The standards for safe body contact have been exceeded during significant portions of the summer for many locations during the period of record. Standards are still exceeded more than 20% of the time at most of the stations except Ben Lomond and Sycamore Grove. The Rivermouth, which experiences the most demand for recreational use, exceeds the standards continuously. Based on exceedence of standards, bacterial contamination is having a significant adverse impact on body-contact recreation. However this does not appear to have resulted in any significant incidence of disease among swimmers.

When a bathing area exceeds standards it is usually posted as unsafe until followup tests reveal that the standards are being met. However, the signs are frequently torn down, and swimming continues to occur at posted areas. Although it is difficult to evaluate the extent to which contamination may have resulted in actual public health impacts and incidence of disease among swimmers, there has been no documentation of outbreaks of serious disease resulting from swimming in the San Lorenzo River.

Some of the more serious diseases which may be water-borne are reportable to the County Health Services Agency. This includes hepatitis, salmonella, cholera, and shigella. There have been no reported incidents which are believed to have come from swimming in the River. Some unconfirmed incidents of gastro-intestinal illness have been reported by people who were swimming at the Rivermouth area.

Three physicians who practice general family medicine in the San Lorenzo

Valley area were asked if they had seen any incidence of disease related to swimming in the River. None had reported seeing any gastro-intestinal complaints resulting from swimming in recent years. Two doctors reported that there had been some incidence of gastro-intestinal upset and ear infections in the mid to late 1970's, but not much since then. One doctor attributed that to a suspected improvement in water quality. The other doctor thought it might relate more to increased knowledge of the potential hazards of swimming in the River. One doctor reported still seeing a small number of incidents of infection of cuts and abrasions received while swimming in the River, but the other two had not noticed any of that.

Although there has been no recent incidence of disease from swimming in the River, the opportunities for swimming and wading are significantly reduced by the high bacterial levels which result in posting of areas as unsafe, and which result in a general perception that much of the River is unsafe for swimming.

Bacterial contamination does not have any significant impact on the other beneficial uses of the River. Bacteria and other potential pathogens are easily removed by water filtration and disinfection for water supply. There is no impact on fishery productivity, and bacteria in the water present no hazard for the consumption of fish caught in the River, provided the fish is properly cleaned and cooked.

4.2.5 Significance of Bacterial Indicators

In evaluating the degree of health hazard represented by presence of bacterial indicator organisms, such as fecal coliform, the reliability of those organisms as an indicator must be evaluated. It has not been considered practical to routinely test for actual pathogenic organisms because they would be present in low concentrations, a wide variety of organisms could be present, the analytical procedures are expensive and difficult, and the absence of a particular pathogenic organism would not rule out the presence of other potential organisms from fecal contamination. An ideal indicator of human fecal contamination would have broad occurrence in the intestines of humans, would have limited occurrence in the natural environment, and would behave similarly to actual pathogens in soil and water. Unfortunately the ideal indicator has yet to be identified.

Fecal coliform has been used for years as the primary indicator of fecal contamination and potential health hazard. This use was based on studies conducted in the late 1940's and 1950's in the Eastern United States, which showed a relationship between high fecal coliform levels and incidence of water-borne disease in swimmers. However, although fecal coliform bacteria are found in great quantities in humans, they are also found in other warm-blooded animals, and in vegetable wastes in the absence of any fecal contamination (EPA, 1986). Once introduced into the environment, fecal coliform may remain viable for long periods of time, up to several months, making it somewhat problematic to relate them to a particular source (Bohn and Buckhouse, 1985).

The utility of fecal coliform was called into question by a 1986 EPA report which investigated the occurrence of water-borne illness in swimmers, as related to levels of various bacterial indicators: fecal coliform, fecal streptococci, E.coli, and enterococci. Work was done on several bathing areas in the Midwest and East Coast which experienced different degrees of pollution from municipal sewage discharges. The studies found that there was a significant incidence of illness with increased levels of E.coli and enterococci, but that there was no statistically significant relationship between incidence of disease and fecal coliform or fecal strep levels (EPA, 1986). As a result, the EPA has recommended discontinuing use of fecal coliform as a standard for water contact sports, and instead to use E.coli and/or enterococci.

E.coli is a type of fecal coliform that is supposed to be more specific to the intestines of warm-blooded animals (EPA, 1986). Analysis of E.coli was included in the San Lorenzo monitoring program for a period to evaluate its utility as an indicator of wastewater contamination. In 1987, a total of 134 samples from 4 stations were analyzed for E.coli. A linear regression analysis showed that the E.coli levels were directly related to the fecal coliform levels (r2=0.97) and averaged 125% of the coliform levels. (Although the test for fecal coliform includes E.coli organisms as well as others, the E.coli results were probably greater than the fecal coliform levels because the test includes a resuscitation period which would revive stressed organisms which might not otherwise show on a standard fecal coliform test (APHA, et al., 1985).) Of the four stations, the strongest linear relationships were at the Rivermouth (r2=0.95) and at Sycamore Grove (r2=0.97). Weaker relationships occurred upstream at Big Trees, in Felton, (r2=0.85) and at

River Street, below Boulder Creek (r2=0.81). A summary of the E.coli values for the four stations are shown in Table 2.

The very close observed relationship between fecal coliform levels and E.coli levels would suggest that in the San Lorenzo Watershed, E.coli would probably not provide an indication of the potential for water borne disease that would be significantly different than the indication provided by fecal coliform. If the proposed E.coli standard of 126/100ml was applied, based on the observations made, it would generally be exceeded twice as frequently as the standard for fecal coliform was exceeded. There is no evidence to suggest that such a tighter standard is needed, or even appropriate for the San Lorenzo Watershed.

Enterococci were the other bacteria group which were proposed by the EPA as a better indicator of public health hazard by fecal contamination. The enterococci are a specific subgroup of the general fecal streptococci group of bacteria. The enterococci group excludes some fecal strep which are more specific to animals and is therefore thought to be more indicative of human contamination. However, the enterococci group does contain significant numbers of fecal strep of plant origin (Kibbey, 1978). Enterococci and fecal strep have both been observed to survive for long periods in saturated soil, up to at least 120 days, with little die-off (Ibid).

The San Lorenzo monitoring program has also included analyses for enterococci bacteria in order to evaluate its significance. Since June 1988 over 270 enterococci analyses have been performed, in conjunction with most of the regular and special samples. Summaries of the results are contained in

Table 2.

When all the data was analyzed together, enterococci showed a statistically significant relationship to fecal strep (correlation coefficient of 0.71), and a very weak relationship to fecal coliform (correlation coefficient of 0.043). However, this relationship varied throughout the study area. At some stations enterococci was correlated with fecal strep, at other stations it was correlated to fecal coliform, at other stations it was correlated to both, and at some stations there was no significant correlation to either parameter. There was no obvious pattern to these relationships. There was also no significant correlation between enterococci levels and known sources of human fecal contamination.

If the proposed enterococci standard of 33/100ml was applied to stations in the San Lorenzo Watershed, it would be exceeded two to three times more frequently than the fecal coliform standard is currently exceeded. However, as discussed above, enterococci does not appear to be particularly useful as an indicator of human fecal contamination in the San Lorenzo Watershed.

Although there are problems with the use of fecal coliform and fecal strep individually as indicators of fecal contamination, some investigators believe that the ratio of the two provides a good indication of the source of fecal contamination (Feachem, 1975). In some of the reported studies, it was found that if the source was human, the fecal coliform to fecal strep (fc/fs) ratio was greater than 4,; if the source was animal, the ratio was less than 0.7; and if there was a mixture of sources, the ratio was between 4 and 0.7, (Geldreich, 1969). However these numerical relationships were not found to be as reliable if samples were collected at some distance from the source, due to differential die off rates of the two bacteria groups (Feachem, 1975). Feachem postulated that if the source was human, the ratio would start high, and drop off with time and distance from the source; if the source was animal, the ratio would start low and tend to rise with distance (Ibid). This difference is attributed to the different types of strep that are present in animal feces versus human feces.

The County's sampling program has utilized frequent analysis for fecal strep in conjunction with fecal coliform in order to help indicate the source of fecal coliform contamination. Sampling has also been done downstream of known sources of human or animal contamination in order to evaluate the value of the ratios for interpreting results in the San Lorenzo Watershed. Although the results were quite variable and were not necessarily consistent with the suggested guidelines, they do support use of the fecal coliform/fecal strep ratio as a potential indicator of the source of contamination.

In order to evaluate the use of the ratio, all of the 430 special samples were analyzed. These samples are not collected as part of the monitoring of regular stations, and are frequently collected from small drainageways, or stream reaches where contamination has been observed or suspected. All the samples were grouped into one of seven categories, ranging from confirmed animal (non-sewage) contamination, to suspected animal contamination, to unknown contamination, to suspected human (sewage) contamination, to confirmed human contamination. Extreme data points with fecal coliform or fecal strep values greater than 10,000/100ml were eliminated from the analysis.

An ANOVA (analysis of variance) test was performed to determine if the mean values of the fc/fs ratio varied significantly from group to group. Although there was considerable variability within each group, the test confirmed that the group of samples from suspected or confirmed human contamination were significantly different from the groups with suspected animal contamination (at the 0.05 confidence level). The mean ratio for cases of suspected animal contamination was 0.58 with a standard deviation of 0.80 and an observed range of 0.00 to 3.95. The mean ratio for suspected human contamination was 1.42 with a standard deviation of 1.76 and an observed range of 0.02 to 7.60.

Correlation analyses of the data were also performed which showed significant correlations ($p<0.001$) between the suspected source and the fc/fs ratio (correlation coefficient of 0.31), the amount of fecal coliform (correlation coefficient of 0.33), and the concentration of nitrate (correlation coefficient of 0.46). The stronger the presence of wastewater, the higher the ratio, the fecal coliform, and the nitrate level. There was only a weakly significant correlation between the suspected source and fecal strep, and no correlation between the source and the enterococci value.

