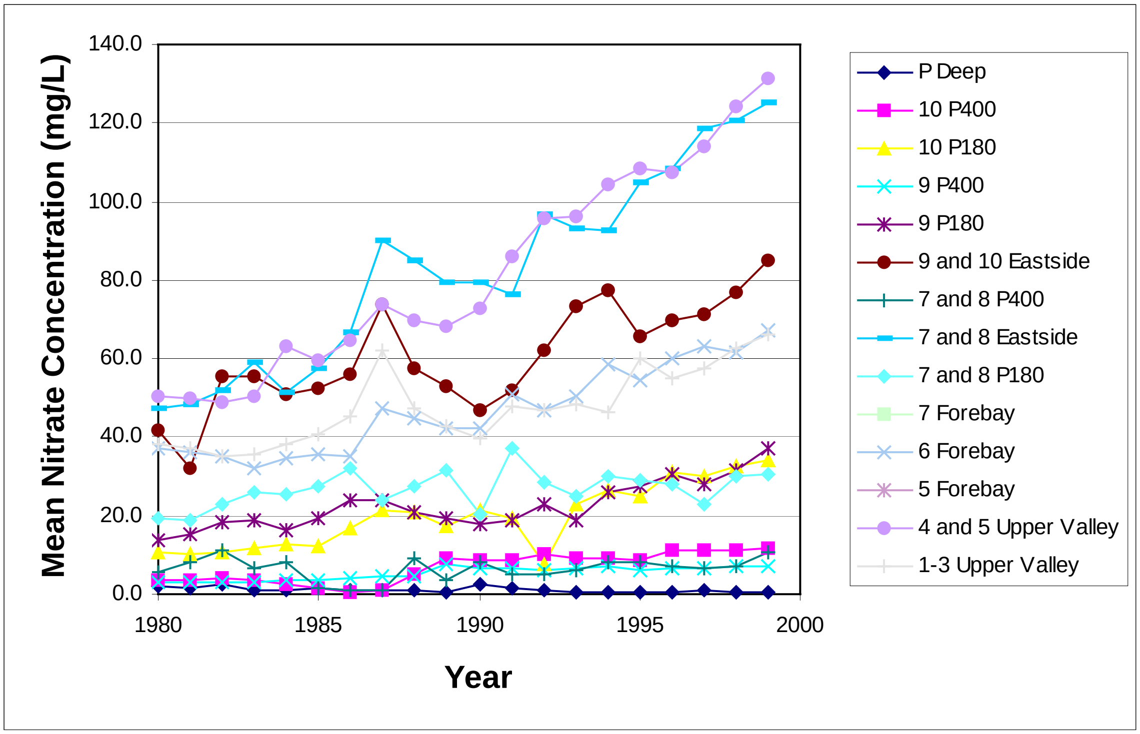


Figure 7: Annual mean nitrate concentrations by group

The nitrate concentrations are not distributed normally, as the mean and median values for some groups are quite different. Comparing figures 5 and 6, the most obvious difference is in the Eastside zones 7 and 8 group. The median nitrate concentration is much lower than the mean and the median increases less quickly with time. A small subset of wells in this zone are increasing sharply and the two graphs illustrate how much more sensitive the mean is than the median to these outliers. A similar trend is seen in the Eastside zones 9 and 10 group. The disparate behavior of wells in the Eastside subarea can be attributed to the discontinuity of the aquitards in this area. I suspect that investigation of well drilling logs would reveal communication between the surface and the aquifer in the areas of these “hot” wells. The wells in this group that behave more like the wells in the Pressure area are probably similarly protected by the aquitards.

All three zone groups in the Pressure 180 subarea had higher means than medians, though not to the extent of the Eastside groups. This might be explained by inconsistencies in the thickness of the aquitards or lateral movement of contamination around their edges. Like in the Eastside subarea, a few wells, which might be located in particularly vulnerable areas, increase more quickly than the majority of the group.

It is reassuring to notice that all zones in the Pressure 400 and Deep subareas have means and medians that are consistently well below the drinking water standard. There were two individual P400 wells with nitrate concentrations well above the drinking water standard, as much as 83 ppm NO_3^-. This has serious implications for the City of Salinas' municipal supplies. These wells were very close to each other and very close to the East Side boundary. Their well logs ought to be examined to determine if, in fact, the aquifer is confined at this location. If the well driller recorded penetrating thick clay layers above the screened depth of the well, these nitrate levels might be indicative of contamination intruding from the East Side.

