to rise back into unsaturated areas, picking up nitrate that may have percolated into those areas, possibly resulting in a short-term increase in nitrate concentration. These effects of pumping will be discussed more extensively in the section on the Quail Hollow groundwater basin.

4.5.3 Impacts of Nitrates on Aquifers in the San Lorenzo Watershed

Nitrate levels in shallow groundwater discussed in Section 4.4. This section will focus on the impacts on deeper groundwater aquifers which are used for drinking water supply. Approximately two thirds of the residents of the Watershed obtain their water supply from underlying groundwater. Much of the supply comes from the Santa Margarita sandstone, which has experienced significant increases in nitrate levels in at least two areas. Significant groundwater supply is also provided by small private wells which tap localized groundwater bodies and municipal wells which tap small aquifers in the Lompico Sandstone and granitic rocks. To date, there has been no report of seriously elevated nitrate levels in the small aquifers or localized groundwater bodies.

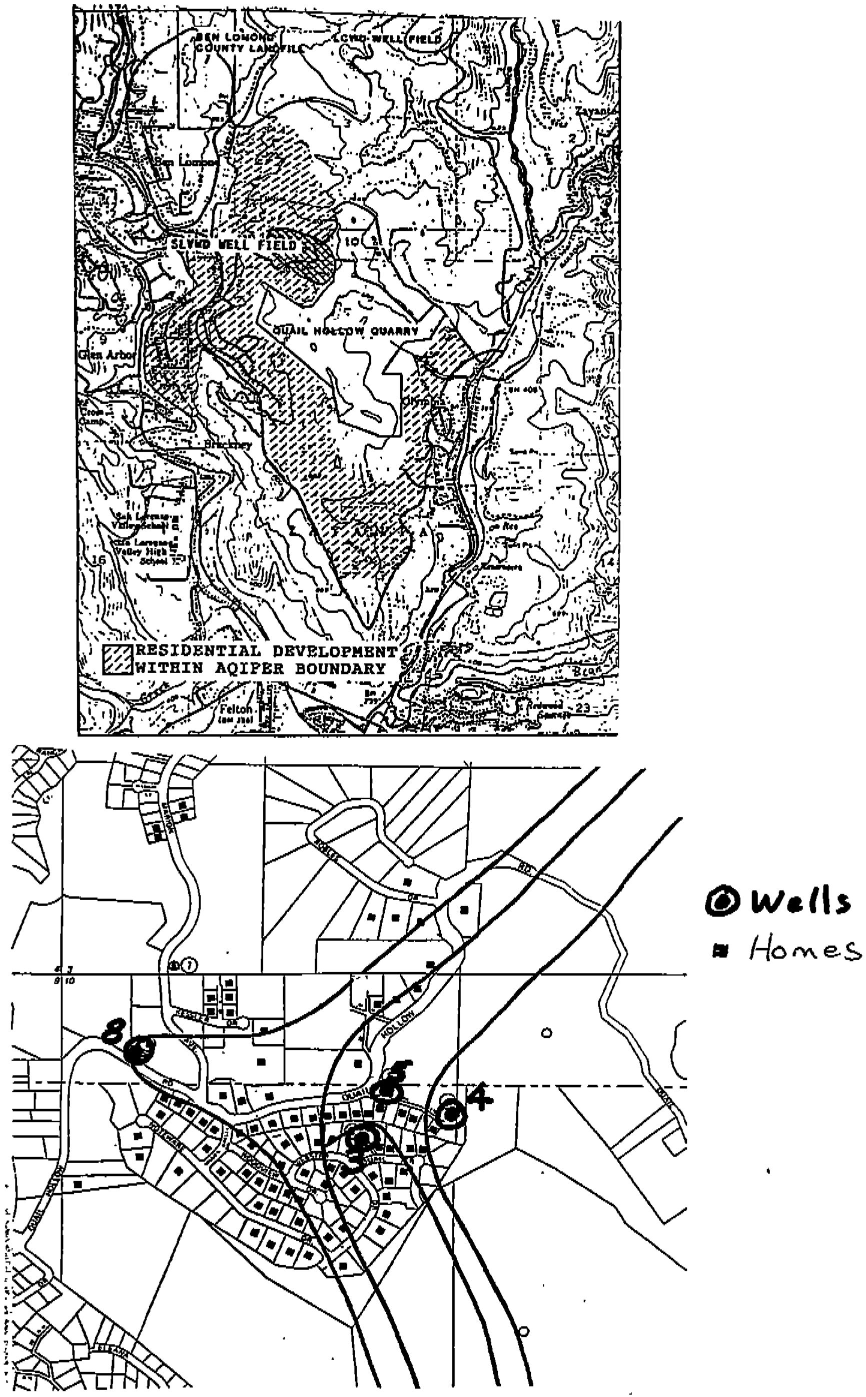
The major water-bearing geologic formation used for water supply is the Santa Margarita Sandstone. Although the main extent of this formation is collectively known as the Santa Margarita groundwater basin, or the Scotts Valley groundwater basin, it is actually divided by creeks and ridges into several distinct aquifers: the Quail Hollow, Olympia, and the Scotts Valley sub-basins. The Santa Margarita contains groundwater in unconfined conditions, and the soils that form on it are very sandy and highly permeable. The aquifer is thus very susceptible to impacts from overlying land use activities and wastewater discharge.

Two of the groundwater basins in the Santa Margarita Sandstone have experienced seriously elevated levels of nitrate in municipal water supply wells: the Quail Hollow area and an area of the Scotts Valley sub-basin. They have both been the subject of a number of studies and will be discussed at some length in the following subsections. This will be followed by a discussion of the potential for nitrate contamination in other aquifers of the Watershed.

4.5.3.1 Quail Hollow Groundwater Basin

The Quail Hollow groundwater basin is an unconfined aquifer in the Santa Margarita Sandstone between Zayante Creek, Newell Creek and the San Lorenzo River. This basin is tapped by private wells, industrial wells for two quarries, and municipal wells of the San Lorenzo Valley Water District. The District wells form a well field in a fairly small area of the basin between Newell Creek and the Watershed divide to Zayante Creek. This well field is partially surrounded by residential development on lots less than one half acre in size, all of which are served by septic systems installed in the very sandy soils. (See Figure 4.)

Figure 4: Quail Hollow Well Field, Including Zones of Influence during Normal Pumping, and Developed Parcels Around Wells (Source: Johnson, 1988)



The potential threat of nitrate contamination from the surrounding development was first addressed in the study by H. Esmaili and Associates (HEA, 1982). That study evaluated existing nitrate levels and used a simple nitrogen mass balance model to calculate the eventual "average" nitrate level that would be expected in underlying groundwater as a result of existing septic system discharge. The model predicted concentrations of 1.8 - 3.1 mg/l-N, which were consistent with readings from the wells at that time (2.5 mg/l-N). However, the study also predicted that higher localized peaks could occur, and that nitrate levels would increase for the next eight years as the groundwater system reached equilibrium with the existing development. If more development were to take place, higher nitrate levels would result (HEA, 1982.

In fall of 1986, sampling of the District's Quail Hollow wells showed a very dramatic increase in nitrate levels in all four of the wells, with a high level of 6.2 mg/l-N in Quail 3. There was serious concern that this sudden upward trend would continue, making the wells unsuitable for drinking water supply, and causing a very severe emergency for the District. The District and the County began a joint effort of weekly monitoring, and an investigation of the causes of the increase in nitrates. The District also hired a geohydrologist to prepare a detailed groundwater model and an analysis of the increase in nitrate in the Quail Hollow wells.

The findings of the geohydrology report were based primarily on the computer model of the Quail Hollow basin which simulated groundwater input, flow, discharge, and well withdrawal from the basin (Johnson, 1988). This model was able to accurately predict the water levels that would occur in the wells under different conditions of pumping. The model also simulated nitrate input from the homes surrounding the wells and accurately predicted the prevailing nitrate concentrations in the individual wells. The model could not account for the sharp peaks which occurred in all wells in the fall of 1986.

The measured nitrate concentrations for the four Quail Hollow wells are presented in Figure 5, along with records of monthly pumping volumes and static groundwater levels, as available. Nitrate levels have increased significantly since the late 1970's, when nitrate levels in all the wells were less than 1 mg/l-N (Johnson, 1988). However, until 1986, measurements were only taken at most once a year, during the spring when nitrate levels tend to be the lowest. The recent monitoring results show some sharp increases for most of the wells over the last three years, but with the possible exception of Quail 8, the nitrate levels have generally returned to the levels that prevailed prior to fall of 1986.

Although the wells are all within one quarter mile of each other, they evidence quite different behavior, as indicated by the monitoring data and the model results. The mean concentrations of nitrate in the individual wells were directly related to the number of homes within the zone of influence of each well. Well 3, which receives effluent from 13 homes under average pumping conditions has much higher mean nitrate levels (2.6 mg/l-N) than Well 4, which is only influenced by one home mean of (0.6 mg/l-N). Figure 4 shows the zone of influence for each well under average pumping rates.

Figure 5: Fluctuations of Nitrate, Groundwater Level, and Monthly Pumping Volumes in the Quail Hollow Wells