These statistical analyses of the fecal coliform fecal strep ratio indicate that the ratio can provide a statistically significant <u>indication</u> of whether or not bacterial contamination is derived from human or non-human sources. However, there is a broad range of observed values for both animal and human contamination. For example, in the data analyzed, 46% of the samples with ratios greater than 1.0 were from primarily non-human sources, and 20% of the samples with ratios equal to or less than 1.0 were from primarily human sources.

Despite the drawbacks of the various bacterial indicators of fecal contamination, it does appear that fecal coliform, in conjunction with the fecal coliform/fecal strep ratio, can be used to a certain extent in the San Lorenzo Watershed as an indicator of potential human contamination. However, these indications are not statistically precise, particularly for individual samples, and in a particular contamination episode, the water quality results should be followed up by source investigations and sanitary surveys to confirm the actual source of contamination.

4.2.6 Seasonal Effects on Bacteria Levels

In order to help determine the causes of the bacterial levels observed in the San Lorenzo Watershed, various analyses have been performed to determine the extent to which bacteria levels are affected by various climatic and hydrologic factors. Bacteria concentrations vary significantly with season, rainfall, soil saturation, water temperature, turbidity, volume of streamflow, and other factors. Some of these seasonal variations have already been noted by previous investigators (S.C. County Health Dept., 1969; Sylvester and Covay, 1978; S.C. County Planning Dept., 1979; J.M. Montgomery, 1983).

These relationships have been further investigated in the current study, through a review of seasonal fluctuations, and statistical analysis of the effects of various climatic factors on bacterial concentrations. Each water year was broken into four seasons, and the data summarized for each season. Season delineations were not based solely on arbitrary dates, but were based on the occurrence of actual climatic changes, the timing of which may vary from year to year. Fall is characterized by decreasing air and water temperatures, generally low streamflow, an accumulation of leaves and organic material in the streams, and a few scattered storms. Winter is a time of high rainfall and storm runoff, cold temperatures, and a flushing of the stream channels. Spring is the period after most of the rainfall has occurred when the ground is saturated, many intermittent streams are flowing, stream baseflows are high, and water temperatures are rising. During the summer period, stream temperatures are elevated and flow levels are low.

In Table 4, water quality data has been summarized for each season for the San Lorenzo River at Big Trees. (Seasonal data for three other stations is contained in Appendix B.) A review of the table shows how bacteria levels and other water quality parameters fluctuate according to regular seasonal patterns from year to year. In spite of these patterns, there were also significant differences between the three years, related to the very different weather patterns that prevailed. Various statistical analyses were used to help identify significant relationships between bacteria levels and seasonal factors.

Table 4: Summary of Water Quality Data by Season, San Lorenzo River at Big Trees, 1985-88

Season of the Year when Sample Collected	Mean Temperature	Mean pH	Mean Electoconductivity	DISSOLVED OXYGEN / PERCENT SATURATION	Mean Weekly Rainfall	Mean Daily Discharge	NITRATE-NITROGEN MEAN(mgN/l) /NUMBER	NITRATE-NITROGEN MAXIMUM MINIMUM	FECAL COLIFORM LOGMEAN (/100ml) /NUMBER	FECAL STREP LOGMEAN (/100ml) /NUMBER	Mean FC/FS Ratio	E.COLI LOGMEAN (/100ml) /NUMBER	ENTERO-COCCI LOGMEAN (/100ml) /NUMBER
Fall '85 (Oct-Nov)	14.20	.	390.00	. .	.02	13.71	.40 2	.40 .40	185.04 3	357.77 2	.53	. 0	. 0
Winter '86 (12-3/16)	9.73	.	357.50	. .	4.18	504.59	.48 4	.50 .40	239.55 14	1829.41 4	.27	. 0	. 0
Spring '86 (3/17-Jn)	13.73	.	610.00	. .	.30	97.25	.33 3	.40 .20	177.93 18	218.56 3	1.16	. 0	. 0
Summer '86 (Jul-Sep)	16.03	.	400.00	. .	.08	26.47	.70 3	.90 .30	149.98 16	402.93 3	.26	. 0	. 0
Fall '86 (Oct-Ja/87)	8.09	7.98	192.00	12.62 106.48	.19	20.74	.52 6	.70 .40	78.00 20	225.50 8	.24	66.33 2	. 0
Winter '87 (Feb-Mar)	9.55	7.81	179.90	13.08 115.55	1.92	48.88	.49 11	.71 .30	169.01 11	397.25 11	.53	. 0	. 0
Spring '87 (Apr-Jun)	15.60	8.09	325.00	9.24 93.05	.09	20.59	.36 16	.50 .20	126.90 16	375.20 16	.38	219.63 10	. 0
Summer '87 (Jul-Sep)	16.68	8.09	363.64	8.81 91.23	0.00	14.70	.38 11	.40 .30	140.85 11	606.36 11	.27	232.76 8	. 0
Fall '87 (Oct-Nov)	14.15	7.93	366.67	9.41 92.20	.26	12.62	.40 14	.50 .30	205.42 14	588.77 14	.45	250.58 11	. 0
Winter87-88(Dec-Jan)	9.69	7.88	288.89	10.28 91.06	1.70	64.00	.50 7	.60 .40	587.21 9	1702.68 9	.46	508.74 3	5791.37 2
Spring 88 (Feb-May)	13.35	7.89	381.82	9.03 86.76	.29	20.33	.48 19	1.40 .20	190.62 21	155.95 21	.61	. 0	. 0
Summer 88 (Jun-9/10)	19.88	8.00	456.25	8.67 95.47	0.00	8.82	.27 18	.40 .10	189.32 18	391.67 18	.61	. 0	63.95 8
Fall 88 (9/11-12/15)	13.82	8.03	405.88	9.96 96.50	.37	8.47	.31 17	.50 .01	233.41 17	774.92 17	.42	. 0	93.90 14

An initial analysis of variance (ANOVA) test was performed to determine if there were statistically significant differences between the mean bacterial levels for the four seasons. The test confirmed that the seasons were significantly different (the probability of no significance was less than 0.05). Fecal strep levels were significantly lower in winter and spring and higher in the summer. Fecal coliform levels were significantly lower in the winter if the periods of rainfall were excluded. These relationships primarily show the effect of temperature.

During the spring period, fecal coliform/fecal strep ratios were inversely correlated with the low fecal strep levels and tended to be higher, often in the range typically associated with human contamination. However, at that time of year at most stations there was no associated increase in fecal coliform levels and the elevated ratios are attributed to the depressed fecal strep levels, unrelated to any human source of contamination.

In order to further analyze seasonal effects on water quality, correlation and multiple linear regression analyses were performed to identify significant relationships between bacterial levels and rainfall, temperature, and streamflow during the different seasons, at different locations. The correlation analysis provides a measure of the strength of the association, and the regression analysis is used to define the actual mathematical relationship among variables. Results from the regression analysis can indicate how much influence a particular factor has on the bacterial level, and how much of the range of variation can be explained by the effect of the climatic factors. Results were only considered statistically significant if the significance levels were less than 0.05.

The statistical analyses showed that rainfall had the greatest influence on both fecal coliform and fecal strep levels. If significant rain (greater than 0.1 inch) had occurred one to three days prior to sample collection, bacteria levels generally increased 1000-100,000% above mean levels. In the multiple regression equations, fecal coliform levels were inversely related to the amount of rain that had fallen in the previous thirty days. This may indicate that higher baseflows result in greater dilution, and lower bacterial concentrations.

Stream temperature also had a significant positive influence on fecal coliform and fecal strep levels, but temperature variations would only result in fluctuations of 50-100% of the mean levels. For example, during the coldest periods bacterial levels tended to be about 50% of their mean values. This was particularly noticeable when the colder temperatures of late fall, winter, and early spring periods, would keep bacteria levels low if there was no rain. During the dry water-year of 1986-87, temperature had an equally significant effect on fecal coliform levels as short-term rainfall.

For three seasons of the year, the statistical analyses showed that the effects of rainfall, temperature and streamflow could account for most of the observed variation in bacterial levels at the main stations on the River and on many tributaries. However, during the summer of "normal" years, during drier years, and at stations on some of the smaller tributaries, the analyses revealed fewer statistically significant relationships between the climatic factors and observed bacterial levels. There were apparently strong influences on water quality, which were operating independently of climatic factors.

To summarize the effects of climatic and hydrologic factors, a description can be provided of the bacterial levels that might be expected to occur during the course of a normal water year. In the fall, before the first rains, temperatures are low, as are fecal coliform and fecal strep levels. They remain low throughout the winter and early spring, except during storm periods, when the bacterial levels increase 1000-100,000%. Four or five days after a storm, the levels drop back down again. In the spring bacterial levels are low initially, with the low water temperatures, and high, diluting baseflows. Average bacteria concentrations tend to increase 50 to 100% going into summer as the temperatures rise, and the flows diminish. During the summer, bacteria levels fluctuate by as much as 100-400% in response to factors which cannot be statistically quantified: recreational disturbance, sewage contamination, animal contamination, etc. After summer, the average bacteria levels again decline in response to colder temperatures and the flushing out of stream channels by the first storms.

The statistical analysis reveals the effect of rainfall, but it does not explain the cause of that effect. There has been considerable discussion regarding the source of the high bacterial levels during the storm periods of fall and winter. Some investigators have proposed that the high levels result from sewage discharge from saturated or failing septic systems (S.C.County Health Dept, 1969). Others have suggested that a different species of fecal coliform exist during the winter months (J.M. Montgomery, 1983). However, the large amount of data available indicates that the high bacterial levels during storm periods are related primarily to washoff of bacteria from developed areas, independent of wastewater disposal. Fecal coliform levels of 100,000/100ml were found in storm runoff from areas of the county that are sewered, but more densely developed than the San Lorenzo Valley (Live Oak and Santa Cruz). During the same storms, fecal coliform levels flowing out of the Valley were only 60,000/100ml (S.C. County Planning Dept., 1979). Storm runoff from the Valley also has very high levels of fecal strep in relation to coliform levels (fecal coliform/fecal strep ratio of 0.17), further indication that the high bacterial levels result from background contamination carried by surface runoff, and not human contamination from septic systems.