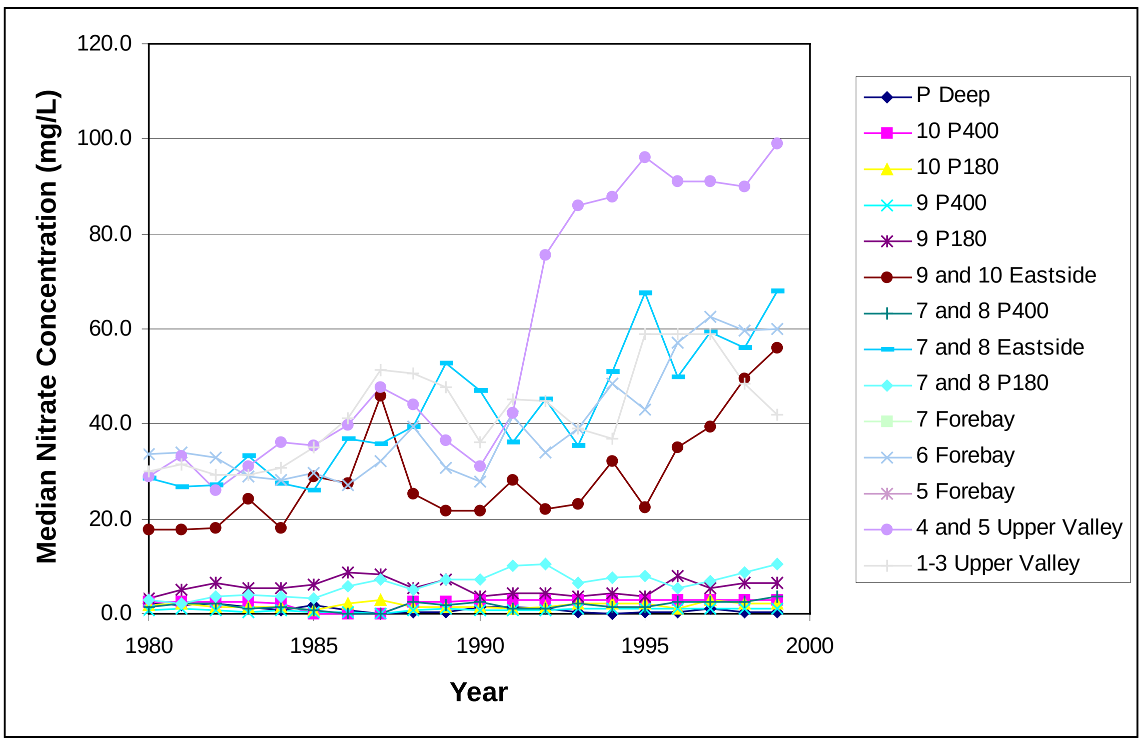


Figure 8: Annual median nitrate concentrations by group

The GIS display of the data also points toward the Upper Valley and East Side as hot areas of nitrate introduction into groundwater. Nitrate levels appear to increase over time in most of the valley. Dark spots on the map in the Upper Valley and Forebay grow more or less radially, with no apparent preference toward down-valley motion. It is not possible to see "pulses" moving down-gradient toward the ocean

A close look at the animation reveals some interesting activity at the ocean-side boundary of the Eastside and Pressure subareas, starting in the late 1980s and becoming more serious in the 1990s. There appears to be intrusion of nitrate from the western edge of the Eastside subarea into the Pressure area. It advances and retreats, making unsteady progress toward the coastline. This is the most compelling evidence produced by this study for contaminants moving down-gradient with groundwater flow. I'm unable to determine what causes the fluctuations in this nitrate plume's advance toward the ocean. The pattern is not obviously related to annual precipitation. Future studies would benefit from statistical regression of this movement against pumping rates, fertilizer application rates, and other relevant variables. I think it is reasonable to hypothesize that pumping in the pressure area speeds up the lateral advance of water from other subareas because recharge from above is not possible.

The GIS images correlate more closely with the graph of mean nitrate concentrations than the graph of median nitrate concentrations. I think it's reasonable to infer that the GIS images are similarly sensitive to the effects of unusually small or large values.

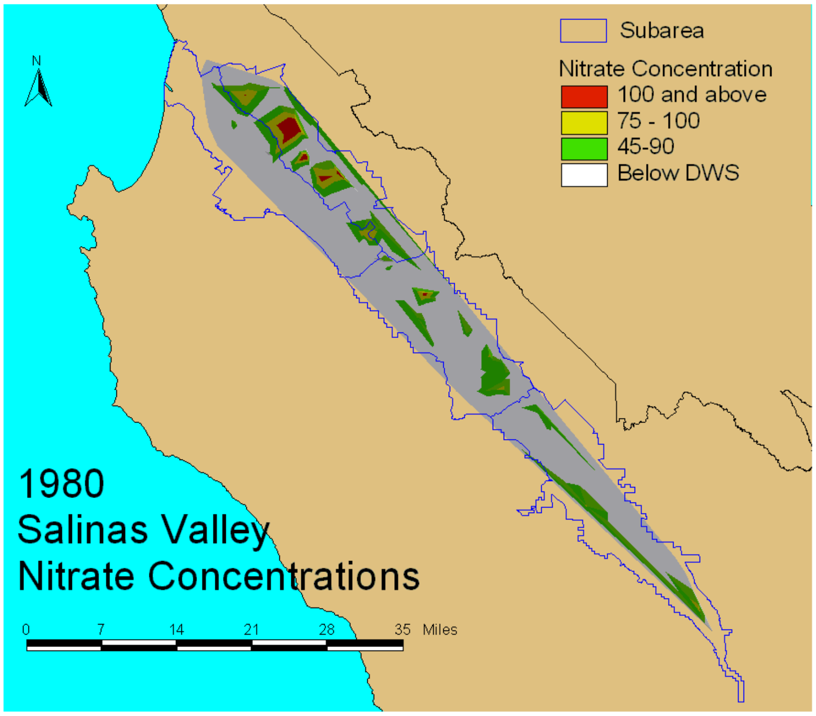
The overall lack of motion of the nitrate "hot spots" in the GIS images might indicate that contamination is a local problem, or that the time scale of motion is larger than that examined here. Provided that the MCWRA is able to continue its annual surveys and to keep the number of wells surveyed each year high enough, more precise conclusions should be available in the future. I don't believe it would be practical to increase the study's precision by decreasing the distance between study wells because of prohibitive costs of drilling new wells.

This study was not able to quantify the time required for changes in behavior at the land surface to be reflected in groundwater quality. This information would be very useful for policy makers charged with maintaining our water supplies and I recommend further research in this area.

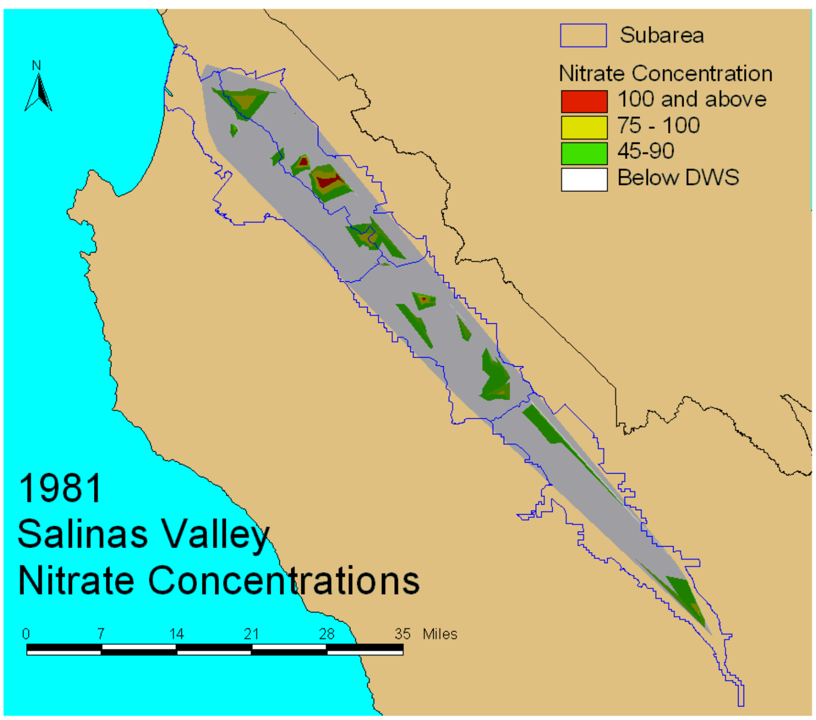
Conclusion

Nitrate concentrations are increasing across the Salinas Valley. The hydrologic subareas in decreasing order of nitrate concentration change are: Upper Valley, East Side, Forebay, Pressure 180, Pressure 400, and deep Pressure area. Each area contains wells that are exceedingly high, skewing the distribution away from normal. Close monitoring of the Eastside/Pressure boundary is in order, as intruding nitrate may eventually threaten municipal supply wells. The primary mechanism of nitrate transport in the rest of the valley appears to be diffusion.