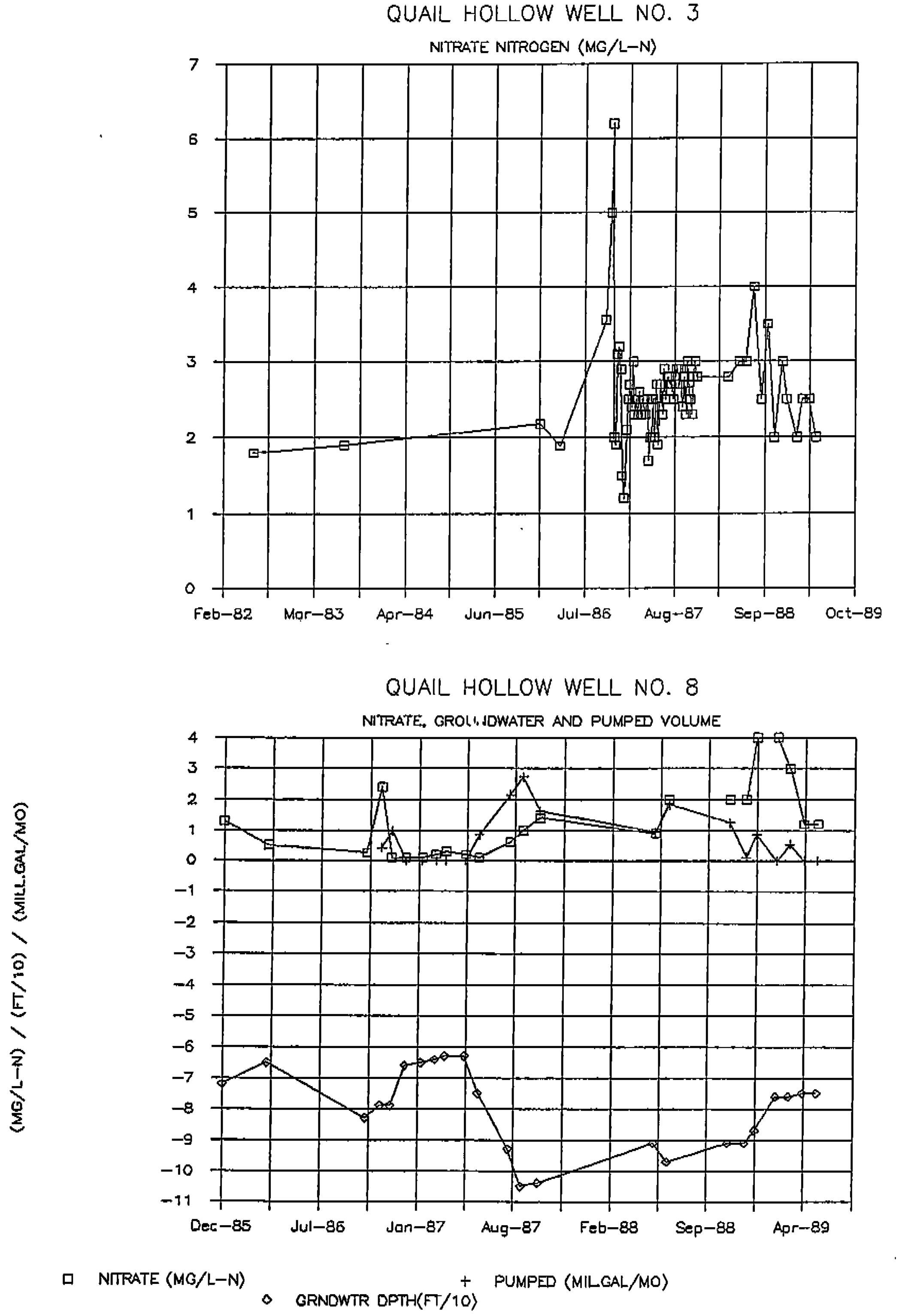
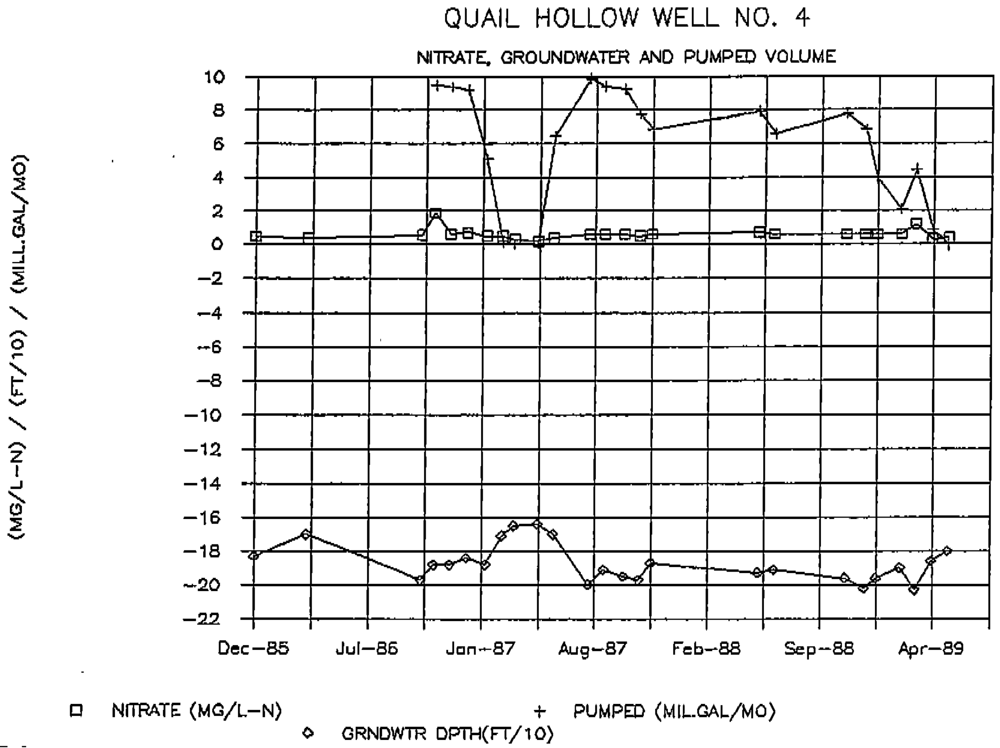
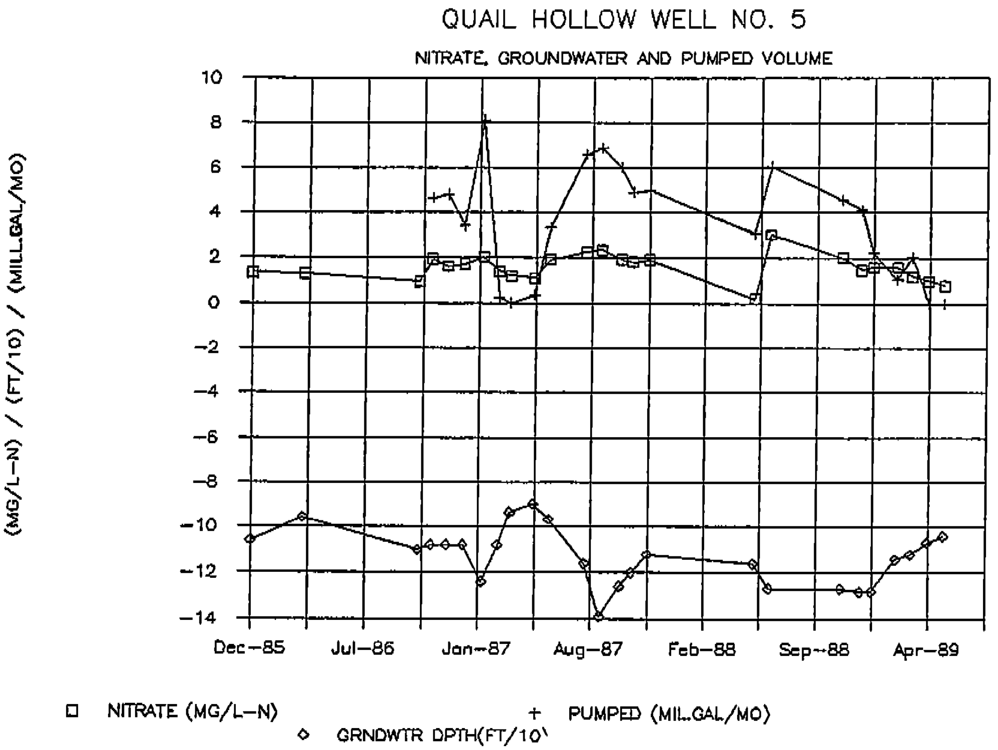


Figure 5: (Continued) Fluctuations of Nitrate, Groundwater Level, and Monthly Pumping Volumes in the Quail Hollow Wells





The model showed that the number of homes affecting two of the wells varied with the pumping rate and resultant water level in the wells. As pumping rates increase, the water table was drawn down further and the zones of influence, particularly for Well 5, significantly expanded. The increased nitrate contribution from the additional homes results in higher nitrate concentrations in the wells. The number of homes contributing to Well 5 increases from 5 homes under average pumping rates to 12 homes at maximum pumping rates and the calculated nitrate concentrations increase from 0.7 to 1.4 mg/l-N, corresponding closely to measured increases.

The graphs show the seasonal relationship between nitrate concentration, pumping, and groundwater level. These relationships are most obvious in Wells 5 and 8, for reasons discussed above. A correlation analysis also showed a significant correlation between pumping and nitrate concentration for Quail 5 (correlation coefficient of 0.61), but not for the other wells.

Nitrate concentrations are also affected by other seasonal factors. Generally nitrate levels are lowest in the spring, after dilution by rainfall and recovery of the groundwater level. This can readily be seen in the spring of 1987 and 1989, for Wells 3 and 5. During the period since 1986, annual rainfall has been much below normal, leading to reduced recharge, reduced dilution of nitrate contributions, lowered water levels and increased pumping. Although this has lead to increasing average nitrate concentrations, the lower nitrate levels in the spring of 1989 suggest that the trend will drop back down with normal rainfall years.

Although the groundwater model was able to accurately predict the mean nitrate concentrations found in each well, it did not clearly explain the occurrence of the very high peaks that occurred in all of the wells in fall of 1986. This event was preceded several months by record rates of pumping from the well field. The peak in nitrate occurred after pumping returned to lower levels. This may have resulted from flushing of accumulated nitrate in the unsaturated zone as the water table recovered from the period of heavy pumping. Some sort of nitrogen spill may have occurred, but it is unlikely it would have affected all wells. Those high peaks appear to be an anomaly.

The source of the nitrates in the Quail Hollow wells would be expected to be septic systems and other nitrogen sources associated with residential development, as this is the only overlying land use. As discussed above, the nitrate concentrations are directly related to the number of homes contributing to each well. As a basis for simulation, the model assumed that there was no treatment at all of the septic effluent in the soil, resulting in a discharge to groundwater with a nitrate concentration of 50 mg/l-N. The study also recognized that residential fertilizers could contribute an additional 20-60% of the amount of nitrogen from the septic systems. Model results were very close to typical observed concentrations if a 20% additional contribution from fertilizers was assumed (Johnson, 1988).

It seems likely that there is some nitrogen removal from septic effluent through nitrification and denitrification after the effluent is discharged from septic tanks. To balance the model results and make up for the nitrogen removed by treatment of the septic effluent, the contribution from fertilizers and other sources might be greater than 20%, perhaps closer to the 60% level, or even the 100% additional contribution as was measured in Long Island (Ragone, 1981). It is thus probable that in the residential Quail Hollow area, there are significant sources of nitrate in addition to septic systems, with septic systems contributing at least 50-80% of the total. (This is discussed further in Section 4.6.1.)

Because of wide variations in fertilizer applications, fertilizers can have sharp impacts on the underlying groundwater. Johnson points out that if fertilizer was applied simultaneously on several nearby lots, it could result in "sudden and extreme peaks" in nitrate concentrations in affected wells (Johnson, 1988).

The sudden increase in nitrate concentration in their wells in 1986 caused the San Lorenzo Water District considerable concern that they might be in danger of losing their wells. Even if average concentrations did not exceed drinking water standards, periodic high peaks could render the wells unusable. Based on the follow-up studies and the modelling, it now appears that the wells are not in imminent danger, and that nitrate levels are fairly stable at levels generally less than 30% of the drinking water standard. The District has taken steps to educate the property owners on the need to reduce fertilization and other discharge of nitrogen on their property. The groundwater quality is also protected by current County policies limiting density of new development in the area. If ongoing monitoring shows a further increase in nitrate levels, further measures may be needed to protect the water supply.

The situation in Quail Hollow indicates how susceptible the groundwater is to release of nitrate and other possible contaminants from overlying land use.

Any increase in development or change in land use practices could result in significantly increased nitrate levels, again endangering the water supply. The potential cumulative threat to underlying groundwater is one of the primary reasons the County adopted the requirement that new development in the San Lorenzo Valley can only occur on lots greater than one acre in size. There are 10-20 small lots in the recharge area for the Quail Hollow well field that are limited by this restriction. If these lots were allowed to be developed, it is likely that there would be a significant increase in nitrate levels in the wells. To provide further protection, the County has also adopted a policy that requires a ten acre minimum for creation of new lots in areas designated as groundwater recharge areas.

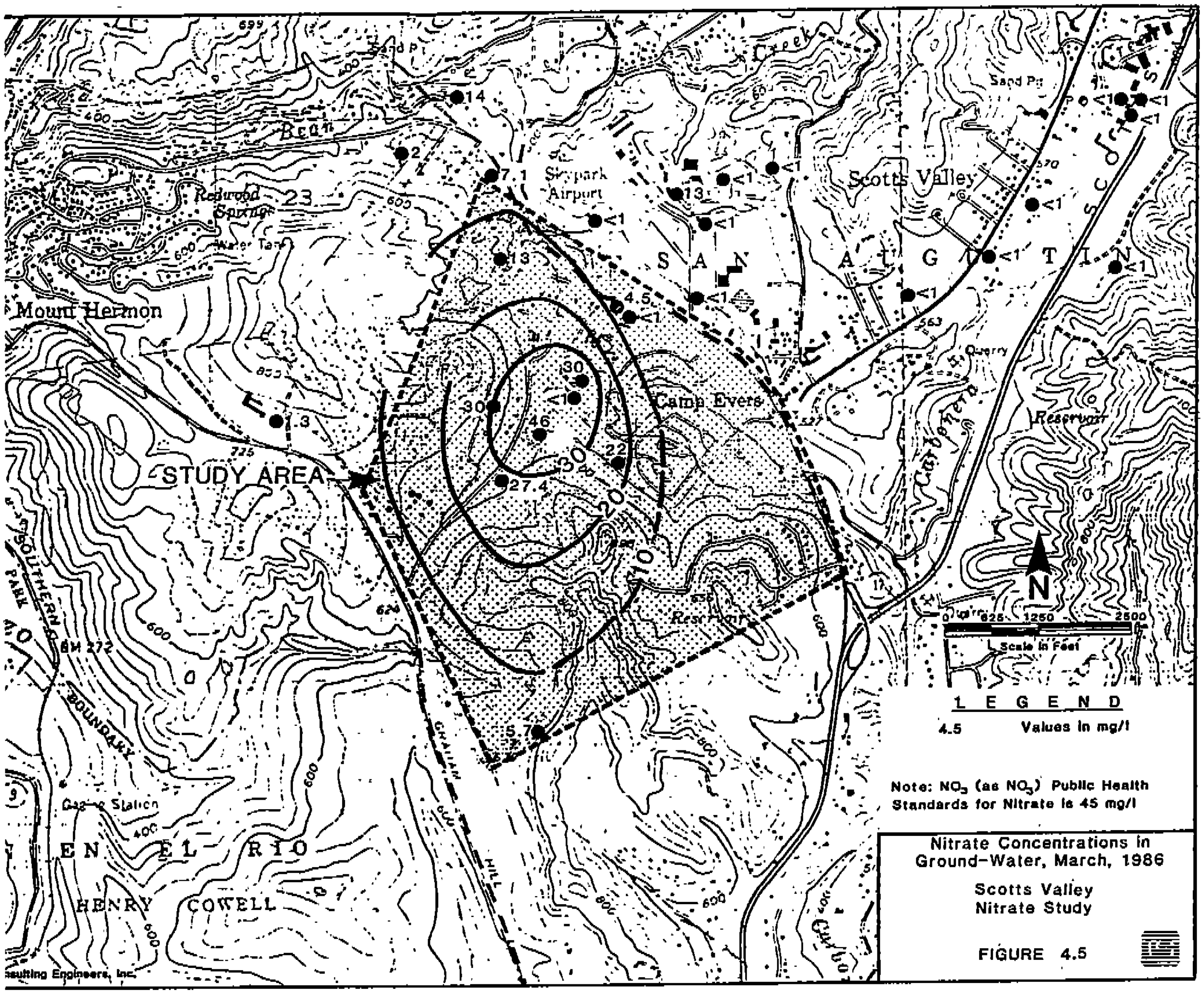
4.5.3.2 Scotts Valley Groundwater Basin

High nitrate concentrations have also been found in groundwater in another part of the Santa Margarita Sandstone in southwestern Scotts Valley. Wells of the San Lorenzo Valley Water District in the Lockwood Lane/Pasatiempo Pines area were found to have nitrate concentrations at or above the state drinking water standards beginning in 1981. The wells are located in the middle of residential areas, and septic systems have been blamed as the primary source of the nitrates.