The analysis of seasonal factors also provides some insight into the conflicting effects of wet years and dry years on bacteria levels. In wet years, soils are more saturated, possibly contributing to more septic system failures, and easier transport of effluent to a stream channel. Although this would increase bacterial contamination, there is also more dilution which would tend to reduce bacteria levels. In dry years there is much less dilution, so any bacteria input to a stream would have a more pronounced effect; however, there is a lower potential for wastewater discharges. Low flow conditions often result in higher bacteria counts from garbage, animals, and other non-wastewater sources. The contradictory operation of these influences probably explains why there is no obvious pattern in the wet and dry year fluctuations in bacteria levels.

4.2.7 Source Investigations

Although the analysis of seasonal factors reveals how rain and surface runoff can cause very significant increases in fecal bacteria levels during the winter, it does not offer any explanation of the causes for the sudden peaks or the long periods of elevated counts that occur at some stations during non-storm periods. Despite the potential limitations of fecal coliform as an indicator of human fecal contamination, any regular exceedence of the fecal coliform standard for body contact is a cause for concern, particularly if the fecal coliform/fecal strep ratio is high. Such episodes in the Watershed have been subject to follow-up investigation by County staff in order to identify the source. Bacteriologic data alone is of limited value in determining the source and significance of fecal contamination, unless the data is supported by solid results from a sanitary survey or other investigations (APHA, et al., 1985).

When a potential problem area was identified, as indicated by fecal coliform levels exceeding the standard, it was investigated by follow-up sampling at upstream locations in order to bracket the point where the contamination was entering the stream. Samples were also taken of tributaries, seeps, and small drainage ditches. Once the location of the suspected source was narrowed down, a sanitary survey was conducted in which the suspected area was inspected for surfacing septic tank effluent, greywater discharge, animals, putrescible garbage, or stream disturbance. Dye was sometimes used to determine if a particular septic system was contributing to a contaminated seep. When a source was confirmed, the problem was abated, and follow-up sampling was done to confirm that the contamination ceased.

Unfortunately, not all source investigations have successfully identified the cause of an episode of high fecal coliform. Many of the episodes are so intermittent or short-lived that bacteria levels return to normal before an investigation can be completed. Due to the short duration of such episodes their overall effect on water quality is generally limited.

Three examples of completed source investigations are as follows:

* During the summer of 1986, fecal coliform counts in the River at River Street in Boulder Creek averaged 542/100ml, with a fc/fs ratio of 1.11. Upstream sampling located a drainageway which was carrying a mixture of sewage and groundwater discharging from a curtain drain. Fecal coliform concentrations in 8 samples taken from the drainage had a logmean of 4275/100ml, with an average fc/fs ratio of 1.12 (range of 0.17-2.17). During the summer of 1987, after the source of contamination was eliminated, values in the River downstream averaged 45/100ml and 0.33 for fecal coliform and fc/fs ratio, respectively.

* At the station on the River at Pacific Avenue in Brookdale, summer fecal coliform levels in 1987 were averaging 1200/100ml (logmean), with an average fc/fs ratio of 0.64. A very large and persistent concentration of domesticated and wild ducks was found upstream 100 yards. Sampling upstream of the ducks revealed fecal coliform levels of 40/100ml with a ratio of 0.36. Immediately below the ducks, fecal coliform levels had increased to an average of 1770/100ml with a ratio of 0.38 (range of 0.11-0.7). Although efforts have been made to disperse the ducks, ducks and geese still use that general area and the fecal coliform levels have continued to be high.

* Fecal coliform levels at Kings Creek during the summer of 1987 averaged 316/100ml (logmean) with an average fc/fs ratio of 0.39. A repeated streamside survey with sampling every 100 yards revealed no sources of human contamination, but very extensive dog activity, littering, and other disturbance of the streamside area, due to the close proximity of houses to the creek. The bacteria levels were high and the ratio remained the same throughout the developed area. These conditions continued into 1988 and the quality deteriorated further, probably related to the very low flows which occurred in 1988. Due to the lack of any evidence of wastewater entering the creek, the presence of other sources of contamination, and the low fc/fs ratio, it was concluded that the degraded quality is a result of non-point contamination from human encroachment on the creek, unrelated to wastewater disposal.

The source investigations have confirmed that failing septic systems can have a significant, but usually transitory impact on water quality. The investigations have also confirmed that there are many sources of high bacterial levels other than failing septic systems. Other types of sources of high fecal coliform levels that have been identified include: decomposition products from food wastes entering a storm drain, intermittent non-point urban discharge from storm drains in Boulder Creek, and stream bottom disturbance from horse traffic near Henry Cowell State Park. These investigations also provide further evidence of the utility of the fecal coliform/fecal strep ratio for helping to differentiate the presence of human versus animal contamination.

4.2.8 Impacts of Development on Bacterial Contamination

The highest average bacteria levels occur in the developed areas of the San Lorenzo Watershed. Although some periods of high counts have been associated with particular incidents of wastewater contamination, the elevated background levels in developed areas appear to be primarily caused by other influences unrelated to wastewater disposal. This conclusion is based on the results of source investigations in the San Lorenzo Watershed, findings regarding impacts on shallow groundwater in the San Lorenzo Valley, and a comparison of water quality conditions found in other developed areas that are sewered.

Significant increases in fecal coliform levels occur as streams pass through urban areas in the San Lorenzo Watershed. Bacteria levels subsequently decline in reaches of the River where there is little development along the riverbank: between Brookdale and Ben Lomond, and between Felton and Santa Cruz. This is shown in the logmean of the fecal coliform values and the mean fecal coliform / fecal strep ratios for the main stations on the River for the 1987-1988 water year, progressing downstream:

	Fecal Coliform	FC/FS Ratio
Waterman Gap	42/100ml.	0.29
Boulder Creek	181/100ml.	0.76
Brookdale	219/100ml.	0.75
Ben Lomond	115/100ml.	0.44
Felton (Big Trees)	223/100ml.	0.54
Sycamore Grove	67/100ml.	0.25
Rivermouth	484/100ml.	2.21

As discussed in the prior section, source investigations have revealed many instances of bacterial contamination in developed areas that were not caused by septic system failures. In the absence of surface failures, it might be possible that the high background levels of bacterial contamination could result from general wastewater contamination of the shallow groundwater that contributes to the stream flow. However, as will be discussed in Section 4.4 of this report, an evaluation of water quality data for shallow groundwater in developed areas of the San Lorenzo Valley does not provide any evidence of significant bacterial contamination. The source investigations did confirm the presence of other sources of bacterial contamination unrelated to wastewater disposal. These findings are also consistent with findings from other areas.

It has been documented in many geographic areas that high levels of fecal bacteria are typically found in waterways draining developed areas, including areas that are served by sanitary sewers. This was well documented in a literature review of the subject performed recently by Brown and Caldwell (1988). That study also reported on research which established a mathematical relationship between mean bacterial levels in a stream and the degree of development of the Watershed. This is consistent with findings in the San Lorenzo Watershed which show greater bacterial contamination associated with increased development and disturbance in close proximity to the stream channel (Kings Creek, Lompico Creek, Zayante Creek).

The County has monitored other streams in the County as a part of its regular surveillance program of natural bathing areas, and the streams that flow into them. This investigations over the last three years have indicated that most small streams in Santa Cruz County which drain developed areas, but which are served by sanitary sewers, show bacteria levels similar to or higher than those found in the San Lorenzo Valley. Examples of these are as follows:

"Intel" Creek (West Santa Cruz) - logmean fecal coliform of 1100/100ml, mean fc/fs ratio of 0.96;
Woodrow Creek (West Santa Cruz) - logmean fecal coliform of 527/100ml, mean fc/fs of 0.74;
Laurel Creek (Central Santa Cruz)- logmean fecal coliform of 693/100ml, mean fc/fs of 0.46; and
Noble Gulch (Capitola) - logmean fecal coliform of 775/100ml, mean fc/fs of 0.28.

Although these streams drain more densely developed areas than most of the San Lorenzo Valley, the very high bacteria levels illustrate the impacts which occur on a more moderate level in the Valley.

The occurrence of very high levels of fecal bacteria in urban runoff during storm events is also a good example of the presence of bacterial contamination from developed areas. Most studies have looked at the impacts of transport of the bacteria and other contaminants during storm events, but in areas where there is little protection of the stream channel by a riparian buffer, this background urban bacterial contamination appears to greatly affect stream quality even during non-storm periods. Although the specific sources of urban contamination have not been well documented, likely sources include: presence of dogs and other animals, littering, decomposition of putrescible material, street runoff, and disturbance of stream channels and bottom sediments. As discussed previously, once these bacteria are introduced into the environment, for instance in fecal material of animals, they can persist for long periods.

With the high levels of background urban contamination in the San Lorenzo Watershed, it is likely that bacterial quality would only improve to a limited extent from the levels that are observed now, if the impacts from wastewater were eliminated. This was the case in the lower Russian River Valley, which bears many similarities to the San Lorenzo Valley, with old dense residential development clustered along a narrow River corridor. When that area was sewered, there was no observed improvement of bacterial levels in the Russian River, according to staff members of the North Coast Regional Board. If anything, the bacterial quality there may have declined. This overriding influence of background bacterial contamination from development must be taken into account in evaluating bacterial quality.

4.2.9 Wastewater Contamination

Even after the high levels of background contamination have been recognized, it is apparent that periodic wastewater discharges from failing septic systems can significantly increase bacteria concentrations above those background levels. The analysis of fecal coliform levels and fecal coliform/fecal strep ratios from the special samples showed that confirmed episodes of wastewater contamination typically resulted in fecal coliform levels significantly higher than background levels and fecal coliform/fecal strep ratios greater than 1. If these characteristics are applied to the data from all samples collected from regular stations during non-storm periods, wastewater contamination is indicated in 7-12% of the samples collected during the past three years. Of the samples that had fecal coliform levels in excess of 200/100ml, it is estimated that 25% were caused by wastewater contamination. This is probably an upper estimate, since the special samples were mostly collected as a part of problem investigations and are biased towards a higher proportion of wastewater discharges.