GIS Images



N
Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
1980
Salinas Valley
Nitrate Concentrations
0
7
14
21
28
35
Miles



N
Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
1981
Salinas Valley
Nitrate Concentrations
0
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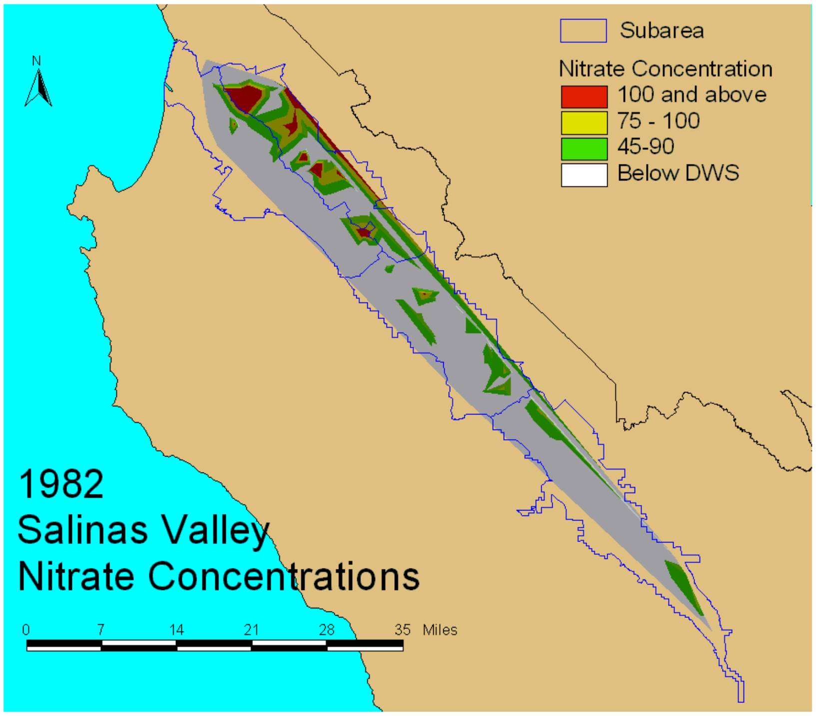
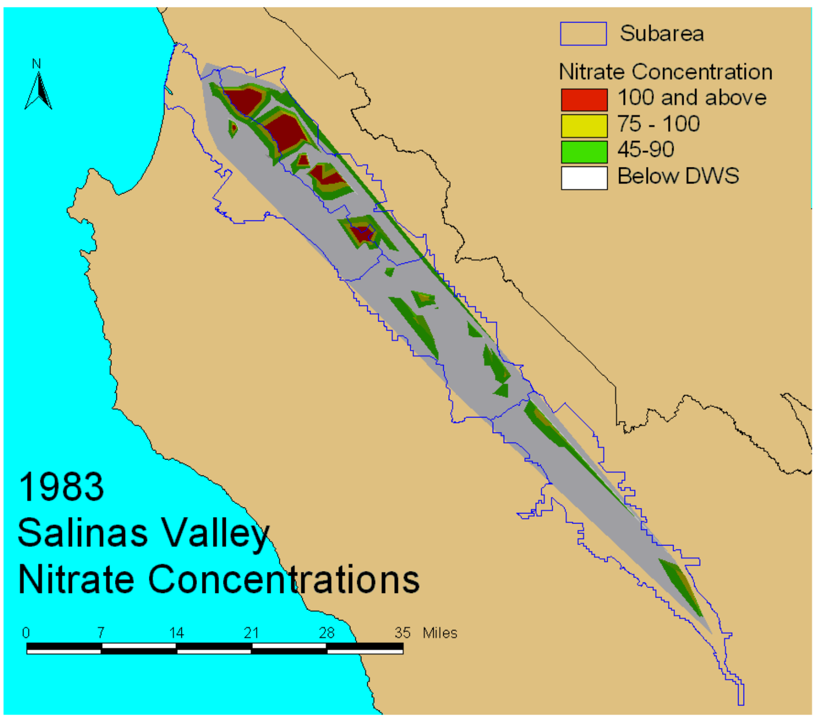
Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1982
Salinas Valley
Nitrate Concentrations