In 1984-86, the consulting firm of Luhdorff and Scalmanini conducted a study of the area under contract with the Association of Monterey Bay Area Governments, San Lorenzo Valley Water District and Scotts Valley Water District. The study included a review of past water level and water quality records, construction of some new monitoring wells, and monitoring of surrounding nitrate levels for one year. The study also included measurement of nitrogen concentrations in underlying soil and in the unsaturated zone.

The study found that the high nitrate concentrations were limited in extent, with concentrations diminishing in all directions out from the center. The nitrate concentrations are shown in Figure 6, which is taken from the final report (which shows nitrate concentrations expressed as nitrate, 4.5 times the values presented in this document). With the exception of one well, the concentrations in the center of the area were 6.7 mg/l-N, below the State drinking water standard of 10 mg/l-N. The Estrella well, which had the highest concentrations (10.2 mg/l-N), was believed to be affected by unknown "localized" sources of nitrate contamination. No significant increasing or decreasing trend in the nitrate levels at the center of the study area was observed. There was an increasing trend in nitrate in a well at the northern edge of the problem area. It was believed that this was related to a declining water level in that area in response to heavy pumping to the north. With the exception of high levels of organic nitrogen in the surface soils, the unsaturated zone was not found to hold significant amounts of nitrate, with soil water concentrations of 0.9-2.2 mg/l-N.

Figure 6: Scotts Valley Nitrate Contamination (Note: nitrate concentrations are shown as NITRATE, not nitrogen) (Source: Luhdorff and Scalmanini, 1986)



The study did not analyze any seasonal trends in nitrate levels, or any response to actual pumping volumes. It also did not evaluate the density of the overlying development to determine the extent to which the observed nitrate levels at different locations were related to development density. Potential sources of nitrate in the residential areas, other than septic systems, were not addressed. Although the past occurrence of septic system failures in the area were presented as evidence of contribution from septic systems, it would be expected that less nitrate would be released to groundwater by a failing septic system than a non-failing system, due to the increased potential for nitrate removal at the soil surface.

It is still unclear how much of the observed nitrate contamination resulted from onsite sewage disposal, and what the mechanism was which resulted in the relatively localized area of high nitrate concentration. The axis of the zone of contamination follows a surface drainageway, and also an underlying groundwater trough. Surface sources of nitrate percolating from the drainageway may be significantly contributing to the high nitrate levels. This was indicated by the relatively high nitrogen levels near the soil surface at two monitoring wells near the drainageway. This contribution could also be increased by upstream septic system failures. Perhaps the nitrate levels became higher as nitrate laden recharge water was concentrated as subsurface flows were directed toward the axis of the groundwater trough.

In 1987, most of this area was connected to sewer to eliminate the nitrate discharge from septic systems. Ongoing monitoring in the next few years will help to provide information on the remaining sources of nitrate contamination in the residential area. By the end of 1988, nitrate levels in most of the wells in the immediate area had shown significant change, and still had levels of 7-8 mg/l-N (Scotts Valley Water District, unpublished data).

The Scotts Valley study also investigated the recovery of the groundwater from contamination by past municipal wastewater disposal from Scotts Valley. From 1972 to 1981, the City of Scotts Valley discharged up to 400,000 gallons of treated wastewater per day to an abandoned sand pit between the City and Bean Creek. Monitoring of nitrate in a well downgradient of the pit showed that nitrate levels had declined from about 6.7 mg/l-N in 1981 to 1.1 mg/l-N in 1986. Much of this decline had occurred in the first year, when nitrate concentrations dropped to about 3.3 mg/l-N. Flushing was undoubtedly accelerated by the high rainfall of 1982 and 1983. This indicates a potential for fairly rapid recovery of groundwater quality in the Santa Margarita once discharge of nitrate is reduced.

4.5.3.3 Potential for Nitrate Contamination in Other Areas

The studies of high nitrate levels in wells in Quail Hollow and Scotts Valley indicate the potential for significant nitrate release to groundwater from septic systems and other sources, particularly where development takes place in highly permeable groundwater recharge areas. Although these conditions exist in some other parts of the San Lorenzo Watershed, the nitrate concentrations have not reached problematic levels as they have at Quail Hollow and Scotts Valley. Initial testing of new private wells, and periodic testing of small water system wells and municipal wells, has not yet shown any indication of excessively high nitrate levels in other parts of the Watershed. In most locations, development densities are much lower, providing for adequate treatment of the nitrate and dilution by rainfall recharge.

Even in areas that do not contribute recharge to major aquifers, it is important to prevent excessive cumulative nitrate release. Groundwater in other areas supplies water to private water systems, and releases water to the streams. It is thus important to manage development density and to utilize waste disposal techniques that maintain nitrate discharges at an acceptable level. As indicated by results from Quail Hollow and Scotts Valley, lot sizes of less than one acre can cause serious threats to underlying water supply.

4.6 Nitrate Release to Surface Water

The discharge of nitrate to shallow groundwater and deeper aquifers was discussed in previous sections. Nitrate in groundwater is eventually discharged to streams, along with the groundwater which provides the streamflow during non-storm periods. Although nitrate can also enter streams by surface runoff, contribution by groundwater is of most concern because this is the primary supply during the critical periods when excess nitrate may have adverse impacts on stream quality. Nitrate concentrations in streams are related to the same factors that affect nitrate levels in groundwater: land use and geology of the Watershed.

Although surface water nitrate concentrations in the San Lorenzo Watershed rarely exceed 10% of the safe drinking water level, even low levels of nitrate in streams can have adverse effects on water supplies. The nitrate can serve as a nutrient to stimulate biological growth in the stream environment, with resulting influences on tastes and odors and other aspects of drinking water quality. These impacts have reached moderate levels in the San Lorenzo River, which is a major source of water for the City of Santa Cruz. Nitrate-influenced biological growth can also affect the recreational value of streams, although the severity of these impacts has not been clearly established in the San Lorenzo Watershed.

The following section will discuss the levels and sources of nitrates found in Watershed streams. This will be followed by a section describing the impacts of current nitrate levels, including a description of the effects on the stream ecosystem.

4.6.1 Past and Present Nitrate Levels

During the County's present study, nitrate levels have been measured on a monthly basis at 22 stations, and on a weekly basis at three stations along the River. Individual measurements have also been made at selected locations as a part of special investigations. Periodically samples have also been run for other nitrogen compounds: nitrite, ammonia, and Kjeldahl nitrogen, which is primarily a measure of organic nitrogen. A summary of nitrate levels at the major stations is presented in Table 2 and Appendix A.

Nitrate is the primary form of nitrogen that has been regularly monitored over the years in the Watershed. It is easier to measure analytically, its concentration is more reflective of nitrogen input from the surrounding Watershed, and it is the form of nitrogen that can directly stimulate instream biological activity. The concentration of ammonia and nitrite are generally insignificant in stream water, amounting to about 1-5% of the nitrate concentration.

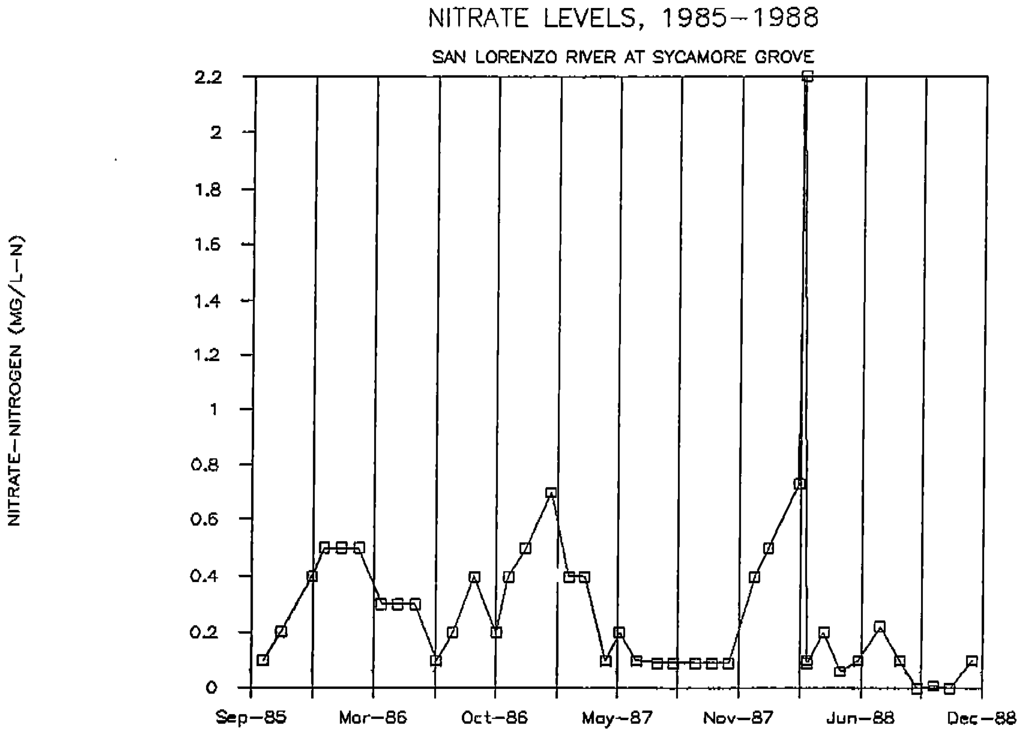
Although most of the data acquisition and evaluation focuses on nitrate, it must be kept in mind that the concentrations of Kjeldahl nitrogen are very significant, with mean concentrations two to ten times greater than nitrate concentrations, depending on the station. Although the concentration of Kjeldahl nitrogen is affected by surface runoff, during non-storm periods it appears to be primarily a product of biological activity in a stream reach. Kjeldahl concentrations do not generally correlate closely with nitrate concentrations, but tend to increase in a downstream direction as a reflection of cumulative biological activity. Nitrate and Kjeldahl nitrogen levels for some of the main stations are shown later, in Table 7, and will be discussed at some length.

Table 7: Nitrate and Kjeldahl Nitrogen Discharge from Various Parts of the San Lorenzo Watershed

STATION NUMBER	LOCATION	DISCHARGE (cfs)	PERCENT OF BIG TREES DISCHARGE	MEAN NITRATE (mg/l-N)	NITRATE LOADING (lb/day)	PERCENT OF BIG TREES NITRATE	ALGAE STUDY NITRATE (mg/l-N)	KJELDAHL NITROGEN (mg/l-N)	KJELDAHL NITROGEN LOAD (lb/day)	PERCENT OF BIG TREES KJELDAHL NITROGEN	TOTAL NITROGEN LOAD (lb/day)	PERCENT OF BIG TREES TOTAL NITROGEN
345	SLR @ Waterman Gap	0.85	4%	0.17	0.8	1%	0.08	0.8	3.7	3%	4.0	3%
310	Kings Creek	0.57	3%	0.27	0.8	2%						
289	SLR @ Brimblecom Rd.	1.9	9%	0.22	2.3	4%	0.04	0.85	8.7	7%	9.1	6%
271	Bear Creek	1.5	7%	0.15	1.2	2%						
2581	Upper Boulder Creek	0.6	3%	0.3	1.0	2%	0.1	0.7	2.3	2%	2.6	2%
251	Boulder Creek @ SLR	1	5%	0.6	3.2	6%	0.66	0.78	4.2	3%	7.8	5%
245	SLR @ River Street	4.5	21%	0.28	6.8	13%	0.23	1.04	25.3	20%	30.9	19%
225	SLR @ Brookdale	5	24%	0.25	6.8	12%						
180	SLR @ Ben Lomond	7.2	34%	0.25	9.7	18%						
171	Love Creek	0.5	2%	0.24	0.6	1%						
150	Newell Creek	2.5	12%	0.8	10.8	20%						
140	SLR below Glen Arbor	10	48%	0.46	24.8	46%	0.41	1.68	90.7	71%	112.9	71%
0762	Upper Zayante Creek	0.7	3%	0.22	0.8	2%	0.18	0.63	2.4	2%	3.1	2%
07528	Lompico Creek	0.26	1%	0.32	0.4	1%						
07109	Bean Cr @ Lockhart Gulch	1.7	8%	0.75	6.9	13%						
07105	Bean Cr @ Mt. Hermon	3	14%	0.75	12.2	22%						
070	Zayante Creek @ SLR	6	29%	0.7	22.7	42%	0.63	1.17	37.9	30%	58.3	37%
060	SLR @ Big Trees	21	100%	0.48	54.4	100%	0.27	1.13	128.1	100%	158.8	100%
050	Shingle Mill Creek	0.5	2%	0.8	2.2	4%						
030	Gold Gulch	0.5	2%	0.18	0.5	1%						
022	SLR @ Sycamore Grove	24	114%	0.32	41.5	76%	0.1	1.2	155.5	121%	168.5	106%
0121	Branciforte Creek	1.4	7%	0.43	3.3	6%						
01149	Carbonera Cr @ Scotts Valley	0.25	1%	1.03	1.4	3%						
0111	Carbonera Cr @ Santa Cruz	0.7	3%	1.13	4.3	8%						

The concentration of nitrate measured at any given point at any time is a result of upstream inputs from surface runoff and groundwater discharge, and instream biological activity which can absorb or release significant amounts of nitrate. The effect of these different factors varies by season. During fall there can be significant nitrogen input by decomposition of riparian leaves and Watershed runoff from the first winter storms. Nitrate in runoff is derived from decomposed vegetation, animal wastes, septic system failures, garbage, runoff of fertilizers, etc. Winter storms also result in the flushing of nitrate through soil, into shallow groundwater, into deeper groundwater and into streams. Later in the winter, after adequate flushing has occurred, additional rainfall and runoff has a diluting influence, as does the increased groundwater discharge to the streams. In spring and summer, instream biological activity increases, resulting in very dramatic fluctuations in nitrate as it is first taken up in plant tissue, and then released in large amounts as the plants die. These instream effects are the most pronounced in lower reaches of the main River. Kjeldahl nitrogen levels are also highest at this time of year. These seasonal fluctuations are most obvious in the River at Sycamore Grove, as shown in Figure 7.