A review of the data from individual stations shows that most of the incidents of wastewater contamination are not persistent or chronic, typically occurring for periods of a few days to a few weeks before bacterial levels return to normal levels for the particular station. The scattered nature of the high counts indicates that the contamination results from isolated, individual wastewater discharges. As discussed in the section on source investigations, some of these incidents have persisted long enough to allow the source to be identified and eliminated.

In the absence of any persistent indications of wastewater contamination, there is not evidence of significant chronic degradation of bacterial quality from wastewater disposal in any large area of the Watershed. There are some small areas which have experienced repeated problems, such as the downtown Boulder Creek area. These will be discussed in the following section. These areas which show signs of regular wastewater contamination are becoming the subject of more intense wastewater management efforts.

4.3 Description of Water Quality at Specific Areas

Following from, and expanding on the general discussions of the factors affecting bacterial contamination, this section provides a more specific description of water quality for each major area of the Watershed. This includes some discussion of the water quality history and sources of contamination in that area. (Refer to Tables 1 and 2 for the specific numeric values for water quality parameters at the different stations; station numbers are shown in parentheses.)

4.3.1 San Lorenzo River Headwaters

The Waterman Gap station (349) has a largely undisturbed Watershed, with only a few houses, located at some distance from the stream. Water quality is indicative of undisturbed headwater conditions, with low temperature, low nitrate, very low fecal coliform levels, and low fecal coliform/fecal strep ratios. Although this station provides a useful indication of background water quality in undisturbed conditions, the water quality at this station cannot be compared directly to water quality at downstream stations. Independent of the effects of development, there are also differences in water quality downstream which are related to increasing drainage area, lower stream gradient, more open channels, larger flow volumes, and changing geology. These downstream changes tend to result in increased temperatures, increased nitrates, increased bacteria and other indirect effects.

4.3.2 Upper San Lorenzo River and Kings Creek

This area of the Watershed encompasses the River and its tributaries north of Boulder Creek. This includes San Lorenzo Woods (Station 3435), Kings Creek (Station 310), and San Lorenzo River below Two Bar Creek (Station 289). Water quality is greatly influenced by the very close proximity of development along the stream corridors. Stream channels in this area have been observed to have greater than the normal amount of garbage and debris that has been thrown in from neighboring homes and roadways. Soils in this area tend to have high clay content, and perched water tables can occur in the winter. Historically, Two Bar Creek and the River downstream from Two Bar have been identified as having excessive fecal contamination (200-500/100ml), with a high average fc/fs ratio (4.5) (S.C. County Planning Dept., 1979 and 1984). Kings Creek was identified as having severe bacterial contamination in 1981 (J.M. Montgomery, 1981).

During the current study, most of the stations in this area are improved over historical levels, but still have logmean fecal coliform levels approaching, or greater than 200/100ml, indicating significant bacterial contamination. However, the mean fc/fs ratios are low (0.2-0.5), indicating that the contamination is primarily from non-sewage sources. The absence of wastewater contamination on Kings Creek was confirmed by intense sampling and two sanitary surveys along the stream channel. Sampling of some of the small drainages within the developed portions of this area during the wet winter of 1986 did not reveal significant sewage contamination, except in one area near Two Bar Creek, where several failing septic systems were located and repaired.

All of the parcels in the portion of the Watershed around Two Bar and Kings Creeks were surveyed during the winter of 1986, and repairs were made to the septic systems that were found to be failing. Although fecal coliform levels in Kings Creek have increased significantly from 1987 to 1988, follow-up investigations have shown that the contamination is unrelated to wastewater disposal, and it was unaffected by the repair work. Fecal coliform values in the River downstream from the entire area (Station 289) dropped from a logmean of 254/100ml in 1986 to logmeans of 167/100ml and 180/100ml in 1987 and 1988, respectively.

4.3.3 Bear Creek

Moderately dense residential development occurs on primarily alluvial soils along the lower reaches of this stream corridor. One area is served by sewers, with a large community leachfield. Historically, Bear Creek was identified as having moderate fecal contamination (logmean of 212/100ml) with a slightly elevated fc/fs ratio, indicating human contamination (S.C. County Planning Dept., 1984).

During the current study, sampling near the mouth (Station 271) had shown fecal coliform levels generally below the standards, but in 1988, the fecal coliform logmean rose to 420/100ml. This has probably resulted primarily from the keeping and feeding of geese in the creek near the station. In Bear Creek and at other locations in the county, geese have been observed to cause fecal coliform levels well in excess of standards, with an fc/fs ratio greater than 1.0 (Schwann Lake, Capitola Lagoon, and Antonelli Pond).

Bear Creek is also showing intermittent fecal coliform levels in excess of the body contact standard at the Bear Creek Scout Camp (Station 273) Upstream sampling and investigation has not confirmed a source. The bacterial indicators suggest that there may be an intermittent wastewater impact.

4.3.4 Boulder Creek

The Boulder Creek corridor has moderately dense development along the creek on rocky, sandy soils. The creek is fairly deeply incised, and in most areas homes are well set back from the creek, minimizing development impacts. The upper Watershed has a golf course and areas on sewer with a community leachfield. Boulder Creek was identified as having high to moderate fecal coliform levels in 1973, 1976, 1978, and 1980 (Regional Board, 1974; S.C. County Planning Dept., 1979 and 1984). Since then the sources of contamination must have been controlled, as the fecal coliform levels have been low during the last three years (logmean less than 120/100ml). The high level of turbulence and aeration in this stream would also contribute to a high level of instream treatment of any contaminants that might reach the creek.

Boulder Creek has one of the highest nitrate levels in the Watershed (0.58mg/l-N). This is probably related to past golf course irrigation with reclaimed wastewater, golf course fertilization, discharge of high volumes of treated effluent from the sewered areas into leachfields, and the rapid transmission of nitrates from septic systems and other sources through the highly permeable soils of the area. (See Section 4.6.1 for a further discussion of nitrate in Boulder Creek.)

4.3.5 Central River Corridor

The central River corridor extends from the confluence with Boulder Creek, on south to Felton. Conditions along this stretch are uniformly variable. Most of corridor has well drained, alluvial soils, but areas of shallow, impermeable bedrock and areas of high groundwater also occur. In some reaches houses are very close to the River on steep banks that drop directly into the water, and there are also long stretches with wide flood plains and relatively undisturbed riparian corridors. Water quality varies significantly along the corridor, and has varied a great deal over the years.

4.3.5.1 Town of Boulder Creek

Boulder Creek has the most dense commercial and residential development along the River corridor north of Santa Cruz. The town was served by an old sewer line that was abandoned in the 1940's, but which was found to be carrying sewage to the River as recently as the mid 1970's. Portions of the town are also served by a storm drainage system that readily conveys surface and subsurface flow to the River. High groundwater and clay soil occurs in a several block area downtown, and some 20 businesses utilize sewage holding tanks. The River downstream from the town has experienced excessive bacterial contamination over the years.

In 1986 very high fecal coliform levels (logmean of 450/100ml) and high fc/fs ratios indicated wastewater contamination was occurring (Stations 249, 245). Two point sources of contamination were identified and corrected, and in 1987 and 1988, fecal coliform levels were significantly lower with logmeans of 122/100ml and 181/100ml, respectively. Although a large number of problem systems were identified and repaired in the Boulder Creek area in 1987, intermittent sewage failures from one localized area continued to occur in 1988-89, with wastewater being transported readily to the River by the storm drain system. Additional enforcement actions have been taken to control the situation until a satisfactory long-term solution can be provided for this problem area. During the course of the three year study, the station downstream from Boulder Creek (245) has shown the greatest incidence of periodic wastewater contamination of any of the stations in the San Lorenzo Valley.

4.3.5.2 Brookdale

Brookdale is a small residential community with many homes on relatively larger lots, mostly located well back from the River. Soils are rocky and well drained. There is little historical record of water quality conditions in Brookdale. The most significant contamination in Brookdale in recent years has resulted from a large concentration of domesticated ducks, as discussed in Section 4.2.7 (Station 241). This contamination has produced the highest summertime fecal coliform levels in the Valley (logmean of 1200/100ml). At the downstream end of Brookdale (Station 225) logmean fecal coliform levels were 323/100ml in 1986, dropped to 114/100ml in 1987, and rose to 220/100ml in 1988. The downstream bacteria levels relate directly to the high levels occurring at the upstream station.

4.3.5.3 Ben Lomond

There is relatively little development directly adjoining the River between Brookdale and Ben Lomond, allowing the River to cleanse itself. Much of the development in Ben Lomond, itself, is set back away from the River on alluvial soils. Bacterial counts in Ben Lomond over the years have been consistently the lowest of any developed area in the Valley (logmean of less than 100/100ml at Station 180). Although the area of Brook Lomond, above Ben Lomond is well-known for a very high water table, septic failures there have not had any obvious impact on bacterial levels in the River.

<u>Love Creek</u>, which enters the River at Ben Lomond, has had some history of high fecal coliform (S.C. County Planning Dept., 1979 and 1984). Current sampling showed quite low levels (logmean of 114/100ml at Station 171). <u>Newell Creek</u> (Station 150) also had very low fecal coliform levels (80-127/100ml), although occasional high fecal coliform levels accompanied by fc/fs ratios greater than 1.0 suggest there may be intermittent sewage contamination during late winter conditions.

South of the mouth of Newell Creek is the developed area of Glen Arbor. This area has high groundwater, frequent septic system failures, and periodic wastewater contamination in roadside ditches. Although the River downstream from Glen Arbor (Station 140) generally meets fecal coliform standards (logmean of 130/100ml), standards were occasionally exceeded, with elevated fc/fs ratios (1.4) during the wet months of late winter, 1987.

There is a substantial input of nitrate in the River in the Ben Lomond area, resulting from input from Newell Creek and the other drainages from sandy areas east and south of Ben Lomond. These nitrates are derived from wastewater disposal and other impacts from development, and are readily transmitted through the highly sandy soil to groundwater and surface water. Newell Creek has average nitrate levels of 0.9mg/l-N and the River at Mt. Cross, below Glen Arbor, has a mean level of 0.46mg/l-N, almost double the level in Brookdale.