0 7 14 21 28 35 Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
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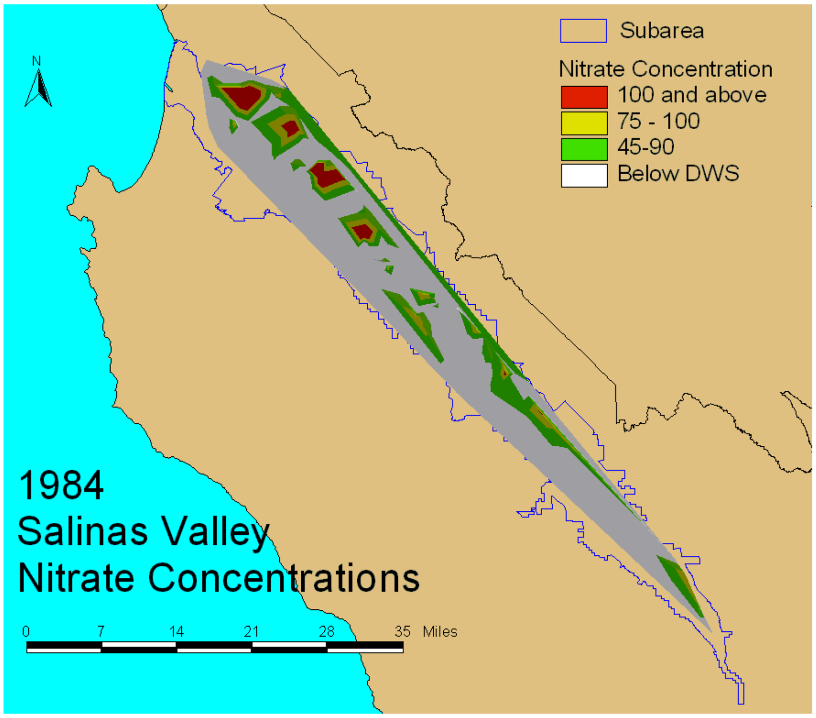
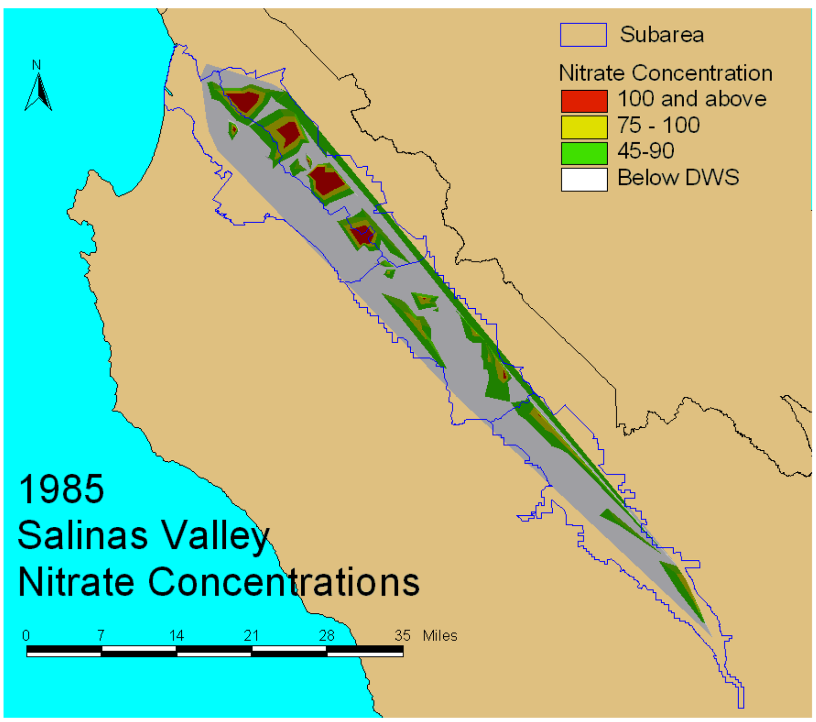
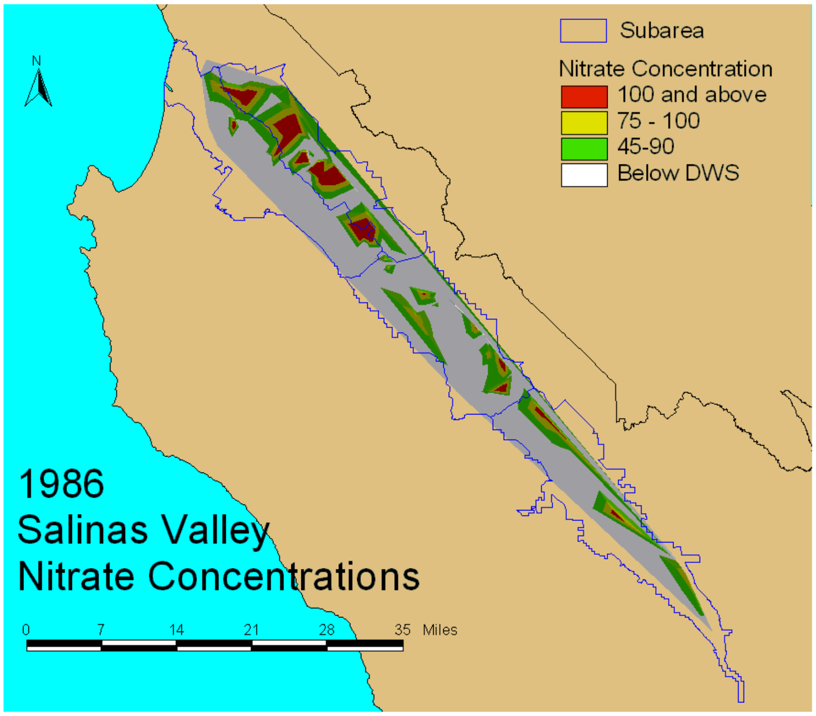
1983
Salinas Valley
Nitrate Concentrations
0 7 14 21 28 35 Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1984
Salinas Valley
Nitrate Concentrations
0
7
14
21
28
35
Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1985