Figure 7: Seasonal Fluctuations of Nitrate in the San Lorenzo River at Sycamore Grove, 1985-88



4.6.1.1 Nitrate Contributions from Different Areas

Geology and land use have an overriding effect on nitrate levels in the different tributaries of the River. Due to the increased treatment capabilities of the predominantly clay soils, the streams which enter the River north of Boulder Creek, and flow from areas north of the Zayante Fault have predominantly low nitrate levels (0.1-0.2 mg/l-N). This includes Bear Creek, the upper River at Waterman Gap, Upper Zayante Creek, and Love Creek. Kings Creek and Lompico Creek, which have more dense development along their channels, have average nitrate levels of 0.2-0.3 mg/l-N. Areas with development on very permeable soils have nitrate levels of 0.6-0.8 mg/l-N. These include Boulder Creek, Newell Creek, Lower Zayante Creek, Bean Creek, Carbonera Creek, and Branciforte Creek. The latter three also have significant amounts of grazing by domestic livestock. The main River, which is affected by the input of the tributaries, and by the effects of dense development on the adjacent moderately-permeable alluvial soils, has nitrate concentrations of 0.2-0.5 mg/l-N.

Table 7 shows the proportional contributions of nitrate and Kjeldahl nitrogen from different tributaries and reaches of the River. Nitrogen concentrations have been multiplied by the volume of streamflow at each station to calculate the total amount of nitrogen discharge in pounds per day. Measurements of summer flows in 1986 were used along with the mean concentration of nitrate for the period of 1986-88. In the second part of the table, mean nitrate and Kjeldahl nitrogen levels are shown as determined from a set of data where both parameters were measured, in order to determine the relationship between the two at different stations. The total nitrogen loading was calculated using the same flow volumes.

The nitrate loading calculations from Table 7 give a good indication of the areas which contribute most of the nitrate to the River at Big Trees (Felton). The area north of Ben Lomond (Station 180) contributes 34% of the streamflow, but only 18% of the nitrate. Practically all of the remainder of the nitrate comes from the areas underlain by Santa Margarita Sandstone, with Newell Creek contributing 20% and Zayante Creek and Bean Creek contributing 46%.

The contribution from areas immediately adjacent to the River may be more significant than shown, but would be reduced by removal of nitrate by instream biological activity. The effect of this activity is clearly shown by the 24% drop in total nitrate loading between Big Trees (Station 060) and Sycamore Grove (Station 022). The uptake of nitrate by biological activity is also reflected in the Kjeldahl nitrogen loads, which show much greater proportions relative to the nitrate loads at stations along the main River (Stations 245, 140, and 022). Inclusion of the Kjeldahl nitrogen load at Sycamore Grove accounts for the nitrate that was "lost" at that station. The far right column shows a total nitrogen load at each station, and is probably more reflective of the total amount of nitrogen released by the Watersheds above each point.

4.6.1.2 Nitrates from Various Land Uses

Nitrate inputs in localized areas can be measured in order to determine the magnitude of the contribution from particular land uses, particularly from wastewater disposal. HEA measured the increase in nitrogen loading along particular stream reaches, and compared that increase to the total amount of nitrate released by septic systems in the area (HEA, 1982). They concluded that in clay areas, nitrate only entered the streams from septic systems immediately adjacent to the streams. In areas underlain by sandy soils, a large proportion of the nitrate from all the septic systems in the basin reached the stream. They assumed there were no significant nitrogen sources other than wastewater in those areas.

HEA's Measurements were made twice, in October of 1981 and May of 1982. At all stations the contributions in October 1981 were less than half the amount of June 1982, when soils were much more saturated. The two measurements provide a range for the expected nitrate contributions. In areas with clay soils, nitrate in streams amounted to 4-25% of the nitrate produced by streamside septic systems and 1-4% of the nitrate from all the systems in the whole area drained by the creek. In a very sandy with highly permeable soils area, Quail Hollow, 25-70% of the nitrate produced by all the septic systems in the basin reached Newell Creek. The contribution was half of that in other sandy areas where the soil was less permeable and contained much more organic material, (Lockhart Gulch, Shingle Mill Creek, and a small creek in Mount Hermon). In Bull Creek, which drained a flat alluvial area in Felton, the nitrate load in the creek was equal to 2-35% of the load from streamside septic systems and 0.3-10% of the load from all systems in the basin.

As discussed in the groundwater section, it is likely that in residential areas there are sources of nitrate in addition to wastewater, such as fertilizers, which could increase the calculated nitrogen release to groundwater by 20-100% over the amount discharged from septic systems. Taking into account this nitrogen contribution from other sources, the amount of nitrate from septic systems which enters the creeks would be only 50-80% of the proportions calculated by HEA. With this adjustment, it would appear that in very sandy areas, 12-55% of the nitrate from septic effluent eventually reaches the creeks and in moderately-sandy soils 1-28% of the nitrate reaches the creeks. In some alluvial and clay soils the nitrate load seems to be more related to the number of systems adjacent to the creeks, with a contribution of 1-28% of the nitrate from those systems.

The low percentages of nitrate from septic systems that eventually reach streams indicate that there is significant removal of nitrate from septic effluent and other sources, even in sandy soils. This removal may take place in soil before the nitrate reaches groundwater and it is also likely that there is significant nitrogen assimilation by riparian vegetation and denitrification in the soil as groundwater flows through biologically active soil prior to discharge to the stream channel.

Currently there is not adequate data to accurately determine the extent to which other sources and land uses contribute nitrogen to surface water. In the above calculations, it was estimated in residential areas that septic systems produce 50-80% of the nitrate and other sources such as fertilizer contribute 20-50%. In areas with significant grazing and agriculture, the proportion of nitrate from non-wastewater sources would be much greater. Grazing, agriculture and past poultry-raising are probably primary sources in Branciforte Creek, which has high nitrate levels, but relatively low density of residential use, and occurrence of orchards and grazing areas. There are also significant grazing and stable areas in the Bean Creek Watershed and lower Zayante area. Bean Creek has also been impacted by past discharge of treated municipal wastewater to percolation pond near the creek, and an ongoing flow of nitrogen-rich groundwater from the Scotts Valley area.

4.6.1.3 Trends in Nitrate Levels

As would be expected with increasing development of the San Lorenzo Watershed, nitrate levels in the River and its tributaries have generally increased over the years. Mean nitrate levels measured during past studies at different stations are shown in Table 8. The historical low for the San Lorenzo River at Felton is a mean of 0.07 mg/l-N based on two samples each year from 1952 to 1962. During the 1963-64 study in which monthly samples were collected, mean nitrate levels along the full length of the River, including the headwaters, were between 0.14 and 0.19 mg/l-N. This might represent a more uniform background level for the River. Since the 1960's, nitrate levels in the River have increased by 2-3 times. Most of this seemed to occur in the late 1960's to mid 1970's. Since 1975, nitrate levels at Big Trees have not shown any statistically significant trend (See Figure 8).

The increase in nitrate concentrations in the River and its tributaries is closely related to increases in development. The period of the late 1960's to mid 1970's was the time when much of the shift from summer occupancy to year round residency occurred and a number of large subdivisions were developed. All of this development was served by septic systems, or sewers with in-basin effluent disposal. From 1960 to 1976 there was a 180% increase in the permanent population of the Watershed (S. C. County Planning Dept., 1979).

Figure 8: Trends in Nitrate Concentrations in the San Lorenzo River at Big Trees, 1975-88

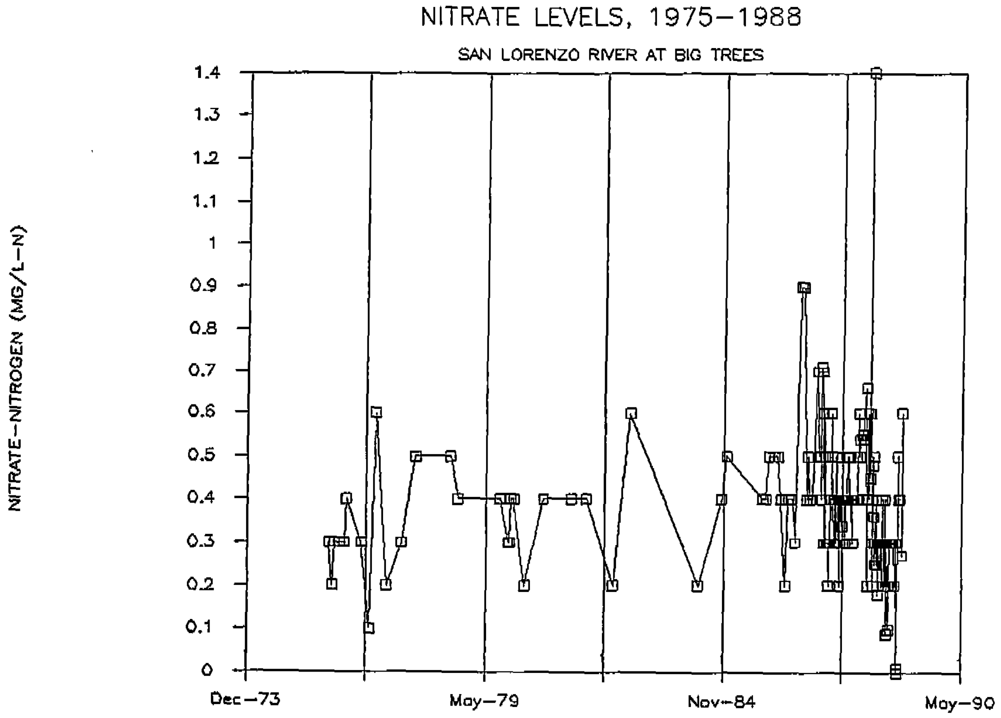


Table 7: Historical Nitrate Levels in Various Parts of the San Lorenzo Watershed, 1952-88

STATION NUMBER	LOCATION	MEAN NITRATE CONCENTRATION (MG/L-N)								
		1952-62 (DWR)	1963-64 (DWR)	1973-75 (USGS)	1975-79 (SCCPD)	1979-87 (SCCPD)	1981 (JMM)	1986 (SCCHSA)	1987 (SCCHSA)	1988 (SCCHSA)
349	SLR @ Waterman Gap		0.15	0.02	0.17	0.1	0.02	0.17	0.1	0.11
310	Kings Creek		0.13				0.1	0.27	0.22	0.32
289	SLR @ Brimblecom Rd.		0.19	0.02	0.17	0.08	0.04	0.22	0.16	0.14
271	Bear Creek		0.15	0.01	0.21	0.08	0.11	0.15	0.11	0.1
251	Boulder Creek @ SLR		0.15	0.11	0.53	0.31	0.29	0.42	0.58	0.58
245	SLR @ River Street					0.22	0.11	0.31	0.23	0.31
180	SLR @ Ben Lomond					0.08	0.07	0.27	0.2	0.23
140	SLR below Glen Arbor		0.19				0.37	0.46	0.48	0.45
0762	Upper Zayante Creek		0.17	0.14	0.28	0.38	0.09	0.22	0.18	0.21
07528	Lompico Creek		0.2	0.17			0.14	0.32	0.22	0.21
07109	Bean Cr @ Lockhart Gulch		0.48	0.42	0.82	0.78	0.83	0.61	0.93	0.72
070	Zayante Creek @ SLR		0.37	0.42			0.57	0.7	0.6	0.77
060	SLR @ Big Trees	0.07	0.14	0.25	0.34	0.39	0.36	0.48	0.42	0.39
022	SLR @ Sycamore Grove		0.15					0.32	0.27	0.35
0121	Branciforte Creek		0.66	0.64	0.41	0.17		0.43	0.17	
0111	Carbonera Cr @ Santa Cruz		0.44	1	1.42	0.78		1.13	1.13	

SOURCES OF DATA

DWR	California Department of Water Resources, 1966
USGS	U.S. Geological Survey, Sylvester and Covay, 1978
SCCPD	Santa Cruz County Planning Dept., 1979
JMM	James M. Montgomery Engineers, 1982
SCCHSA	Santa Cruz County Health Services Agency

Much of the growth occurred in sub-basins which now show elevated nitrate levels. From 1970 to 1976, the increase in population in the overall Watershed was 19%. In the Bear Creek, Boulder Creek, Newell Creek, and Zayante Creek sub-basins, the population increase was 33.5%, 32.6%, 90.5%, and 39.7%, respectively (Ibid). With the exception of Bear Creek, all these basins have highly permeable soils with reduced capacity for nitrogen treatment. The dramatic increase in nitrate levels for these three areas during that period is clear in Table 8. (The impacts of Newell Creek are indicated at the San Lorenzo River at Mount Cross (Station 140).) Most of the other streams have not shown a great increase in nitrate levels. This is probably due to better removal of nitrate in clay soils, and more moderate levels of development.