4.3.5.4 Felton

Felton is located in a broad, flat, alluvial valley with moderately elevated water tables in the winter. Most of the development is set at some distance from the River. A combination of animal contamination and occasional wastewater contamination appears to be carried to the River in Central Felton by <u>Bull Creek</u> (fecal coliform levels of 60-3120/100ml, fc/fs ratios of 0.07-1.86).

The main station on the River in Felton, Big Trees (Station 060), reflects the water quality of the Zayante Creek as well as immediate input from Felton and areas upstream. With the large flow of water through that station, the water quality is more strongly influenced by overall climatic factors than other stations, which are strongly influenced by the immediately adjacent areas. The Big Trees station is generally reflective of overall Watershed conditions. Fecal coliform levels were moderate in 1986 and 1987 (logmeans of 183 and 123/100ml) but were higher in 1988 (logmean of 223/100ml). Fc/fs ratios were low, averaging 0.54, indicating primarily non-human contamination.

In South Felton, during the winter/spring of 1986, a major septic system failure resulted in excessive fecal coliform levels in a roadside ditch, and there was additional wastewater contamination in Shingle Mill Creek (winter logmean of 1200/100ml with an average fc/fs ratio of 1.87 at Station 050). In 1987 and 1988, conditions were improved, and bacteria levels in Shingle Mill Creek were lower (logmean of 193/100ml), with a much lower mean fc/fs ratio (0.44). Shingle Mill Creek has many houses located quite close to its banks on small lots with sandy soils. This undoubtedly contributes to the elevated nitrate levels that are found in the Creek (mean of 0.7mg/l-N).

Although several failures and contamination of roadside ditches were noted in the Forest Lakes Area south of Felton, this did not result in serious impacts on downstream water quality, as indicated by moderately low fecal coliform levels in Gold Gulch (logmean of 144/100ml at station 030). Nitrate levels in Gold Gulch are also quite low (0.15mg/l-N), probably resulting from the clay soils in the Watershed.

4.3.6 Upper Zayante Watershed

The upper Zayante Creek drainage includes Zayante Creek and Lompico Creek. In this area relatively dense residential development occurs in the narrow, steep stream canyons. In the communities of Zayante and Lompico, houses and human activities are frequently very close to the creeks. Creekside areas are often underlain by impermeable rock layers.

Fecal coliform levels in Zayante and Lompico were significantly above standards in the early 1970's (Regional Board, 1974; Sylvester and Covay, 1978; S.C. County Planning Dept., 1979). In the current study, levels were high in Lompico (logmean of 242/100ml at Station 07528) and moderate at Zayante (logmean of 187/100ml at Station 0762). Levels were quite variable, and in Zayante were the highest in the summer months. Fecal coliform/fecal strep ratios were generally low, indicating a high degree of background contamination, unrelated to wastewater disposal. Conditions are similar to those found at Kings Creek.

There have been impacts of intermittent, localized wastewater contamination occasionally (less than 10% of the time) in both areas, as indicated by high counts and high ratios. Similar conditions also indicated presence of wastewater contamination in some of the roadside ditches in both areas in the spring of 1986.

4.3.7 Lower Zayante Watershed

This area includes the portion of Zayante Creek below Lompico Creek, including the Bean Creek drainage. Most of this area is underlain by the highly permeable Santa Margarita sandstone, which contributes to relatively high baseflows in the creeks. In part of the area, there is dense development very close to the creek, but in most of the area the stream corridors are relatively undisturbed.

Historically, in the early 1970's, both Bean Creek and Zayante Creek near the San Lorenzo River had fecal coliform levels near, or above, the standards (Regional Board, 1974; Sylvester and Covay, 1978; S.C. County Planning Dept., 1979). In the case of lower Zayante, this may have resulted primarily from the high levels of contamination present in the upper Watershed at that time. During the current study, fecal coliform levels at both stations were variable.

During 1986, fecal coliform levels in Bean Creek were high (logmean of 296/100ml at Station 07109). Periodic very high levels, in conjunction with high fc/fs ratios, suggest contamination from human sources, possibly from the Lockhart Gulch area, where high counts were also found. In 1987 levels on Bean Creek were much lower (logmean of 178/100ml) and the periodic high counts were associated by low ratios and very high levels of fecal strep. Fecal coliform levels were elevated again in 1988 (logmean of 247/100ml), but the ratios were low (0.17-0.28), indicating animal contamination. Horses were observed at times upstream and around the creek. Lower Zayante Creek had generally low fecal coliform levels (annual logmeans of 121/100ml to 185/100ml at Station 070), but did have some intermittently high levels, particularly during the summer of 1986.

Both Bean Creek and Lower Zayante Creek are major sources of nitrate, with mean values of 0.79mg/l-N and 0.65mg/l-N, respectively. The high nitrate levels are a result of development and grazing activities overlying the highly permeable Santa Margarita Sandstone, which readily transmits nitrate to groundwater and surface water.

4.3.8 San Lorenzo River at Sycamore Grove

San Lorenzo River at Sycamore Grove (Station 022) is located approximately 5 miles downstream from Felton. Throughout most of this distance, there is no development at all, and no impact on the River other than recreational use in Henry Cowell State Park. A comparison of water quality at this station to the water quality at Big Trees (Station 060) provides a good indication of the capacity for natural water treatment in the River. During the summer, fecal coliform levels drop 35-55% between the two stations. Also during the summer the nitrate levels drop 67-75% as nitrates are taken up by the instream biota. As the River flows past Sycamore Grove into the City of Santa Cruz, it is quite clean with a logmean fecal coliform level of 75/100ml and a mean nitrate level of 0.3 mg/l-N. Water quality at this station may be indicative of what the water quality in the River would be if there were limited influence from development.

4.3.9 Carbonera Creek

Carbonera Creek joins Branciforte in Santa Cruz City and they flow into the River in the middle of the City. The upper reaches of Carbonera Creek drain the City of Scotts Valley, with very dense development along the banks and in the headwaters. Most of Scotts Valley is now sewered. Historically the quality has been very poor, with very high fecal coliform and nitrate levels coming out of Scotts Valley (Regional Board, 1974; Sylvester and Covay, 1978; S.C. County Planning Dept., 1979 and 1984). Current studies showed a persistence of those conditions, with a logmean fecal coliform level of 539/100ml and mean nitrate level of 1.04mg/l (Station 01149). This water quality is probably related to background contamination from development, as most of the area is sewered, and no persistent point sources of sewage contamination have been found. Fc/fs ratios are generally low, averaging 0.3. Most of the contamination seems to come from the tributary draining the Camp Evers area.

Below Scotts Valley, the Carbonera Creek corridor is largely undisturbed, and fecal coliform levels drop to 140/100ml before the creek joins Branciforte Creek (Station 0111). Nitrate levels actually increase slightly, with a large input from tributaries which drain developed areas and grazing areas overlying the Santa Margarita Sandstone.

4.3.10 Branciforte Creek

Branciforte Creek drains a moderately developed alluvial valley before it flows into the River in Santa Cruz. Historically, fecal coliform levels in the rural portion of the creek have been high (Sylvester and Covay, 1978; S.C. County Planning Dept., 1979 and 1984). During the current study fecal coliform levels were moderately high (logmean of 217/100ml at Station 0121). Generally low fc/fs ratios (mean of 0.36) indicate non-human sources, but there were several episodes of high fecal coliform (480-2530/100ml) and high ratio (3-4), suggesting intermittent wastewater contamination. There are a number of homes located very close to the creek.

Within Santa Cruz, the creek flows through a concrete flood control channel with numerous inputs from storm drains and groundwater seepage. Historically, fecal coliform levels in this part of Branciforte Creek have been very high, with suspected sanitary sewer leakage into the storm drains (S.C. County Health Dept., 1971-85). This trend continued in the current study, with logmean fecal coliform values of 870/100ml and average fc/fs ratios of 1.14 (Station 010). During the summer, the mouth of Branciforte Creek is frequently submerged in the backed-up lagoon of the lower River, and the water quality parameters at those times are more indicative of the lagoon environment, which appears to be significantly different from flowing water conditions (see below).

4.3.11 San Lorenzo River in Santa Cruz

Within the City of Santa Cruz, the San Lorenzo River flows through a broad, unlined flood control channel, with frequent storm drain input. The lower end is sometimes subject to tidal action, and during the summer is frequently backed up by formation of a sandbar at the mouth. The water at such times tends to be brackish and warm, and presents a very different aquatic environment than the flowing freshwater conditions found upstream.

This area has historically had the highest level of fecal coliform of anywhere along the River. The current study showed a logmean fecal coliform level of 824/100ml (Station 0003). Suspected causes of high bacteria levels are storm drain discharge, large concentrations of pigeons and gulls, sewage leakage into the storm drains, and possibly the long persistence of bacteria in the lagoon environment. Although high fc/fs ratios (2.5 at Station 003) suggest significant wastewater input, these ratios may also be influenced by the semi-estuarine environment. Over the years a number of sewer leaks have been identified and corrected, but high bacteria levels persist.

Although little follow-up work has been done yet, there are strong indications that the lagoon environment may have a significant influence on the presence and survival of bacteria, which may persist for long periods, and even multiply in the lagoon conditions. During the summer months the nitrate levels are typically very low (0.1mg/l-N) suggesting that all available nutrients are being taken up by micro-organisms present in the lagoon. Fecal coliform levels on several occasions have exhibited a typical pattern of a population expanding until it reaches the limits of its resources and then declining rapidly. Similar high fecal coliform levels and high ratios also occur in Capitola Lagoon in another part of Santa Cruz County.

4.4 Shallow Groundwater Quality

In order to evaluate whether septic systems are having a general cumulative effect on water quality, it is appropriate to investigate the quality of shallow groundwater in the immediate vicinity of septic systems. Degradation of shallow groundwater can result in cumulative contamination of surface water, and contamination of deeper groundwater bodies used for drinking water supply. Investigations of shallow groundwater can also provide information regarding the performance of onsite systems under different site conditions. This information in turn is useful for developing standards for installation of new systems and the upgrade of existing systems.