Salinas Valley
Nitrate Concentrations
0
7
14
21
28
35
Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1986
Salinas Valley
Nitrate Concentrations
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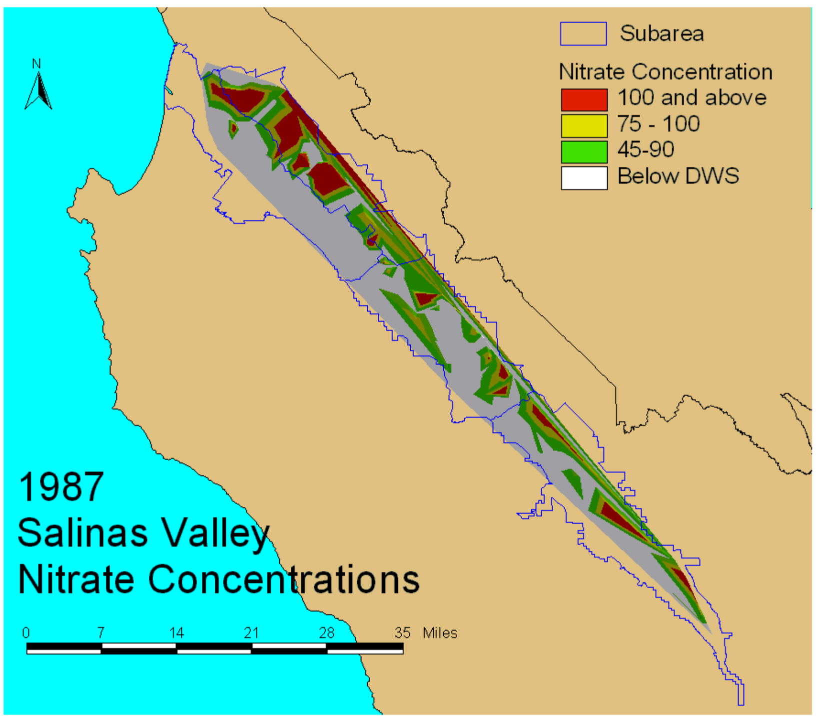
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Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1987
Salinas Valley
Nitrate Concentrations
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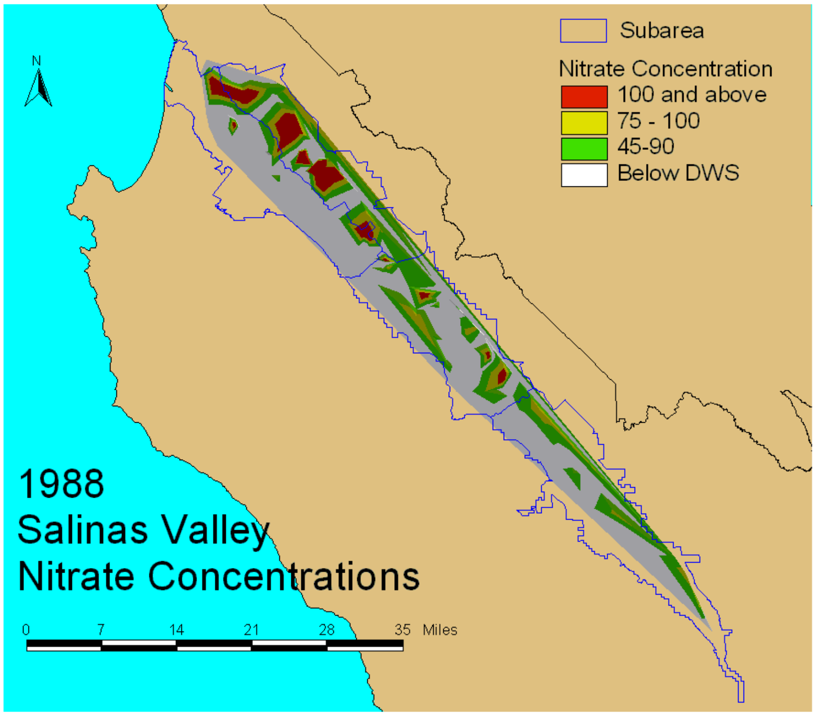