Prior to the impacts of the 1970's, lower Zayante, Bean, Branciforte and Carbonera Creeks historically had nitrate levels much higher than the rest of the Watershed. This is probably related to grazing use, limited agricultural use, and permeable soils in many of the areas, with elevated natural background nitrate levels. Branciforte has actually experienced some decline in nitrate levels, which may result from the decline of agricultural use that has occurred.

4.6.2 Impacts on the Stream Ecosystem

It is clear that there have been significant increases in nitrate in the River and its tributaries at least as far north as Boulder Creek. This increase might be expected to result in impacts on the stream ecosystem and related beneficial uses. Nitrate can have an effect on many components of the ecosystem. In order to evaluate this, it is necessary to provide some discussion of the elements of the ecosystem and how they are related.

The stream ecosystem includes several classes of organisms of immediate concern. Macro-algae are the types of algae which are readily visible in waterways and form the long strands, beds, or mats which can be unsightly and cause nuisance conditions for recreation. Periphyton refers to the assemblage of organisms, primarily micro-algae (including diatoms, green algae, and blue-green algae), which attach to the surface of rocks or other substrates in the stream. Plankton are free-floating organisms, and often include organisms sloughed off from periphyton or macro-algae. Another class of organism, the heterotrophs, include fungi, bacteria, and molds which decompose organic material in the stream.

As plants, all classes of algae require nutrients, including nitrate, for growth. Activity of heterotrophs is also increased by nutrients, which enrich the organic material upon which the heterotrophs feed. Algae and heterotrophs are fed on by insects and other higher organisms, which in turn are fed on by fish. Generally the more algae production in a stream, the more food there is available for higher organisms.

Although the algae species release oxygen into the water during daylight hours through the process of photosynthesis, all organisms consume oxygen from the water during nighttime hours. The decomposition of dead algae also removes oxygen from the stream environment and releases nutrients to the water. In a stream, oxygen is usually readily replenished from the atmosphere by the turbulence of the stream. However, if oxygen is severely depleted by excessive biological activity, it can lead to the death of fish and other organisms. Algae and heterotrophs release organic compounds to the water which can give it unpleasant taste and odor. This is usually worse when organisms are dying and decomposing.

The discharge of nutrients or organic wastes to an aquatic system is termed enrichment, and usually results in an increase in biological activity, if other conditions are suitable. Excessive enrichment and increase in biological productivity is known as eutrophication, and frequently results in depletion of dissolved oxygen, changes in the types of organisms present, and reduction in the overall diversity of organisms.

Nitrate and phosphate are the primary nutrients that are necessary for biological growth in the aquatic environment. Because phosphate concentrations are naturally high in the San Lorenzo Watershed, nitrate is the limiting nutrient for growth (S.C. County Planning Dept, 1979). However, there are also other factors which can limit or promote growth: type of substrate, flow velocity, availability of sunlight, water temperature, availability of micro-nutrients, and presence of "grazing" organisms. The algae also show seasonality in their growth and reproductive cycles. These factors all work in combination, and it may be difficult, and somewhat oversimplified, to isolate the effect of one factor. Nevertheless, it would be expected that an increased level of nitrate in the San Lorenzo River would be expected to increase biological activity, if other factors are also suitable.

Nutrient enrichment, resulting in an increase in biological activity in a stream, can have adverse effects on the stream ecosystem, recreation, and water supply. These impacts can be caused by excessive nuisance algae growth, depletion of dissolved oxygen, and release of compounds by organisms which cause undesirable taste and odor in drinking water. There has been no documentation of serious oxygen depletion in the San Lorenzo and documentation of recreation impacts has been inconclusive. However, the City of Santa Cruz Water Department has definitely experienced periodic taste and odor problems from the River, as will be discussed at greater length.

In order to determine the potential impact of nitrate increases on the aquatic ecosystem and its dependent beneficial uses, a number of studies have been made in the San Lorenzo Watershed to study algal growth, the factors which affect algal growth, and the resultant impacts on water quality. The most extensive studies have been conducted by the County as a part of its San Lorenzo Wastewater Management Program. The following subsections will summarize past studies, discuss the findings of ongoing work, and conclude with a discussion of an appropriate water quality objective for nitrate in the San Lorenzo River.

4.6.2.1 Past Studies

Potential stimulation of nuisance biological growth has been addressed at least to some extent in most of the past water quality studies conducted in the Watershed. In 1964, the State Department of Water Resources (DWR) identified as an "existing and/or potential problem .... aquatic growths fed by nutrients which result from surface runoff, recreational activities, and waste disposal" (DWR, 1966). At that time DWR noted that occasional high nutrient concentrations resulted as much from natural sources as from human activities. It was also stated that recreational impoundments slowed the flow down, resulting in conditions that promoted the growth of algae and aquatic weeds.

In 1973-75, the U.S. Geological Survey conducted an investigation of water quality in the San Lorenzo Watershed (Sylvester and Covay, 1978). Although relatively high levels of nitrogen were noted at some stations, no "harmful effects such as nuisance algal growth" were noted. USGS also conducted a diurnal study on the River at Big Trees and Waterman Gap in October 1975, to determine if there was any serious depletion of dissolved oxygen at night, which would result from presence of oxygen-demanding wastes or excessive biological activity. Nighttime oxygen levels were depressed slightly more at the Big Trees station (8.2mg/l) than the Waterman Gap station (9.0 mg/l), but did not drop below the water quality objective of 85% saturation. They concluded that there was no significant oxygen depletion, particularly in comparison to natural conditions at the Waterman Gap station.

In 1977-78, the Santa Cruz County Planning Department (Office of Watershed Management) conducted a fairly comprehensive assessment of algal growth and water quality as a part of preparation of a Watershed management plan for the San Lorenzo River (Butler, 1978). Work included investigation of macro-algae, periphyton, and plankton at five stations during and after the 1975-77 drought. Species composition, diversity, and abundance of growth were measured. A diurnal study in August 1977 was also conducted at three stations.

The study concluded that there was evidence of moderate nutrient enrichment, with the amount of nitrate and algal growth increasing in a downstream direction to Big Trees. Both algae and nitrate concentrations were lower at Sycamore Grove, indicating less enriched conditions brought about by natural instream treatment below Big Trees. Species composition and diversity were indicative of enriched conditions at Ben Lomond and Boulder Creek during the extreme drought period. During this period, nighttime dissolved oxygen levels above Boulder Creek were found to drop to 5.5 mg/l. The study also found that algae growth was significantly affected by light and flow conditions, with very different algal growth the summer following the drought. The study indicated that the density of algae growth was not generally abnormal, but localized dense populations occurred in some areas. Algae growth was not causing serious adverse impacts to the aquatic ecosystem. Results of this study may be somewhat anomalous, as affected by the drought, but there were many findings that are of use in interpreting data from follow-up studies in 1987-89.

In 1983, an assessment of fishery habitat in the San Lorenzo River and tributaries was made as a part of evaluating the potential environmental impact of a proposal to sewer areas of the Valley (Harvey and Stanley Associates, 1984). This study concluded that water quality changes resulting from wastewater disposal were not having an adverse impact on the fishery. It was pointed out that increased algae growth increased the numbers of insects, promoting growth of juvenile fish.

In 1986, an investigator working with the County compiled records of taste and odor problems experienced by the City of Santa Cruz in water diverted from the San Lorenzo River (Mendenhall, 1986). Diversion of San Lorenzo River water from the Tait Street diversion at the Santa Cruz City boundary provides about 30-40% of the City's total supply. Prior to 1983, there had been occasional instances of taste and odor problems, but these were sporadic and easily treated. In fall of 1983, these became persistent and almost untreatable. From 1983 through 1986 preventative treatment was regularly used from May to November of each year. 1986 was another very bad year, but since then, the tastes and odors have dropped below problematic levels. Costs of chemicals for treatment of the odor problem for the worst years ranged from $33,000 to $50,000 per year.

In problem years, the taste and odor problems would typically begin at low levels in May through July, and then rise dramatically in August or September and stay high through October or November, until the first big flushing storm of the season occurred, after which the problem would cease until the next spring. The problem odors include a wide range of odors, indicating that a number of different organisms were contributing to the problem. The odors could originate from both algae and heterotrophs. A number of different species which can contribute to taste and odor problems have been identified in the River (Mendenhall, 1986). Increased nitrate concentrations alone cannot readily explain the taste and odors, as the onset of the problem had no relationship to any change in nitrate levels. Following the 1982 and 1983 floods, the channel scour and increased light reaching the channel may have resulted in growth of nuisance organisms. Another bad year was 1986, which was also a much wetter year than normal. During the relatively dry years since then, there has not been as much problem, but the City still needs to treat to remove taste and odors on a regular basis in the summer months (Terry Tompkins, S.C. Water Dept, personal communication, 1989).

4.6.2.2 Current Studies

In 1986, the County Health Services Agency began a program to qualitatively describe algae growth at some of the stations in the San Lorenzo Watershed. Factors such as substrate type, shading, extent of bottom coverage by macro-algae, and average length of algae strands were recorded every other month in the spring and summer of 1986.

In 1987, the assessments became more detailed and assistance in water quality analysis was provided by the Regional Board. Algae species were identified and artificial substrates were used to monitor the amount of growth of micro-algae and the types of micro-algae present. The artificial substrates consisted of frosted microscope slides attached to bricks, which were observed every two weeks. Water quality analyses included nitrate, nitrite, ammonia, Kjeldahl nitrogen, phosphate, potassium, silica, sulfate, alkalinity, hardness, pH, dissolved oxygen, turbidity, and temperature. Thirteen locations were evaluated eight times during the summer. At most locations, both riffle areas (with fast-flowing water) and glide areas (with still or slow-moving water) were evaluated. Most of this work was continued in the late summer of 1988, and is ongoing in 1989. Over 300 observation of algae growth have been made.

The findings of the County's work are summarized by station in Table 9. Figure 9 shows the variation in growth factors over time for the San Lorenzo River at Big Trees and at Sycamore Grove. In order to help determine the effect of some of the factors on algae growth, correlation and regression analyses were done for data from individual stations and also for the mean values of the stations as they related to each other. The results of those analyses and other observations are discussed in the following sub-sections on seasonal fluctuations and the effect of various controlling factors and algae growth. This is concluded by a section analyzing the impacts of algae growth on beneficial uses.

4.6.2.3 Seasonal Fluctuations

Algae growth tends to follow a distinct seasonal or cyclic pattern. The extent of algae growth has been measured in four ways: the percent bottom cover by macro-algae, the average length of algae strands, the number of micro-algae organisms growing on artificial substrates, and the concentration in the water of ***chlorophyll a***, a compound present in living algae tissue. Although the available data is somewhat scattered, the seasonal patterns are apparent in Figure 9. There is also quite a bit of variability in the seasonal patterns from year to year, depending on the specific climatic conditions that prevail. The general pattern can be summarized as follows.