The 1981-82 study by H. Esmaili and Associates (HEA, 1982) provides the most comprehensive body of information on shallow groundwater quality in the San Lorenzo Watershed. In addition, the County has initiated a program of monitoring in the Boulder Creek area to specifically evaluate the impacts of systems in that area. These two studies will be discussed in the following sections.

4.4.1 Analysis of 1981-82 Shallow Groundwater Data

The HEA study included the monitoring of 86 shallow monitoring wells throughout the San Lorenzo Valley, upgradient and downgradient of leachfields in various soil and groundwater conditions. Up to 10 water quality samples were collected from each well from January 1981 through June 1982 and analyzed for nitrate, ammonia, fecal coliform, electroconductivity, and temperature.

Some samples were also analyzed for pH, chloride, chemical oxygen demand and Kjeldahl nitrogen. Measurements were made of setback from the closest upgradient leachfield and the depth to groundwater at the time of the sample. Information on the depth of the leachfield installation was used to calculate the vertical separation from the bottom of the leachfield to groundwater at the time of the sample collection.

HEA drew the conclusion that there was extensive shallow groundwater contamination in the San Lorenzo Valley resulting from septic tank effluent. This was based on the evaluation of mean and maximum values of nitrate, ammonia, and fecal coliform found in their monitoring wells. However, there were two significant weaknesses in their analysis, which render some of their conclusions invalid: they did not fully recognize the significant impact of rainfall on shallow groundwater quality, and their analysis did not recognize the very low fecal coliform levels that occurred during most of the study period, when there had been no recent rainfall.

A new analysis of HEA's raw data was performed, which utilized rainfall data and summarized fecal coliform data using logmeans (geometric means) rather than arithmetic means. Because fecal coliform data may vary by several orders of magnitude, the logmean is a more effective way of summarizing data. Logmeans are also typically used in evaluating surface water quality data. HEA used the arithmetic mean in most of their calculations, and as a result their conclusions showed much higher "average" levels of fecal coliform contamination. As an example, at a site with fecal coliform levels of 1000, 100, 1, 1, 1, 1, 1, 1, 1, and 1; the arithmetic mean would be 111, and the logmean would be 3. The logmean is more indicative of the prevalent low counts at that site.

Statistical analysis of the data was done using SPSS-PC+ software. An initial analysis of all 385 complete records was done to test for correlation between water quality parameters and independent factors of antecedent rainfall, leachfield setback, depth to groundwater, and vertical separation between the bottom of the leachfield and groundwater. A significant correlation was only found between fecal coliform levels and the amount of rainfall in the previous three days (A correlation was defined as significant if the probability of no significance was less than 0.05). However, even the correlation with rainfall was weak, with a Pearson correlation coefficient of 0.30, indicating significant variability in the data. The amount of rain in the previous 1 day, 7 days, or 30 days, did not have a significant correlation to water quality parameters.

Although there may not be a significant <u>linear</u> relationship among factors, as indicated by a correlation analysis, there may be a non-linear relationship among factors. This was evaluated by grouping cases corresponding to a range of values for a particular independent variable, and performing an ANOVA (analysis of variance) test to determine if there was a significant difference in the means of the dependent variable for different ranges of the independent variable. (Statistically significant differences were identified when the probability of no difference was less than 0.05.) In order to provide a large number of cases for analysis, and to provide a broad evaluation of water quality, all valid cases were included in the statistical analyses. Thus samples from all geologic types were generally combined in the analyses.

Parameters used for grouping in the ANOVA test included the following (the groups are described in parentheses):

- the degree of influence of septic systems on the monitoring well (downgradient of a particular septic system; upgradient, uninfluenced by septic systems; or influenced by no system in particular, but by a surrounding community of septic systems).
- setback from the closest upgradient septic system (0-15 ft, 15-24 ft, 25-49 ft, 49-74 ft, 74-99 ft, and 100 or more ft.)
- vertical separation between the leachfield bottom and groundwater at the time of the individual sample (submerged in groundwater, 0-5 feet separation, or greater than 5 feet separation).
- the amount of rain that had fallen in the three days prior to the sample collection (whether up to 0.1 inch had fallen or not).

As suggested by the correlation analysis, the amount of rain was found to have an overriding effect on fecal coliform levels, independent of other influences. The logmean of fecal coliform values for all samples collected when there had been no rain in the previous 3 days was only 3/100ml (arithmetic mean of 108/100ml). For all samples collected after rain had occurred in the previous 3 days, the fecal coliform logmean was 15/100ml (arithmetic mean of 543/100ml.

The ANOVA tests of data from wet weather samples showed no significant relationship between water quality values and proximity of septic systems. However, when the samples which were collected during non-rain conditions were analyzed, the ANOVA test showed a significant relationship between water quality and leachfield setback, vertical separation from groundwater, and general type of area sampled. Although these tests excluded samples taken when rain had occurred in the previous 3 days, at least half of the samples included in the analysis were collected during winter periods when soils were saturated and water tables were high.

The distance of the leachfield setback was found to have a statistically significant influence on nitrate levels in shallow groundwater if the setback was less than 25 feet, and a significant influence on ammonia and fecal coliform levels if the setback was less than 15 feet. Although the mean values for all parameters tended to decrease with greater distance from the leachfield, this decrease was not statistically significant beyond 25 feet.

Vertical separation from groundwater also has some statistically significant effect on groundwater quality when the groundwater was tested in relatively close proximity to a leachfield. Samples taken with the upgradient leachfields submerged in groundwater showed significantly higher levels of fecal coliform than those samples taken with the leachfield above the groundwater level. However, there was no statistically significant difference in fecal coliform values between samples collected when the groundwater was between 0 and 5 feet below the leachfield, and when the groundwater was greater than 5 feet below the leachfield. At distances greater than 25 feet from a leachfield, there was no statistically significant relationship between fecal coliform levels and vertical separation to groundwater, even if the leachfield was penetrating groundwater. Although there was no statistically significant relation between vertical separation and nitrate levels under any conditions, nitrate (and total inorganic nitrogen) actually tended to be higher with greater vertical separation. A summary of water quality values for different setback distances and groundwater separations during non-storm conditions is shown in Table 5.

An ANOVA test was also run to determine if there was any significant difference in water quality parameters for septic systems located in different geologic types. Alluvial soils and sandy soils had significantly higher levels of nitrate than clay or granitic soils (means of 2.60 mg/l-N, 3.06, 0.83, and 0.42, respectively). Clay soils had a mean ammonia level of 2.92 mg/l-N, more than double the mean levels in the other type of soils. The areas of clay soils studied had significantly higher groundwater levels and much steeper slopes (generally greater than 25%) than the study areas with other geologic conditions. The monitoring wells in the steep clay soils had much higher fecal coliform levels than alluvial soils, sandy soils or granitic soils (logmeans of 19, 6, 3, and 1 /100ml, respectively).

An analysis was also done to evaluate the effect of leachfield depth on water quality under circumstances where the leachfields were not penetrating groundwater, and the monitoring wells were at least 25 feet from the leachfield. An analysis of all soils combined showed a significantly greater downgradient nitrate level for leachfields deeper than 6 feet (3.7 mg/l-N) compared to leachfields less than 6 feet deep (1.2 mg/l-N).

Table 5: SUMMARY OF WATER QUALITY IN SHALLOW GROUNDWATER DOWNGRADIENT FROM SEPTIC SYSTEMS - NON-STORM CONDITIONS

FECAL COLIFORM DATA - Logmean (Mean) /100ml
Range
Number of Observations

Separation of Leachfield from Groundwater	Distance of Monitoring Well from Leachfield 0-24 feet	25-49 feet	50-99 feet	over 100 feet
Less than 0 feet (Submerged)	16 (439)*** 0 - 8100 54	5 (67) 0 - 980 31	3 (8) 0 - 40 9	8 (25) 0 - 92 5
0 - 5 feet	2 (97) 0 - 2182 21	5 (118) 0 - 1360 21	1 (2) 0 - 8 19	3 (5) 0 - 9 2
Greater than 5 feet	2 (27) 0 - 280 11	4 (53) 0 - 280 7	3 (35) 0 - 509 19	- - - - 0

NITROGEN DATA (mg/L-N): Nitrate: Mean (Maximum)
Ammonia: Mean (Maximum)

Separation of Leachfield from Groundwater	Distance of Monitoring Well from Leachfield 0-24 feet	25-49 feet	50-99 feet	over 100 feet
Less than 0 feet (Submerged)	2.67 (21.9)*** 3.21 (42.1)***	1.06 (8.5) 0.35 (4.8)	1.68 (8.4) 0.51 (2.3)	0.44 (1.54) 0.74 (2.5)
0 - 5 feet	4.71 (41.8)*** 3.48 (48.3)***	2.78 (34.3) 1.03 (11.2)	1.39 (12.1) 1.84 (17.4)	0.11 (0.2) 0.12 (0.23
Greater than 5 feet	5.05 (16.0)*** 4.33 (36.9)***	2.13 (8.7) 0.30 (0.96)	1.61 (9.8) 1.40 (9.3)	- - - -

*** - Denotes groups with mean water quality parameters significantly different fr other groups. Differences among undesignated groups are not statistically significant at the 0.05 probability level.

In order to provide a broad evaluation of overall influence on shallow groundwater quality, an ANOVA test was made on water quality parameters for the three general types of monitoring wells: those unaffected by septic systems, those downgradient of individual systems, and those subject to a cumulative community influence (as determined from descriptions in the HEA report). To discount the effects of immediate contamination, samples were only included in the analysis if the monitoring wells were located more than 25 feet from a leachfield. Nitrate levels in unaffected monitoring wells (mean of 0.44 mg/L) were significantly lower than levels in wells which are influenced by either upgradient septic systems (mean of 1.6 mg/L), or a community of surrounding septic systems (mean of 1.9 mg/L). However, there was no statistically significant difference in ammonia or fecal coliform levels for the three types of wells. The presence of fecal coliform in wells uninfluenced by septic systems also lends further support to the presence of significant sources of background bacterial contamination unrelated to septic systems.