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Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1988
Salinas Valley
Nitrate Concentrations
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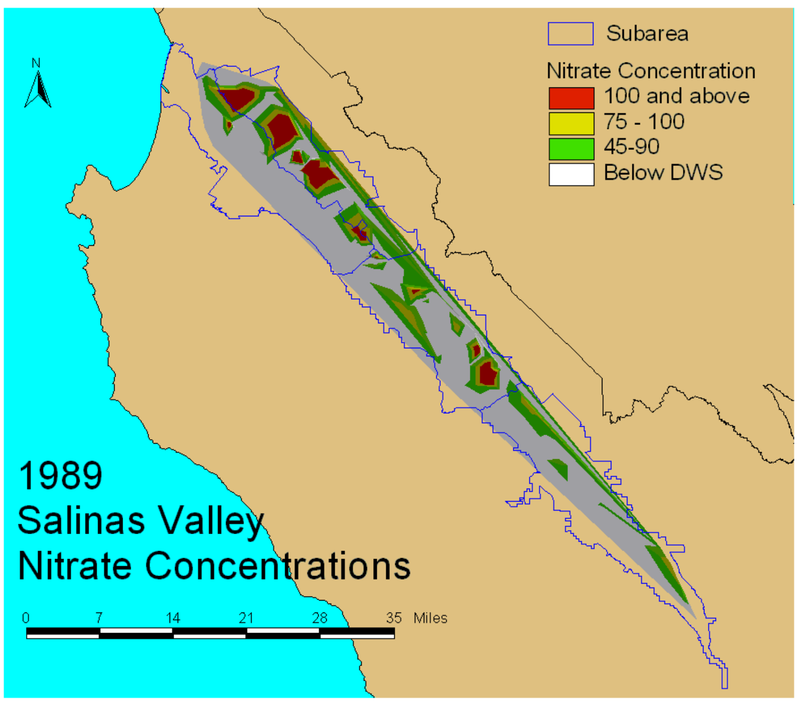
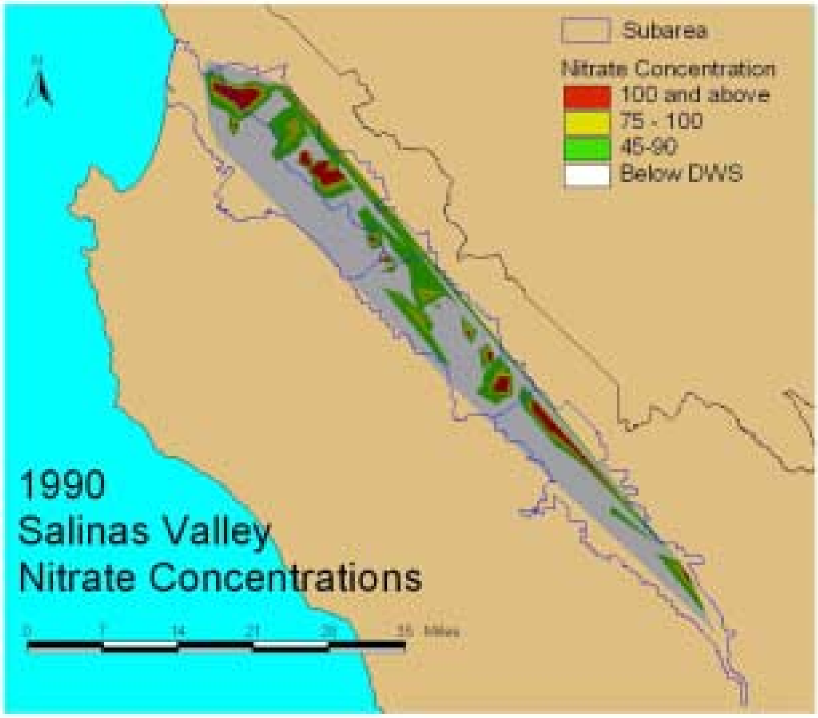
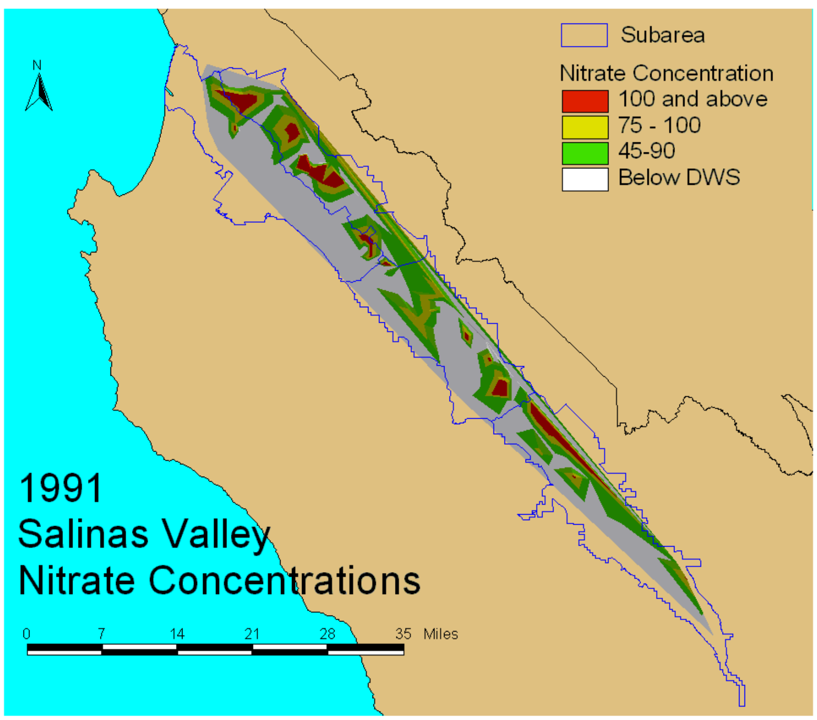
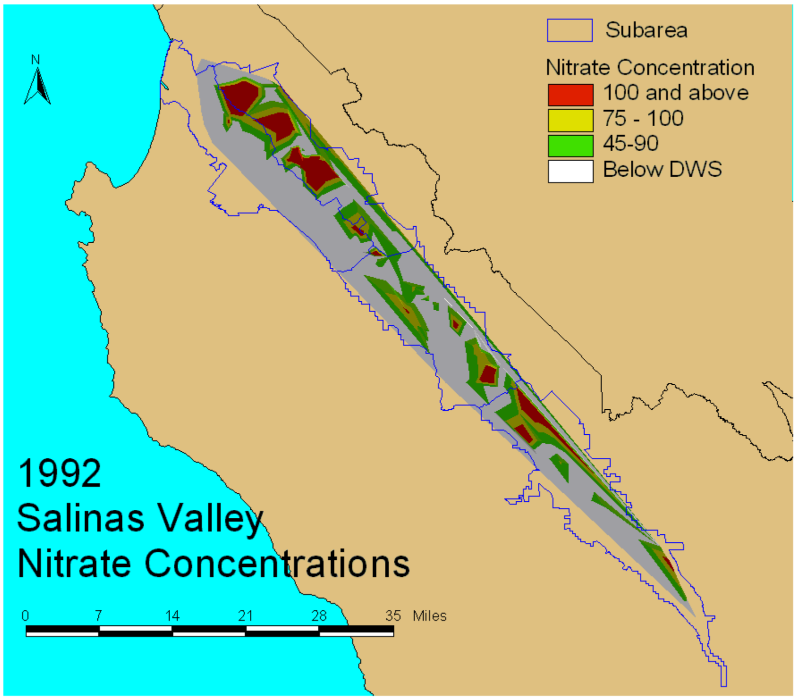
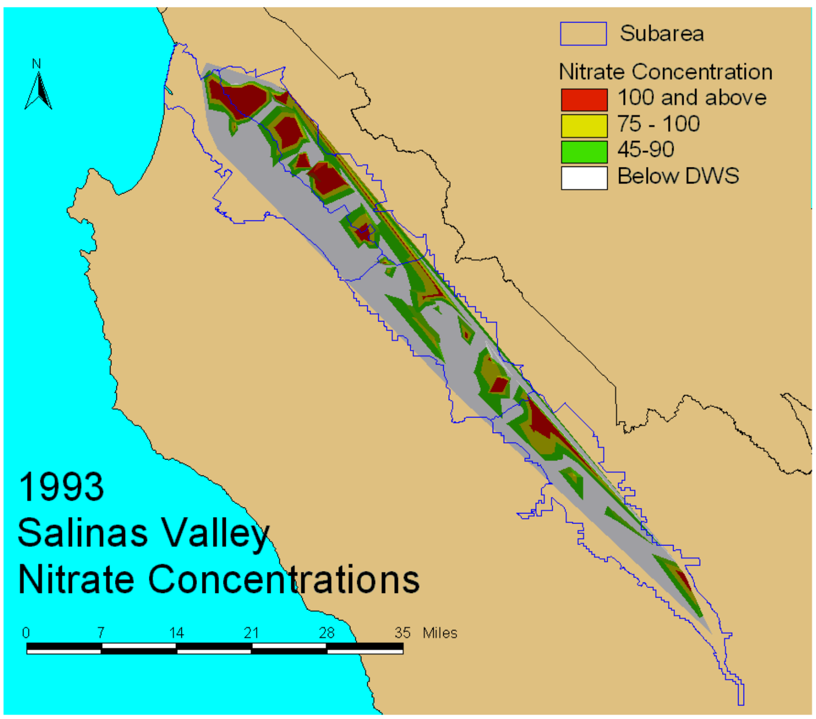
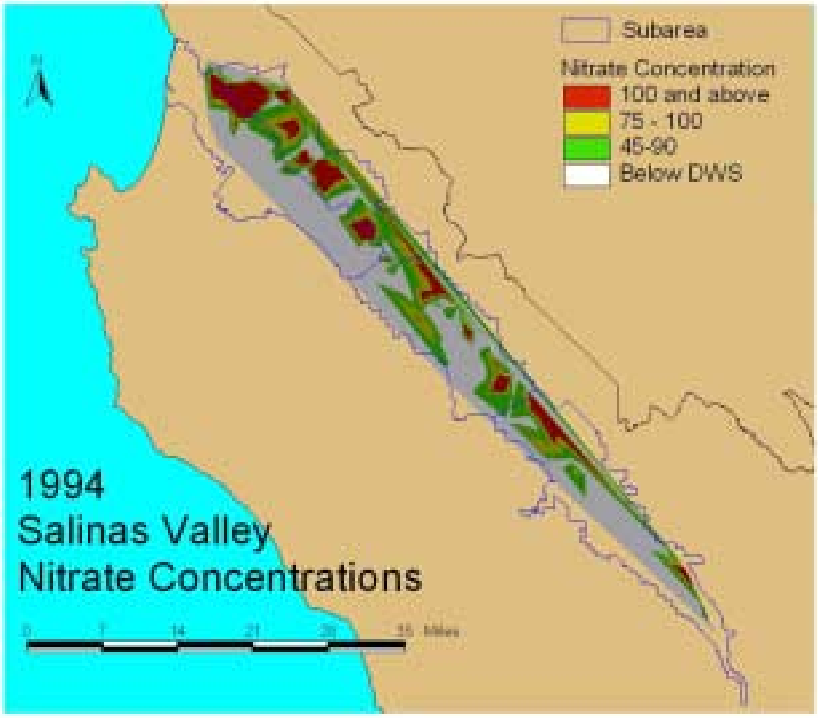

Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1989
Salinas Valley
Nitrate Concentrations
0 7 14 21 28 35 Miles

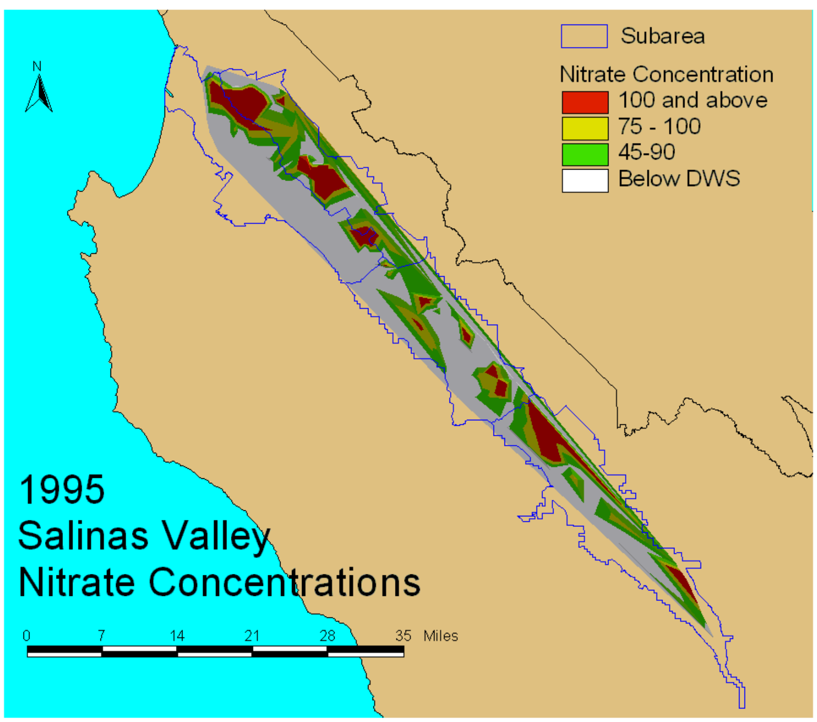

Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
1990
Salinas Valley
Nitrate Concentrations

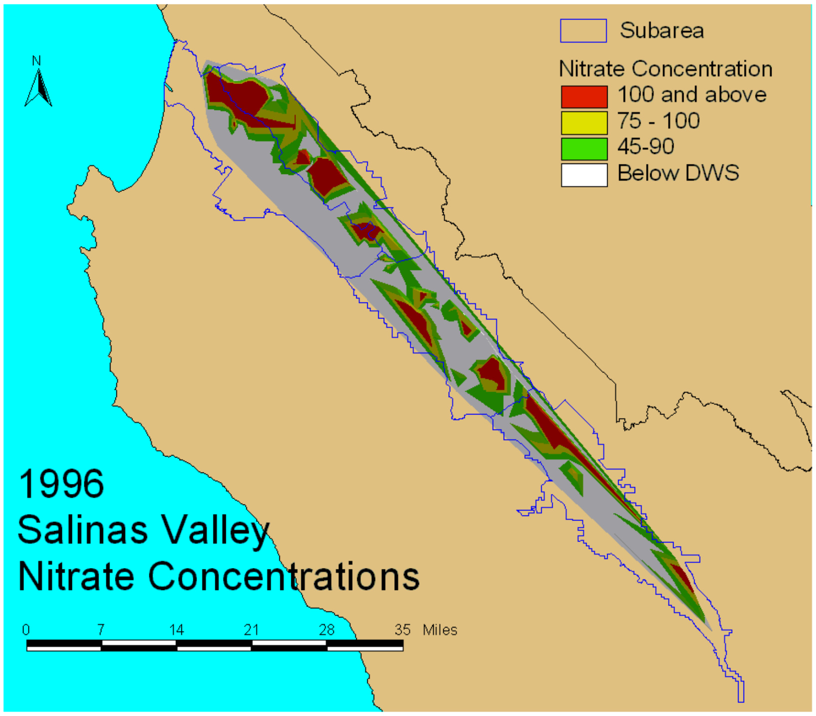

Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1991
Salinas Valley
Nitrate Concentrations
0
7
14
21
28
35 Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1992
Salinas Valley
Nitrate Concentrations
0
7
14
21
28
35
Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1993
Salinas Valley
Nitrate Concentrations
0
7
14
21
28
35
Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
1994
Salinas Valley
Nitrate Concentrations
0
7
14
21
28
35 Miles