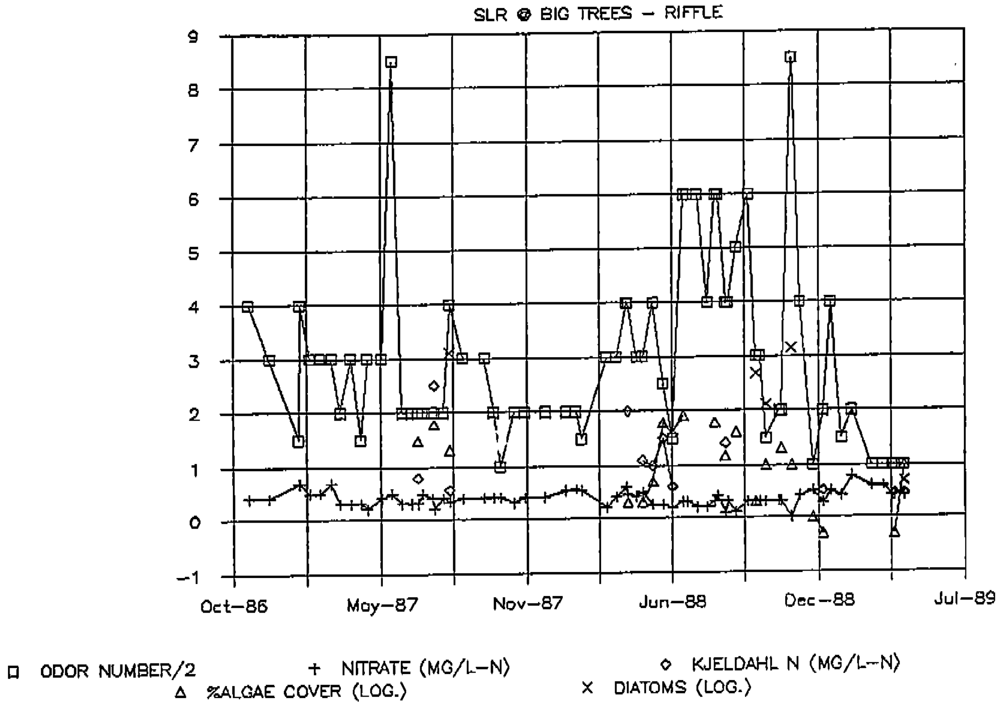
Table 9: Summary of Algae Growth and Related Factors, 1986-89

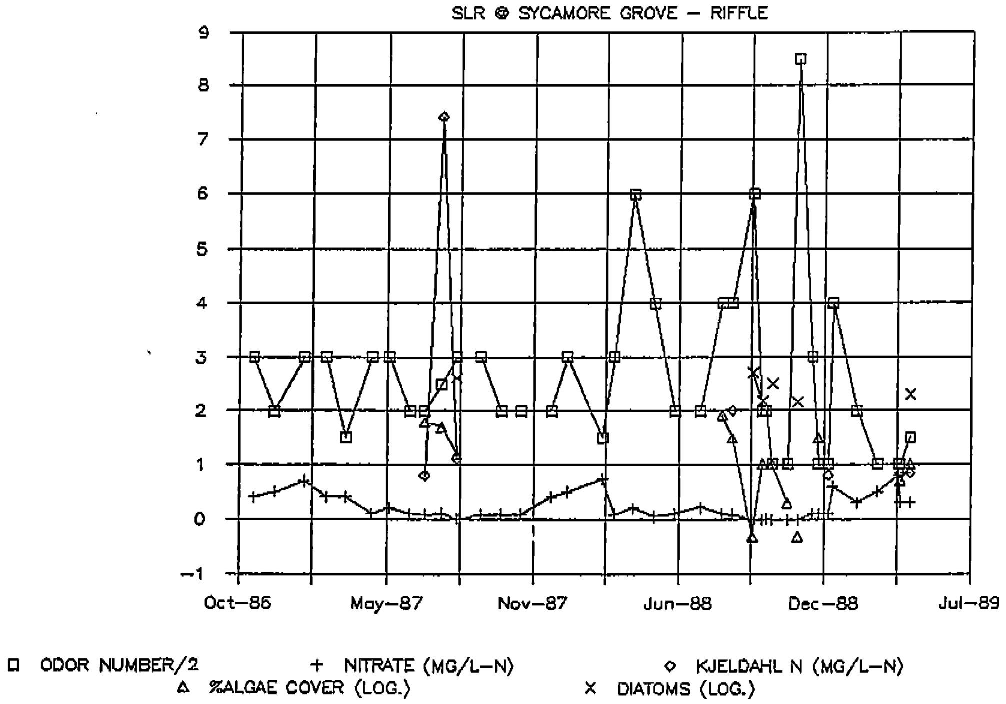
STATION	SAMPLE AREA	PERCENT SHADED	MEAN TEMPER-ATURE (C)	PERCENT SAND ON BOTTOM	MEAN pH	MEAN NITROGEN MG/L-N NITRATE/ KJELDAHL	MEAN TOTAL PHOSPHATE MG/L-P	MEAN NUMBER OF DIATOMS ON ARTFICIAL SUBSTRATE	MEAN CHLORO-PHYLL-A MG/L	PERCENT BOTTOM COVER BY ALGAE MEAN/ MAXIMUM	LENGTH OF ALGAE STRANDS MEAN/ MAXIMUM
SLR @ WATERMAN GAP	GLIDE	90	13.52	0	8.05	.12 .84	.85	118	1.05	16 80.0	.72 4.00
	RIFFLE	90	13.65	0	8.07	.12 .82	.85	164	1.05	14 80.0	1.99 12.00
SLR BELOW TWO BAR CR	GLIDE	90	17.83	30	8.00	.04 .85	.43	63	1.43	14 30.0	.45 1.00
	RIFFLE	90	17.67	25	8.00	.04 .85	.43	47	1.43	12 20.0	2.15 6.00
UPPER BOULDER CR	GLIDE	80	15.83	0	7.97	.10 .68	.32	23	2.12	5 10.0	.17 .50
BOULDER CR @ SLR	GLIDE	30	15.69	0	8.15	.65 .73	.59	1472	3.32	22 60.0	2.66 10.00
	RIFFLE	30	13.92	0	8.17	.63 .78	.59	2280	3.32	23 90.0	1.91 6.00
SLR @ RIVER ST.	GLIDE	70	16.64	0	7.98	.25 1.18	.38	294	1.85	36 100.0	1.34 5.00
	RIFFLE	60	16.08	0	8.02	.31 1.02	.38	392	1.85	22 70.0	1.00 4.00
SLR @ BROOKDALE	GLIDE	30	17.28	45	8.00	.17 1.05	.72	308	3.80	20 70.0	.98 3.00
	RIFFLE	50	15.30	0	7.98	.20 1.03	.72	285	3.80	18 60.0	.83 6.00
SLR ABOVE NEWELL CR	GLIDE	10	19.58	80	8.04	.28 1.03	.45	585	14.57	55 90.0	3.06 8.00
NEWELL CR BELOW DAM	GLIDE	80	14.43	5	8.07	.07 .49	.26	29	2.93	17 20.0	.23 .50
	RIFFLE	80	14.57	5	8.07	.07 .49	.26	19	2.93	14 20.0	.10 .10
SLR BELOW NEWELL CR	GLIDE	10	17.70	0	7.82	.48 2.23	.80	879	8.57	34 90.0	.86 3.00

Table 9: (Continued) Summary of Algae Growth and Related Factors, 1986-89

STATION	SAMPLE AREA	PERCENT SHADED	MEAN TEMPER-ATURE (C)	PERCENT SAND ON BOTTOM	MEAN pH	MEAN NITROGEN MG/L-N NITRATE/ KJELDAHL	MEAN TOTAL PHOSPHATE MG/L-P	MEAN NUMBER OF DIATOMS ON ARTFICIAL SUBSTRATE	MEAN CHLORO-PHYLL-A MG/L	PERCENT BOTTOM COVER BY ALGAE MEAN/ MAXIMUM	LENGTH OF ALGAE STRANDS MEAN/ MAXIMUM
SLR BELOW NEWELL CR	RIFFLE	10	18.19	0	7.91	.41 1.56	.80	984	8.57	38 80.0	1.04 4.00
FALL CR	GLIDE	90	14.90	0	8.27	.04 .51	.21	50	.57	4 5.0	.10 .10
	RIFFLE	90	15.23	0	8.27	.04 .51	.21	46	.57	5 10.0	2.07 6.00
ZAYANTE CR AB ZAYANTE	GLIDE	80	15.57	50	8.10	.06 .85	.71	79	2.03	7 10.0	1.00 2.00
	RIFFLE	90	15.70	20	8.07	.06 .85	.71	318	2.03	15 25.0	1.73 5.00
ZAYANTE CR @ ZAYANTE	GLIDE	.	14.54	.	8.00	.16 .30	.	419	.	38 90.0	4.30 12.00
	RIFFLE	.	13.71	.	7.98	.19 .55	.	397	.	39 90.0	2.95 12.00
ZAYANTE CR @ SLR	GLIDE	60	16.62	80	8.17	.61 1.15	1.47	773	3.23	7 20.0	.75 2.00
	RIFFLE	60	16.10	50	8.14	.63 1.18	1.47	1278	3.23	9 60.0	.62 4.00
SLR @ BIG TREES	GLIDE	30	17.77	20	7.99	.29 1.08	1.09	475	6.13	24 80.0	.50 1.00
	RIFFLE	75	16.22	0	8.00	.33 1.07	1.09	617	6.13	22 80.0	.51 2.00
SLR @ PARADISE PARK	GLIDE	50	18.80	60	8.03	.04 2.11	.47	362	9.33	18 25.0	.28 .50
	RIFFLE	50	18.57	10	8.03	.04 2.11	.47	1390	9.33	23 30.0	.50 .50
SLR @ SYCAMORE GROVE	GLIDE	30	18.26	75	8.17	.13 1.78	.51	237	5.97	35 90.0	.73 4.00
	RIFFLE	30	17.13	0	8.14	.14 1.97	.51	284	5.97	22 80.0	1.19 10.00

Figure 9: Fluctuations in Nitrate, Algae Growth, and related Factors in the San Lorenzo River at Big Trees and at Sycamore Grove, 1986-89





During the winter, there tends to be little algae growth. It is probably limited by a combination of low stream temperatures, scouring storm flows, and high turbidity, which reduces light penetration. However, in mild winters, such as 1988-89, there may be moderate algae growth during much of the winter. In early spring, after the storms have ended and water temperature begins to increase, growth of macro-algae begins to increase significantly. This can readily be seen at Big Trees in May-June, 1988. Spring algae growth absorbs nitrate and is accompanied by a drop in nitrate concentrations at downstream stations, as can be seen in March-April 1987, March 1988, and February-March 1989 at Sycamore Grove. Many of the stations show an inverse correlation between percent bottom cover by algae and nitrate (correlation coefficient of -.92 to -.98). There is also an inverse correlation of temperature to nitrate (-.92 to -.96).

After a peak in bottom coverage by macro-algae in early summer, the coverage begins to decline. This can happen fairly abruptly, or more gradually. At times during the summer, the cover may increase again, but not to the same extent. Most of the macro-algae disappears by August, when it is replaced by a Lemna, a small vascular plant which floats on top of the water in large concentrations. The Lemna are typically flushed out of the River system by December, when macro-algae begins to re-emerge, if flow levels are not too high.

The primary type of macro-algae present at all stations from 1985-89 was Cladaphora. Other types which were present in more limited amounts were Spyrogyra, Mougeotia, Vaucheria, Ulothrix, Rhizoclonium, and Tribonema. During the study in 1977, during the drought, the predominant algae type had been Spyrogyra, which tends to prefer slow-moving water. In 1978, after a relatively wet winter, Cladaphora was the dominant type, as it has been in subsequent years. It would appear that 1977 was an atypical year, with stream conditions and resultant algae growth quite different from normal conditions.

Patterns of micro-algae growth generally paralleled the seasonal cycle of macro-algae growth, although the data for micro-algae is much less complete. Diatoms were very much the predominant type of micro-algae present on the artificial substrates, with limited presence of green algae, and very limited occurrence of blue-green algae at a few stations. Major types included: Closterium, Anabena, Pediastrum, Oscillatoria, and Enteromorpha.

Presence of phytoplankton (free-floating algae) was assessed by measurement of *chlorophyll a*, although only three measurements were made at each station in 1987. Several of the stations show a strong inverse relationship between *chlorophyll a* and nitrate (correlation coefficient of -.97), suggesting that phytoplankton activity contributes to nitrate removal in those areas. In the San Lorenzo, much of the phytoplankton consists of algae types that occur as periphyton or macro-algae, and have been broken off or washed off into the flowing water (Butler, 1978).

4.6.2.4 Controlling Factors

In order to evaluate the potential effects of increased nitrate concentrations on algae growth, it is necessary to be aware of the effects of other factors which may be operating in conjunction with nitrate levels. The main factors expected to affect relative growth of algae at different locations in the San Lorenzo Watershed are flow velocity, substrate, water temperature, presence of light, stream chemistry (pH), and availability of nitrate. Observations of seasonal fluctuations provide an indication of the operation of those factors. Additional information is provided by a comparison of growth from station to station. In the San Lorenzo Watershed, all of these factors seem to play a role to some extent. Other factors which did not appear to have a significant differential effect are variations in dissolved minerals, phosphate, micro-nutrients and consumption by insect larvae and other animals, although the latter may have an effect at certain times of the year.