Many studies in the literature have presented differing findings regarding the travel of contaminants from leachfields in soils and groundwater. Some studies show that bacteria are removed in less than a foot of travel through soils, others show that bacteria can travel hundreds of feet (Kaplan, 1988). The statistical analyses prepared for this study represent a different approach to the issue. The other studies have typically been designed to show how far contaminants <u>can</u> travel. The statistical analysis was done to determine the significance of the <u>amounts</u> of contaminants that typically travel those distances, particularly in relation to conditions found in the study area. The other studies indicate that there is a <u>potential</u> for contamination under certain circumstances; the statistical evaluation of data from operating septic systems indicates that, except for release of nitrate, that potential is small enough to not be statistically significant in conditions typically found in the San Lorenzo Valley.

This analysis evaluated the combined effects of approximately 40 septic systems; it did not provide an analysis of each system. Despite the fact that no statistically significant increase in fecal coliform was shown when all the systems were taken as a group, it is possible that an individual system may have a significant local impact on bacteria levels in shallow groundwater. It should also be kept in mind that this statistical analysis was performed on data from systems which were functioning satisfactorily and not experiencing surface failures. This analysis has no bearing on the impact of failing septic systems, which can have very direct and measurable effects on surface water quality, and pose a significant health hazard.

In conclusion, this analysis of the shallow groundwater monitoring data provides the following findings:

1. At setbacks of greater than 25 feet, there is no significant elevation of fecal coliform above background levels in shallow groundwater, even if leachfields penetrate groundwater.

2. During rainfall events, there is a significant increase in fecal coliform in shallow groundwater, even at locations with no obvious influence from septic systems.

3. During non-rainfall conditions, fecal coliform levels in shallow groundwater in the San Lorenzo Valley are generally very low (logmean of 3/100ml).

4. While it is possible that a single septic system may locally increase fecal coliform levels in shallow groundwater, this is not usually the case and when a large number of systems are evaluated, the cumulative effect is so low that it is statistically insignificant.

5. There is a substantial release of nitrate from septic systems to shallow groundwater, which is not much affected by the separation from groundwater.

6. Although nitrate levels are diminished over 25 feet from leachfields, the general nitrate levels in areas affected by septic systems tend to be 4 times greater than levels found in groundwater unaffected by septic systems and associated development. This is more pronounced in soils which have higher permeability rates.

The re-analysis of the HEA data appears to refute their conclusion that there is extensive fecal coliform contamination of shallow groundwater resulting from septic systems in the San Lorenzo Valley. However, their conclusion that there is significant nitrate release from septic systems is maintained, if not strengthened. This nitrate release seems to be unaffected by groundwater separation. The best way to prevent significant adverse effects from nitrate release is to maintain a low enough density of homes to provide adequate dilution of groundwater by natural recharge. It is also important to construct leachfields shallow enough to allow for nitrogen removal in the upper soil layers. Thus the HEA recommendation for installing shallow leachfields, and maintaining a minimum of lot size of at least one acre are still quite valid. The subject of nitrate release is further discussed in Sections 4.5 and 4.6.

4.4.2 Shallow Groundwater Quality in Boulder Creek

In order to help re-evaluate the validity of the methods used in the collection of data from the HEA study, and to specifically evaluate shallow groundwater conditions in the Boulder Creek area, the County initiated a program for monitoring the quality of shallow groundwater in the downtown area in February, 1988. This area was not included in the HEA study.

Seven monitoring wells were drilled to bedrock, approximately 20 feet deep, in the alluvial soils which underlie the downtown area. An attempt was made to locate all wells at least 50 feet from nearby septic systems in order to evaluate the cumulative impacts on groundwater quality. Subsequently, one well was discovered to be located within 15 feet of an old leaking septic tank, which significantly affected the quality.

The monitoring wells were monitored at least monthly, with 80 samples collected in 1988 and early 1989. Wells were tested for fecal coliform, fecal strep, enterococci, nitrate, ammonia, and Kjeldahl nitrogen. The results of these analyses are shown in Table 6.

Table 6: Summary of Water Quality in Shallow Groundwater in Boulder Creek, 1988-89

MONITORING WELL, LOCATION	DEPTH TO GROUND-WATER (INCHES) MEAN MAXIMUM MINIMUM	NITRATE-NITROGEN (mg/l-N) MEAN MAXIMUM MINIMUM	AMMONIA-NITROGEN (mg/l-N) MEAN MAXIMUM MINIMUM	KJELDAHL-NITROGEN (mg/l-N) MEAN MAXIMUM MINIMUM	FECAL COLIFORM /100ml LOGMEAN MAXIMUM MINIMUM	FECAL STREP /100ml LOGMEAN MAXIMUM MINIMUM	ENTERO-COCCI /100ml LOGMEAN MAXIMUM MINIMUM	FC/FS RATIO MEAN MAXIMUM MINIMUM
#1, JUNCTION AVE	125.36	5.62	.16	1.28	1.36	148.59	2.67	.
	190.7	18.0	.3	2.1	130.0	3750.0	120.0	.
	79.0	.6	.1	.8	0.0	0.0	0.0	.
#2, RAILROAD AVE	103.28	.30	.09	1.40	3.71	164.55	4.81	.12
	124.0	1.0	.1	2.4	580.0	5800.0	100.0	.40
	81.8	.0	.1	.7	0.0	0.0	0.0	.01
#3, OAK / HWY 236	118.63	4.36	.05	2.50	1.21	120.86	3.34	.03
	154.0	9.0	.1	2.8	10.0	4600.0	70.0	.03
	90.0	.5	0.0	2.2	0.0	0.0	0.0	.03
#4, OAK	139.25	7.55	.08	2.50	1.64	497.66	.	.
	178.0	22.0	.1	2.5	12.0	5100.0	.	.
	122.0	1.2	.0	2.5	0.0	33.0	.	.
#5, E. OAK	170.67	10.58	.28	2.13	114.18	474.22	220.00	.49
	206.0	19.0	.5	2.8	1200.0	5700.0	220.0	1.36
	107.0	.5	.1	1.4	0.0	0.0	220.0	.03
#6, OAK / LOMOND	149.43	5.92	.11	1.20	1.00	50.14	4.74	.
	193.0	13.0	.2	1.7	0.0	3200.0	180.0	.
	112.0	.2	.1	.6	0.0	0.0	0.0	.
#7, LAUREL / HWY 236	160.28	3.80	.11	1.85	1.45	233.93	3.31	.
	175.0	10.0	.2	2.1	20.0	4000.0	40.0	.
	124.0	.5	.1	1.6	0.0	0.0	0.0	.

The results of the Boulder Creek monitoring are fairly consistent to those found for the HEA study. Except for the well near the septic tank (#5), there was no evidence of significant contamination by fecal coliform, as indicated by an overall logmean of 2/100ml. Significant levels of fecal strep bacteria and some enterococci were found in most monitoring wells (logmeans of 158/100ml and 4/100ml, respectively). It is suspected that this results from bacteria occurring in the soil, or background levels of non-wastewater contamination. Significant amounts of fecal strep have been reported in both forest soils and pasture soils (Faust, 1982).

The mean nitrate level found in Boulder Creek was 5.44 mg/l-N, somewhat higher than the mean found in other alluvial areas during the HEA study. However, mean ammonia levels are much lower than those from the HEA study. It may be that during the drier conditions of 1988, the ammonia was mostly converted to nitrate. Higher nitrate levels in the shallow groundwater may also result from increased density of septic systems and/or the dry conditions of the previous two years which would result in less dilution of the nitrates released from septic systems. Significant amounts of organic Kjeldahl nitrogen were found in the wells, with an overall mean of 1.83 mg/l-N. There seemed to be no real pattern to the distribution of the Kjeldahl nitrogen, except that it correlated significantly with the amount of antecedent rainfall. It may be related to the flushing of organic compounds out of the upper unsaturated soil layers. This would correspond to findings from the Scotts Valley area (see Section 4.5.3.2).

The localized effect of a septic system was evident in the results from the monitoring well which was located approximately 15 feet from an old leaking tank. The ANOVA test showed that all water quality parameters were significantly different for this well, with a fecal coliform logmean of 114/100ml, compared to a logmean of 2/100ml for the other wells. Nitrates and ammonia were also elevated to twice the levels found in the other wells. Fecal strep levels were not significantly different, but the fecal coliform/fecal strep ratio was significantly higher (0.49), compared to other wells (0.12). This tank was later replaced and relocated, but the monitoring well was destroyed in the process.

The Boulder Creek investigations indicate that there is significant cumulative nitrate release to shallow groundwater which eventually drains to the River. However, there is no evidence of accumulations of fecal coliform in shallow groundwater. This provides further evidence that the periodic bacterial contamination by wastewater of the River downstream from Boulder Creek results from intermittent surface failures, and is not caused by cumulative impacts from the large majority of septic systems that are properly discharging effluent under the ground.

4.5 Nitrate Release to Groundwater

It is clear from the previous section that septic systems release significant amounts of nitrate to groundwater. This input of nitrate, as well as nitrate from other sources, can have significant impact on the quality of groundwater supplies and on surface waters which receive nitrate-rich groundwater. This section will focus on the impacts of nitrate in groundwater, and the following section (4.6) will address the impacts of nitrate release to surface water.

4.5.1 General Considerations

Excessive nitrate in drinking water can cause adverse public health effects. The most notable of these is methemoglobinemia, or "blue baby" syndrome, in which nitrate in the blood impairs the function of hemoglobin in transporting oxygen to body tissue. There is also speculation that ingestion of nitrate may result in formation of nitrosamines, some of which may be carcinogenic (HEA, 1982). However, this action has not been confirmed, and there has been no determination as to the concentrations at which this is a potential danger. In order to prevent methemoglobinemia, the drinking water standard for nitrate has been established at 10mg/l-N (expressed as nitrogen), or 45mg/l-NO3 (expressed as nitrate). For consistency all nitrate concentrations in this report are expressed as nitrogen.

Nitrate is one of many types of nitrogen compounds that may be present in the environment. Nitrogen compounds are essential for biological activity, and are readily transformed into other forms of nitrogen by biological processes which take place in soil and groundwater. Collectively these processes are known as the nitrogen cycle, and have a very strong influence on the amount of nitrate that may eventually enter groundwater or surface water from any given nitrogen source. An overview of the important elements of the nitrogen cycle provides insight into the extent to which various nitrogen sources contribute to eventual nitrate contamination.