N
Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
1995
Salinas Valley
Nitrate Concentrations
0
7
14
21
28
35 Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
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1996
Salinas Valley
Nitrate Concentrations
0
7
14
21
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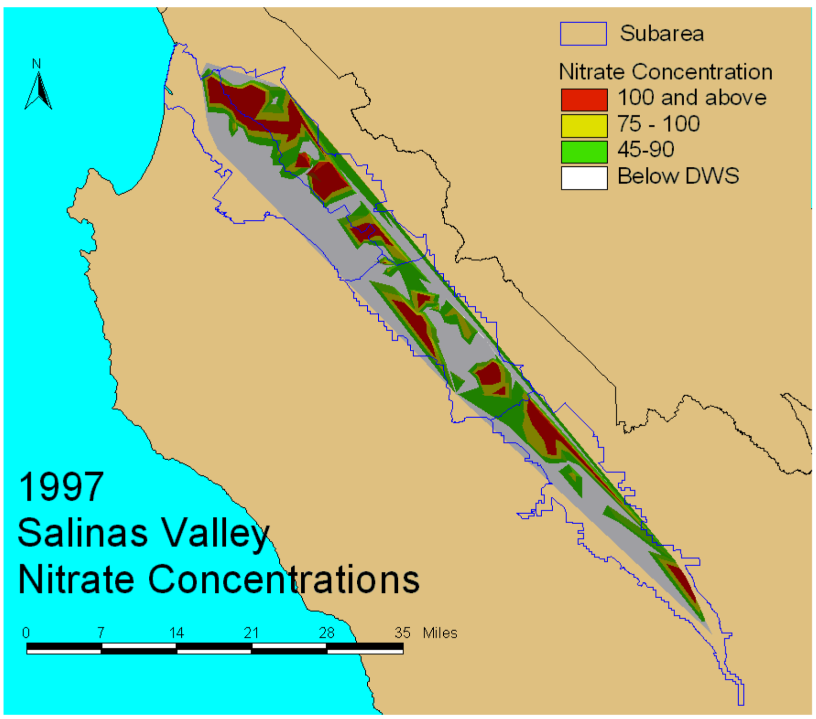
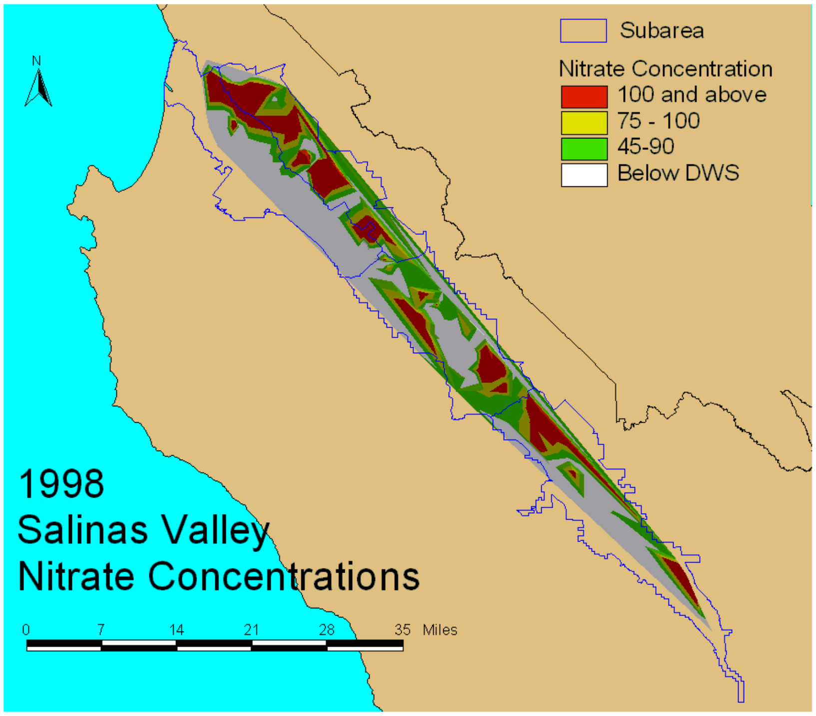
35 Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
N
1997
Salinas Valley
Nitrate Concentrations
0
7
14
21
28
35 Miles


Subarea
Nitrate Concentration
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75 - 100
45-90
Below DWS
N
1998
Salinas Valley
Nitrate Concentrations
0
7
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21
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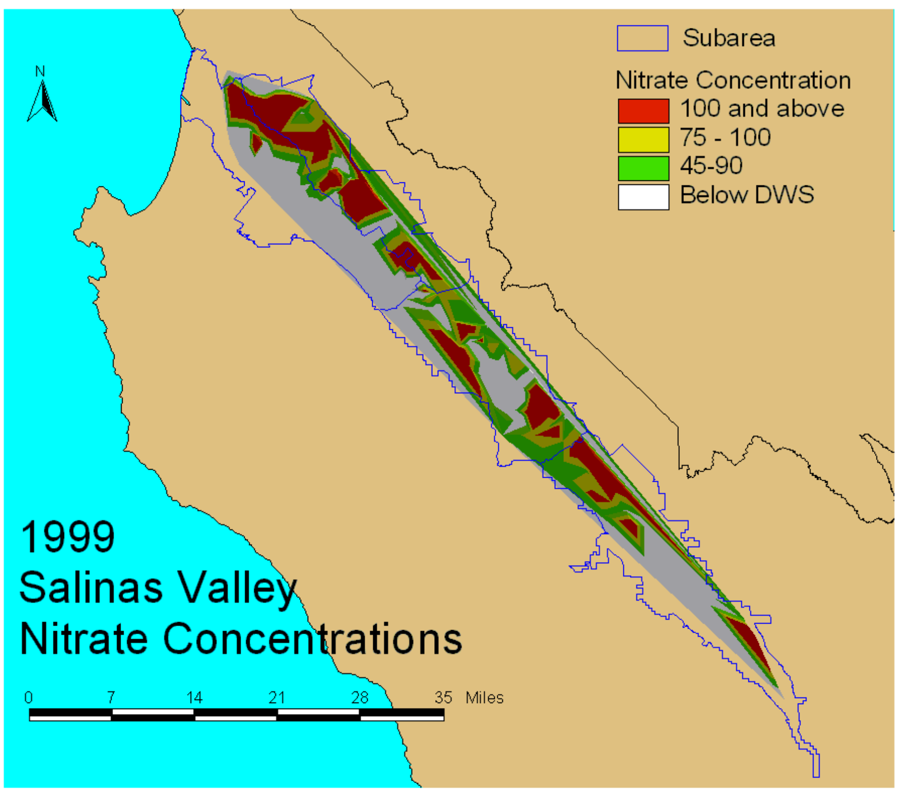
35 Miles


Subarea
Nitrate Concentration
100 and above
75 - 100
45-90
Below DWS
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1999
Salinas Valley
Nitrate Concentrations
0
7
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35 Miles

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