The effect of streamflow velocity can be seen in the difference between the slow-moving glide areas and the fast-flowing riffle areas. Micro-algae growth is generally 30-40% higher in the riffle areas. The increased flow of water makes nutrients relatively more available, because they are continually being replenished. The percentage of bottom cover by macro-algae growth was somewhat greater in most of the glide areas compared to the riffle areas. In much of the main River channel, glide areas are much more extensive than riffle areas and algae growth in the glides seems to significantly reduce nitrate levels and increase *chlorophyll a* levels, as indicated by correlation analyses for the glide areas. Flow conditions can also have an effect on the occurrence of certain types of macro-algae as shown by the replacement of Spyrogyra by Cladaphora in 1978 after flow levels increased to more normal levels.

Both macro algae and periphyton need a solid substrate for attachment, particularly in riffle areas. Although the amount of sand did not show an independent, direct relationship to macro algae bottom cover, when it was included with shade, temperature, pH, and nitrate in a multiple regression analysis of bottom cover, the amount of sand present on the bottom did show a significant negative influence on the amount of algae growth. Based on the regression equation The amount of sand present at different stations, varying from 0 to 50%, accounted for a 30% difference in mean macro-algae bottom coverage.

Water temperature had a marked relationship to algae growth. If factors were compared over time, at many of the stations temperature was positively correlated with bottom cover by algae (correlation coefficient of .95), number of diatoms (.87), and *chlorophyll a* (.87). Temperature was inversely correlated with nitrate at many stations (-.92), indicating that nitrate was being taken up at the same time temperature was increasing. When mean conditions were compared at different stations, temperature was correlated to both Kjeldahl nitrogen and *chlorophyll a*. Mean temperature also had a significant positive effect on mean bottom cover in a multiple regression analysis which included pH, sand and nitrate. It is not clear whether temperature directly stimulates algae growth, or whether higher temperatures parallel other factors such as light and other seasonal influences on algae growth. Disappearance of algae has been observed after the occurrence of very cold winter temperatures (4 degrees C.). High temperatures and light can eventually reduce algae cover by stimulating algae die-off (Butler, 1978), as has been observed several times in the San Lorenzo River.

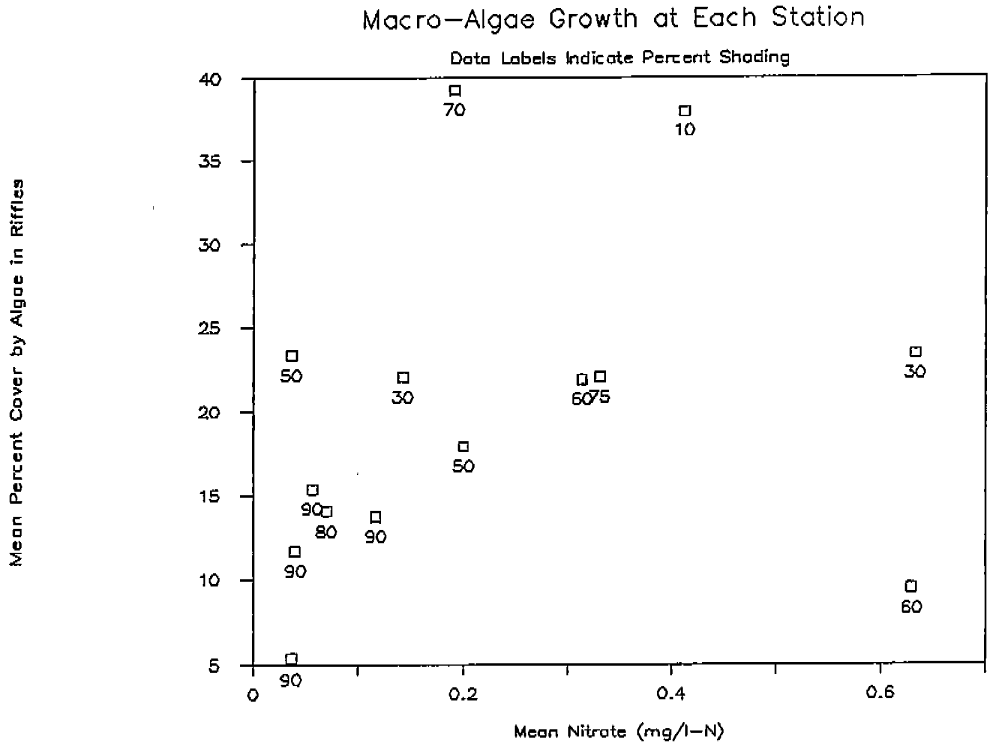
The amount of light reaching the stream has a very strong effect on the growth of algae. Like all plants, algae need light for photosynthesis. Stations were selected to provide a variety of light conditions so that the relative effect of light could be assessed. For each station, the percent of shading by surrounding vegetation was determined in the summer. The relative difference in shading from station to station was assumed to be constant for the study period. When the stations are compared, the amount of shading is the only factor which directly correlates with the amount of bottom cover by algae (correlation coefficient of -.80 in riffle areas -.72 in glide areas). The most significant multiple regression equation analyzing factors which influence mean bottom cover identified the major factors as shading, percent sand on the bottom, and mean pH. (The equation has an r2 value of .88, with a significance of .0002.) Shading accounted for 50% of the variation in bottom cover. Shading in glide areas also has a significant inverse correlation with green algae growth (-.80), diatom growth (-.67), and *chlorophyll a* (-.79).

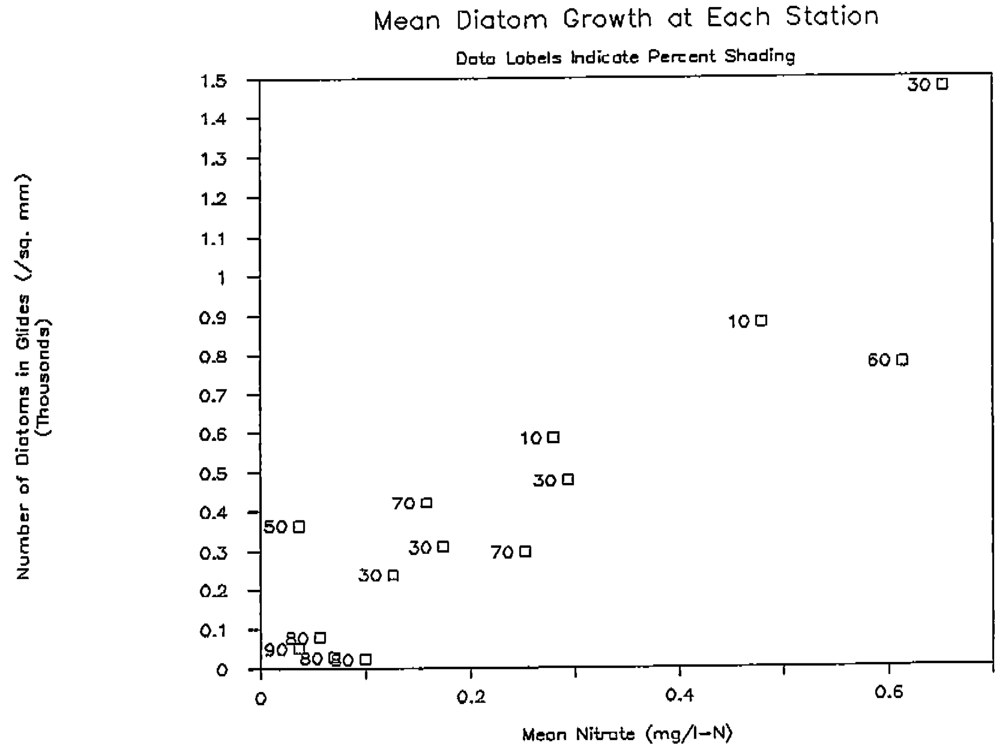
The effect of nitrate on algae growth is the factor of most concern in this study. Statistical analysis of data in the San Lorenzo Watershed indicate that nitrate concentration has a very significant effect on growth of attached micro-algae, and less effect on macro-algae. A comparison of stations shows a significant correlation between mean nitrate concentration and mean number of diatoms (correlation coefficient of .91 in glides and .73 in riffles). A multiple linear regression analysis indicated that mean diatom growth in glides was strongly affected by mean nitrate and shading (r2=.77, significance=.0001). Differences in nitrate concentration accounted for 60% of the explained variation in diatom growth and differences in shading accounted for 40% of the variation.

There was not a significant direct correlation between mean nitrate and bottom cover by macro-algae. However, when nitrate was included as a factor in a multiple regression analysis with the other factors of sand, shading, temperature, and pH, the analysis showed that variations in mean nitrate concentrations accounted for 10-20% of the variation in mean bottom cover from station to station. The effects of nitrate and shading on diatom and algae growth are shown in Figure 10, which plots mean algae growth against mean nitrate concentration, and also shows mean shading next to each data point.

The relative independence of macro-algae growth and nitrate concentration is indicated by the moderately-heavy growth of algae at the stations on Zayante Creek at Zayante and on the San Lorenzo River at Waterman Gap, which are located in the headwaters and generally uninfluenced by development. Although these stations have the lowest mean nitrate levels of any station (0.16 and .12 mg/l-N), they both had very significant mean bottom coverage by algae (38% and 16%, respectively). At times both stations had 80-90% bottom coverage with strands 3-12 inches long. In the case of macro-algae, it would appear that they are efficient in utilizing nitrate, even at very low concentrations, and that light and substrate have a much greater effect on the amount of macro-algae growth.

Figure 10: **Influence of Mean Nitrate Concentration and Shading on Mean Macro-Algae Growth and Diatom Growth at Different Stations**





4.6.2.5 Impacts on Beneficial Uses

Excessive algae growth can affect stream-based recreation by its impact on either the visual or olfactory senses. "Sliminess" of the stream bottom resulting from algae growth can also create unsafe conditions. There is no easy quantitative measure of the impact on aesthetics or stream recreation resulting from algae growth, as the severity of the impact from algae is more of a subjective determination based on the individual user's attitudes. This judgement would be based on the extent to which the area was covered by macro-algae, the extent to which "slimy" periphyton covered the rocks, and the degree of senescence (decomposition) of the macro-algae. When algae decomposes it turns dark and slimy and can emit a strong odor. During the several week period during mid to late summer, when this typically occurs in the River, recreational use could be significantly limited in areas that had significant algae growth.

There has been no documentation of historical loss of recreation due to algae growth in the San Lorenzo River, although this is mentioned as a potential problem in 1964 (DWR, 1966) and in 1978 (Santa Cruz County Planning Dept., 1979). To the extent that macro-algae growth is only moderately affected by nitrate concentrations, it would also seem that potential impacts on recreation are only moderately related to nitrate concentrations.

The impact of algae growth on taste and odor in water supply for the City of Santa Cruz has been well-documented. In the years prior to 1987, the impact was measured by the amount of chemicals required to treat the water and remove the odor. Since October of 1986, the City has analyzed the water for odor, and calculated a "threshold odor number" twice a month. These values for the River at Big Trees and Sycamore Grove are plotted on Figure 9. Odor data has been analyzed to try to determine statistically significant relationships between the odor problem and characteristics of algae growth.

Odors can come from algae growth, algae decomposition, growth of fungi such as actinomycetes, or wash-off of material from the Watershed during storm events. Many of the algae which are present in the River are known to produce compounds with distinct odors (Mendenhall, 1986). Because there are a variety of the odors in the River at different times, it appears that the odors may originate from a variety of sources which may be active at different times of the year.

The worst odors generally occur in late summer, and are probably related to algae decomposition. High odor levels for both Big Trees and Sycamore Grove correspond to periods of declining algae bottom cover in September of 1988. This would correspond with the times of worst odor in other years, usually August and September. Both stations also show a brief, but significant increase in odor in April 1988. Although there were no quantitative measurements of algae growth during that period, observations made during the regular monitoring program indicate a short period of algae growth followed by widespread die-off at all stations at that time. This period was preceded by a marked drop in nitrate at both stations, indicating uptake by algae.

Based on a limited number of observations, there were significant correlations between the odor number and the amount of green algae at Big Trees (coefficient of .94) and between odor and *chlorophyll a* (.99). Regression analyses produced inconclusive information, but suggested that odor numbers at Sycamore Grove increased with declining nitrate concentrations and increased length of algae strands ($r2=.65$, significance=.0011).

Although the quantitative analysis of the causes of the odor problem are inconclusive at this time, it is apparent that there is a strong relationship to algae growth and die-off. It should be noted that during the past 2 years, when odor numbers have been determined, and when most of the algae measurements have been done, there have not been significant odor problems, relative to prior years. The years in which the problems have been the worst, 1983 and 1986, have been wet years. This may have caused more scour and disruption of the algal community and it may also have caused more incidence of light resulting from erosion of riparian vegetation by high winter flows. Based on the work done to date, increased light would be expected to result in much greater amounts of algae growth. More work will be needed to fully assess the causes of the odor problems, and the extent to which nitrate levels may affect them.