<u>Nitrogen fixation</u> is the process by which certain soil bacteria and blue-green

algae can convert elemental nitrogen from the atmosphere into organic nitrogen compounds for their own use, for plant uptake, or release to the soil through decay. Fixation is the primary mechanism by which nitrogen compounds enter the terrestrial ecosystem under natural conditions. Nitrogen assimilation is the uptake of mineral forms of nitrogen, such as ammonia or nitrate, by plants which convert it to organic forms of nitrogen in the plant tissue. This is available for consumption by animals or eventual return to the soil by decay. Animals, including humans, excrete nitrogen back to the environment, primarily as ammonia, or closely related compounds.

Ammonia is not very mobile in soil, and will be held until it is taken up by plants, or converted to oxidized forms of nitrogen through nitrification. This takes place readily in the presence of oxygen, and results in the formation of nitrate. Nitrate is very mobile and is carried readily by water moving through the soil. In highly permeable soils, nitrate can be rapidly carried out of the biological zone of the soil and down into groundwater. In the presence of organic material and absence of oxygen, nitrate will be converted to elemental nitrogen through the process of denitrification. Although denitrification tends to take place under saturated conditions, it can also occur at "micro-sites" with very localized saturated conditions in an unsaturated soil, if there are adequate amounts of organic compounds present (Mendenhall, 1986).

Dilution is also a factor which greatly affects the nitrate concentrations in underlying groundwater. Where sources of nitrate are limited and natural rainfall is high, or there is rapid movement of uncontaminated groundwater, the nitrate levels will be significantly reduced.

Different soil and groundwater conditions will affect the operation of the various elements of the nitrogen cycle, with significant effects on the amount of nitrate which may be released to groundwater. Clay soils tend to promote nitrogen assimilation, reduce rates of nitrification, and increase rates of denitrification, resulting in relatively higher ammonia levels and little release of nitrate. In highly permeable sandy soils, oxygen is generally available, contributing to nitrification and rapid leaching out of nitrate, with reduced opportunity for denitrification or assimilation. Because sandy soils transmit much greater amounts of nitrate to underlying groundwater, most of the discussion of nitrate contamination will focus on nitrate release from areas of sandy soils.

High groundwater conditions and soil saturation may tend to result in lower nitrate levels by limiting the formation of nitrate by nitrification. A fluctuating water table may present opportunities for alternating nitrification and denitrification at the boundary of saturation. High groundwater may also lead to reduced nitrate levels through increased dilution. The shallow groundwater sampling done by HEA (1982) showed significantly greater nitrate (and total nitrogen) where the depth to groundwater below septic system leachfields was greater, particularly in areas with alluvial soils. The monitoring data seemed to indicate that even in sandy soils, nitrogen from septic systems was being reduced significant treatment and dilution. Nitrate concentrations in groundwater very close to leachfields were only 20% of the nitrate concentration typically found in effluent. Nitrate removal might also be expected to take place to some extent in the leachfield environment, as discussed in the next section.

4.5.2 Potential Sources of Nitrate

Release of nitrate to groundwater can result from any activity which produces nitrogen compounds. These can include natural growth of vegetation, land disturbance, animal wastes, fertilizers, garbage accumulation, or septic systems.

Under natural conditions, certain types of vegetation and micro-organisms fix nitrogen from the atmosphere and convert it to organic nitrogen, which is then stored in plant tissue and in the organic material in soil. As the organic material is decomposed, soluble nitrogen compounds are produced which may be taken up by plants or carried down into underlying groundwater by percolation of rainfall. As a result of these processes, groundwater in the Santa Margarita Sandstone of the San Lorenzo Valley has a natural background nitrate level of 0.3 mg/l-N (HEA, 1982). If natural vegetation and soils are disturbed through vegetation removal, grading, tilling, or other activities, the nitrogen compounds that were held in the soil and vegetation break down and are converted to nitrate which may leach into underlying groundwater. This would be expected to be a short-term impact, and as vegetation recovered the impact would diminish.

Accumulations of animal wastes can contribute nitrogen compounds to soil and underlying groundwater. This would be most significant where there are concentrations of large animals, such as horses, particularly in areas that are underlain by sandy soil. There are locations in the San Lorenzo Watershed where horses are kept in confined areas: Bear Creek, Lower Zayante Creek, Felton, Bean Creek, Carbonera Creek, and Branciforte Creek. With the exception of Bear Creek, all these areas experience some of the highest nitrate levels in surface water. Diffuse accumulations of animal waste and garbage would add to the total nitrogen release from residential areas overlying sandy soils, and would become more significant with increasing density.

Fertilizer applications can have very dramatic impacts on nitrate levels in groundwater. In many agricultural areas of the state, nitrate levels in underlying groundwater exceed safe drinking water standards. Although there are no large agricultural areas in the San Lorenzo Watershed, fertilizers applied to residential landscaping can have a significant effect. For example, in a suburban area of Long Island, where septic tanks were also used, it was found that residential fertilizer applications contributed 50% of the nitrates found in groundwater (Rayone, 1981). There is extensive landscaping in residential areas of the San Lorenzo Watershed, particularly in areas with very sandy soils, such as Quail Hollow and Scotts Valley. In the Quail Hollow area it was estimated that nitrogen from fertilizers could add an additional 20-60% of the nitrogen released by septic systems (Johnson, 1988). There are also several golf courses in the Watershed, above Boulder Creek and Scotts Valley, which would be expected to utilize large amounts of fertilizer.

The nitrogen source of major concern for this study is wastewater disposal. Septic system effluent has a typical nitrogen concentration of 50 mg/l-N, 80% of which is in the form of ammonia, with the remainder as organic nitrogen (HEA, 1982). The amount of nitrogen which eventually percolates to groundwater depends on the extent of treatment provided by the disposal system and the soil, which provides for removal of nitrogen by plant assimilation and denitrification.

Soil treatment of effluent is greatly affected by the soil and groundwater conditions where disposal takes place. Nitrogen removal is high in clay soil, as indicated by the relatively low nitrogen levels measured by HEA (1982) in shallow groundwater greater than 15 feet from septic systems in clay soils (0.5 mg/l-N), and the low levels of nitrogen in streams draining areas with clay soils. In sandy and alluvial soils there is reduced potential for treatment, and increased potential for rapid downward leaching of nitrate. In sandy soils, average combined nitrate and ammonia concentrations in shallow groundwater in close proximity to septic systems were found to be 9.4 mg/l-N (HEA, 1982). In alluvial soils, average levels were 6.8 mg/l-N. It thus appears that in addition to dilution, significant treatment occurs in sandy and alluvial soils.

It would be expected that the leachfield and sandy soil environment presents conditions suitable for at least some removal of nitrogen through nitrification and denitrification (Mendenhall, 1986). Wherever there is an alternation of unsaturated and then saturated conditions, there is opportunity for nitrification and then denitrification In the controlled environment of a sand filter, up to 50% of the nitrogen is removed by biological treatment in the sand (ODEQ, 1982). Even in a conventional leachfield, there is opportunity for some treatment. The effluent is first subject to nitrification as it percolates through the upper, unsaturated portion of the leachfield, and then a suitable environment for denitrification is provided in the saturated area at the bottom of the leachfield.

If septic systems have shallow leachfields, with effluent disposal in the upper 6 feet of soil, there is more opportunity for biological treatment and removal of nitrogen by plant assimilation and denitrification. Septic systems with pits or deep leachfields will contribute more nitrate to groundwater, due to the diminished biologic treatment at deeper levels. The shallow groundwater monitoring by HEA in sandy areas of the Watershed showed nitrate levels three times greater for leachfields over 6 feet deep than for more shallow leachfields.

Alternative types of onsite disposal systems can help promote nitrogen removal. As mentioned above, sand filters provide for removal of 50% of the nitrogen. Similar action might be expected in mound systems and pressure-distribution systems where there is dosing of the effluent absorbtion device, and an alternation of saturated and unsaturated conditions. In the HEA study, mean nitrogen levels close to mound systems were 3.7 mg/l-N, about half the level found in similar alluvial soils with standard disposal systems. Experimental system designs have also been proposed which directly promote denitrification, resulting in removal of 75% of the nitrogen prior to discharge to the soil (Laak, 1982).

Regardless of the potential source, once nitrogen is converted to nitrate, it is relatively mobile and begins to percolate downward towards the water table, which marks the upper edge of the saturated zone. In a highly permeable geologic formation like the Santa Margarita sandstone, virtually all of the nitrogen in groundwater is in the form of nitrate. However, the unsaturated zone between the soil surface and the water table may hold significant amounts of organic nitrogen and nitrate, as indicated by sampling done in the Scotts Valley area (Luhdorff and Scalmanini, 1986). This stored nitrate may enter the groundwater in large concentrations of nitrate as a result of downward flushing of recharge water, or by a rise in the water table which saturates the area where the nitrogen is stored and mobilizes it.

Nitrate concentrations in an aquifer are also affected by the broad characteristics of the groundwater basin. These include the location and density of potential nitrogen sources, location of recharge areas and amount of recharge, direction and rate of groundwater flow, the structure of the basin, the depth to groundwater, the location of wells, and the amount of groundwater withdrawal. Water in a groundwater basin generally moves quite slowly with little mixing, and contaminant plumes tend to remain intact (Miller, 1985). There can thus be significant vertical and horizontal variations in nitrogen concentrations. Variations in recharge will also affect nitrate concentration. During periods of high rainfall, nitrate inputs are significantly diluted, generally resulting in lower concentrations. However, periods of recharge may also have the potential to flush accumulated nitrates out of the unsaturated zone between the ground surface and deep groundwater.

Groundwater withdrawal from a well can have a significant effect on nitrate concentrations measured in that well. The localized drawdown of the groundwater surface will alter the direction and rate of flow, generally diverting flow from the surrounding area toward that well. If there are sources of nitrate within that increased zone of influence, nitrate concentrations will increase. Cessation of pumping will cause the water level