In addition to taste and odor problems, algae growth and die-off also leads to the release of organic compounds to the water. When water rich in organic material is disinfected for water supply by the addition of chlorine, it results in the formation of trihalomethanes (THMs), a group of carcinogenic compounds. The City water supply currently meets the drinking water standards for THMs, but these standards are expected to be made more stringent by the EPA. Depending on what the ultimate standard is, the City may have difficulty achieving compliance without pursuing a different method of treatment. THMs are currently much higher in water from the San Lorenzo River, than in water taken from the City's north coast stream sources. The north coast streams are subject to little or no algae growth, probably as a result of heavy shading of the stream channels. (Nitrate levels there are similar to those found in the San Lorenzo River.) Depending on the future standard for THMs, release of THM precursors by algae may become a more serious problem than the taste and odors.

Based on the discussion above, at this time it appears that the impacts on beneficial uses of the River which result from algae growth are low to moderate, but with some potential to become more significant, depending on the levels of trihalomethanes that are determined to be safe. It is likely that these impacts of algae growth have been increased to some extent by increased nitrate levels, although other factors appear to be more influential. While it cannot be quantified at this time, it would be expected that further increases in nitrates would cause these potential problems to worsen.

4.6.3 Nitrate Objective for the San Lorenzo River

From the preceding discussions, it is clear that increased levels of nitrate in surface water could be expected to result in greater amounts of algae growth, with potential adverse impacts on beneficial uses. In order to reduce or prevent such impacts, the Regional Board is required by State law to establish a water quality objective for nitrate, which is then used as a guideline to determine appropriate approaches for management of existing and future land uses and waste disposal practices. State law also requires that the objective be based on past, present and probable uses of the water;

environmental characteristics of the area; water quality conditions that could reasonably be achieved through appropriate management measures; economic considerations; and the need to develop housing in the area (Regional Board, 1982).

The Regional Board's Basin Plan contains general objectives which apply to all streams in the Central Coast Basin which support particular beneficial uses. It also includes specific objectives for individual streams based on the unique conditions and uses of those streams. The Plan contained two general objectives for total nitrogen, which were set at levels to prevent impacts from excessive algae growth: 0.5 mg/l-N for recreation waters, and 1.0 mg/l-N for spawning or coldwater fish habitat. Because of concern that there were problems of excessive algal growth in the San Lorenzo, even though the nitrate levels were in compliance with the general objectives for nitrogen, the Regional Board in 1982 adopted a more specific objective for nitrate in the San Lorenzo River.

In adopting the specific objective, it was desired to determine a nitrate level which was below the threshold for algae growth, and which was attainable (Jagger and Van Voris, 1981). However, at that time there was little information available relating algae growth to nitrate. A recommended objective was derived from historical nitrate levels in the 1950's, which were presumed to be at the natural background level. A nitrate objective of 0.25 mg/l (measured as nitrate) was adopted. This is equivalent to 0.06 mg/l-N (measured as nitrogen). Although this objective was well below prevailing nitrate levels at the time, it was believed that the objective could be attained through erosion control, upgrade of septic systems, and the expected installation of sewage collection and treatment facilities in certain areas.

Since the adoption of the nitrate objective, substantial work has been done to evaluate the factors affecting algae growth, the severity of resulting impacts on beneficial uses, and the effectiveness of various control measures to reduce nitrate levels in Watershed streams. It does not now appear that the specific objective for the San Lorenzo River is reasonable. In 1986, and again in 1988, the Regional Board directed their staff to reevaluate the objective. The findings of the County's current study can contribute information pertinent to that evaluation.

The conclusion that excessive algae growth was reaching nuisance conditions at the current nitrate levels was based on the findings of the 1977-78 algae study for the San Lorenzo Watershed Management Plan (SC County Planning Dept., 1979). As discussed in a previous section, that study indicated moderately excessive growth at two sites above Ben Lomond and above Boulder Creek. Other areas of the River and the Watershed did not have abnormal algae growth (Butler, 1978). The study concluded that the River was at a threshold condition, that increased nitrate and algae growth could result in much more severe impacts. Much of the work was carried out during the 1977 drought, a time when stream conditions and resultant algae growth was significantly abnormal. Conditions at that time might be considered to be worse than normal, but still indicative of potential problems.

Current work during the last three years has confirmed that increased nitrate does contribute to increased micro-algae growth, and to a more limited extent contributes to macro-algae growth. Although nitrate has a measurable influence on macro-algae growth, the presence of light and suitable substrate seems to be much more important, and high volumes of growth can occur even in undisturbed, low-nitrate headwater areas. Studies in the 1960's noted algae growth in bathing areas that was probably as much from natural as human-induced causes (DWR, 1966). Seasonal variations in nitrate levels, Kjeldahl nitrogen levels, algae growth, and odor levels indicate that there are many factors at work in addition to nitrate concentration.

The work that has been done during the past two years does not seem to provide any indication that there is a "threshold" level of nitrate for the San Lorenzo River, above which excessive algae growth will occur. At the nitrate levels which currently prevail, there appears to be more of a linear relationship between nitrate and algae growth: algae growth will increase in some proportion to an increase in nitrate. It is possible that there may be a threshold concentration which is higher than the prevailing levels that have occurred during these studies. Higher nitrate levels than currently experienced might result in a stronger influence on algae growth than the current studies have indicated. Other studies have found that significant increases of algal growth occurred above nitrate levels of 0.2-1.0 mg/l-N, depending on the study (Mendenhall, 1986). More work will be done on this.

Despite some of these uncertainties regarding the magnitude of the impact from increasing nitrate, it is clear that increased nitrate does result in increased algae growth, and that it is desirable to prevent significant increase in nitrate release from human activities, and to reduce the existing release to the extent that is reasonable. However, it is very unlikely that the current objective could be met without exporting all sewage from the

Watershed, prohibiting the keeping of grazing animals, and limiting the use of fertilizers.

Because the severity of existing problems does not seem to justify such extreme measures, a more reasonable approach would be to regulate new land uses to prevent significant increases in nitrate release, and to upgrade existing uses to reduce current nitrate release as much as possible, with low to moderate expenditure of public or private funds. Such measures could include limiting density of new development, utilizing shallow leachfields or other wastewater disposal methods to reduce nitrate release, and restricting or mitigating new uses such as golf courses, playing fields, or large stables which would have significant nitrate release. These measures should be particularly applied to areas with highly permeable soils, as a much greater proportion of the nitrate in the River comes from those areas. Implementation of such measures will be discussed in the latter part this report.

Establishment of a reasonable nitrate objective for the San Lorenzo River should be based on a better understanding of the extent to which nitrate levels affect algae growth and stream-based beneficial uses, and the extent to which moderate waste disposal and land use control measures would reduce nitrate release to the River. The County is scheduled to receive a Section 205j grant from the State Water Resources Control Board in 1989-91 to conduct further investigations into those questions and to develop a recommendations for a nitrate objective and measures for attaining that objective. This project will build on the work that has been done to date on this issue, and address some of the questions that are still unresolved.

4.7 Influence of Wastewater Management Program on Water Quality

The extensive investigations of the past three years have provided a good picture of the extent to which current wastewater disposal practices are affecting water quality in the San Lorenzo Watershed. It is clear that the total number of onsite systems in the Watershed have caused significant cumulative increases in nitrate in surface water and groundwater. It is also apparent that the large majority of systems, which are working properly and providing subsurface disposal of effluent, are not contributing measurably to bacterial contamination of groundwater or surface water. Most of the observed bacterial contamination results from impacts of development which are unrelated to wastewater disposal. However, five to ten percent of the samples collected have high bacteria levels which do result from wastewater contamination. Followup investigations have shown that this results from a relatively small number of individual failing septic systems.

These findings point out the need for a program to identify dysfunctional septic systems, to bring about the improvement of those systems, and to provide for ongoing maintenance and management. For locations where soil or groundwater conditions preclude reliable subsurface disposal, alternative means of wastewater disposal must be provided. These are the objectives of the San Lorenzo Wastewater Management Program. This program has been in effect now for three years, and has brought about the improvement of 300 septic systems in the Kings Creek, Wildwood, Boulder Creek, and Brook Lomond areas, as will be discussed in Section 5.4 of this report.

The findings of the water quality investigations also point out the need for management of development density, land use, and wastewater disposal practices to minimize release of nitrate to groundwater and surface water, particularly in groundwater recharge areas. Although there will be continued investigations of this topic, current and proposed programs address this need, as discussed in the latter sections of this report.

The immediate effects on water quality resulting from improved wastewater management will be mixed, and probably not readily apparent. The immediate drop in fecal coliform levels in the River downstream from Boulder Creek that occurred in 1987 after elimination of two failures in the Boulder Creek area was quite apparent. But the large annual fluctuations in nitrate and bacteria levels and the large proportion of contamination from non-wastewater sources, hampers measurement of any large scale changes brought about by improvements in wastewater management. The objective of the program will be to significantly reduce the proportion (25%) of high bacterial levels which currently appear to result from individual failing systems.

Although water quality monitoring has limited effectiveness for measuring the performance of the wastewater management program, monitoring can make a significant contribution to the management program. Now that background water quality levels have been established, water quality monitoring is useful for identifying episodes of wastewater contamination, and helping to focus the investigations needed to identify and eliminate the source. The best method for monitoring the effectiveness of the program is to monitor the number of systems which are performing properly and which meet standards for long-term successful performance. This is the subject of Section 5 of this report.

5 EVALUATION OF CURRENT WASTEWATER DISPOSAL PRACTICES

Since January 1986, the Santa Cruz County Health Services Agency has maintained an active program to evaluate and improve the effectiveness of current onsite wastewater disposal practices in the San Lorenzo River Watershed. The purpose of the program has been to measure the adequacy of continued onsite wastewater disposal in the San Lorenzo Watershed, and to develop recommendations for long-term wastewater management. As a part of the evaluation program, dysfunctional systems have been required to be upgraded, and several programs have been initiated to promote improved maintenance of systems by the property owners. This section of the report will discuss the results of the system evaluations and the efforts to improve onsite wastewater disposal practices. The report will conclude with a discussion of potential alternatives, and a description of the County's ongoing wastewater management program for the Watershed, including proposed refinements following from the findings of this report.

5.1 Background

The evaluation of current wastewater disposal practices needs to be viewed in relationship to the preceding history of wastewater disposal efforts in the study area, as well as in relation to the evaluation of water quality parameters which would be expected to be affected by improper disposal practices, and, finally, in relation to a set of criteria for system adequacy. A chronology of past investigations was presented in Section 3 of this report and water quality was discussed at great length in Section 4. The following subsections will summarize some of the relevant history of wastewater disposal and its observed influence on water quality. They are followed by a discussion of the repair criteria utilized by the County to evaluate the adequacy of existing systems and govern the repair of systems needing improvements.

5.1.1 History of Wastewater Disposal and Past Studies

Approximately 14,000 properties within the San Lorenzo River Watershed utilize individual onsite wastewater disposal systems. The exceptions are the City of Scotts Valley, which treats its sewage and exports it to Santa Cruz for ocean disposal, and about 325 properties within Boulder Creek Country Club, Bear Creek Estates, and Rolling Woods, which are served by local sewers which collect the sewage for treatment prior to nearby subsurface disposal. As discussed in Section 3.1, many of the properties were first developed for summer homes prior to the 1960's, on small lots, often near creeks. Practically all homes are now used for year-round use, and many of the old disposal systems have been replaced or upgraded. Performance of onsite disposal systems in the Watershed is potentially limited by small lot size, age of systems, steep slopes, high winter groundwater, close proximity to waterways, areas of clay soils, and areas of very permeable sandy soils.

Prior to the early 1960's, there was little supervision of the installation of new septic systems. At that time the County began requiring permits, and established minimum standards for the approval of new systems. As knowledge has been accumulated regarding the potential problems with septic systems, the standards for systems serving new development have become much more stringent. However, until recently, the requirements for repair or replacement of old septic systems has been somewhat minimal. Although a repair permit has been required so that work could be reviewed by the County, up until the late 1970's at least half of the system replacements and repairs probably took place without benefit of a permit. Even when a permit was obtained, the standards for repairs were not well-defined until 1985, when the County established specific standards for system repairs and replacements. These standards will be discussed in Section 5.1.3.

In the past, there have been few efforts toward comprehensive management or maintenance of septic systems in the San Lorenzo Watershed. Improvements were generally made on a case-by-case basis, whereby a County inspector might discover an individual failing septic system as a result of a permit application, a complaint, or an investigation of a particular water quality problem. Once a failure was discovered, a system repair was required, usually with little evaluation of soils, groundwater conditions, or conditions on surrounding properties.

Prior to the current program, there were three occasions when more comprehensive, septic system inspection and maintenance programs have been implemented in the San Lorenzo Watershed. In 1975-78, and again in 1981, the County required inspection and pumping of all septic systems located within 100 feet of a major waterway in the Watershed. During the 1975-78 program, of the 1690 parcels inspected, 11% were found to have system failures or surface discharge of greywater, and 30% of the tanks needed pumping. In 1981, the same properties were inspected, 4.3% were found to be failing, and 36% needed