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# LAND USE IMPACTS ON NONPOINT SOURCE POLLUTION

# IN COASTAL NEW HAMPSHIRE WATERSHEDS

FINAL REPORT

Submitted to the New Hampshire Coastal Program

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by

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# INTRODUCTION

The overall objective of the proposed project was to develop an effective system for assessing the potential for NPS pollution problems in coastal New Hampshire watersheds. The Oyster River watershed (Figure 1) was chosen for study as a model, manageable whole system that has a potentially significant impact on coastal water quality, and detailed land-use assessments have been conducted recently in the two small watersheds. The approach involved treating tributaries to the larger Oyster River watershed as nonpoint sources that could be subject to management activities after initial assessment. The results of management of NPS problems in the tributaries should be improved water quality in the larger watershed as a whole, barring any new or accelerated problems in the main river or other, non-target tributaries. Work was concentrated in in the tidal area of the main river (Figure 2) and in two small watersheds, the Johnson Creek (Figure 3) and Beards Creek (Figure 4) watersheds. Information on land use characteristics and natural features of watershed landscapes was integrated with water quality data to determine conditions that are conducive for significant NPS pollution. Existing literature, NPS models, and related studies were reviewed to insure comprehensive consideration of all potential factors. Field assessment activities added to the database established in a previous project, but focused in great detail on the Johnson Creek sub-watershed, and to a lesser extent, the Beards Creek watershed.

The specific objectives were as follows:

1. To establish a baseline of water quality data for the Oyster River watershed;
2. To conduct an intensive assessment of NPS pollution in a specific sub-watershed within the Oyster River watershed;
3. To identify the critical elements of watershed characteristics and land use information needed to effectively assess the potential for nonpoint source pollution and its abatement;
4. To evaluate the effectiveness of the critical elements identified in objective #3 along with water quality data for predicting NPS loading in other sub-watersheds.

## ANALYTICAL AND SAMPLING METHODS

Microbiological analysis of water samples included tests for fecal coliforms, *Escherichia coli* , enterococci, and *Clostridium perfringens*. Fecal coliforms and *E. coli* were measured using standard multiple tube fermentation, MPN analyses, and

*C. perfringens* by a standard membrane filtration method. Enterococci were measured using methods recommended by the U.S. Environmental Protection Agency. Fecal coliforms are the standard indicator for shellfish-growing waters in New Hampshire based on recommendations by the National Shellfish Sanitation Program. *E. coli* is the standard for fresh recreational waters of New Hampshire and is the actual target organism of fecal coliform tests. Enterococci are the standard indicator for the estuarine recreational waters of New Hampshire, and *C. perfringens* is an indicator of long-term fecal contamination that is being used with increasing frequency in related studies.

Additional water samples taken at the same time as those for microbial analysis were analyzed for total suspended solids, % organic content, photosynthetic pigments and nutrients. All samples were collected in duplicate and 500 ml of each sample were filtered through pre-weighed, pre-dried glass fiber filters (1.2 µm pore retention), for suspended solid analysis and % organic content. The remaining 500 ml of each sample were filtered and analyzed for photosynthetic pigments. Filtrates were analyzed for dissolved nutrients (nitrate-nitrite, ammonium, orthophosphate) using LACHAT autoanalyzer flow injection, spectrophotometric methods.

All water quality data were entered into spreadsheets on Macintosh computers for developing a database, statistical analysis and accompanying graphical representations of the data. Monthly average rainfall for Durham compared to normal rainfall is illustrated in Figure 5. Rainfall amounts for 3 days prior to sampling dates are also presented in Table 1.

## RESULTS

### OBJECTIVE 1

The geometric average levels of fecal coliforms and enterococci at sites along the main tidal portion of the Oyster River are presented in Figure 1-1. Levels are relatively low near the mouth of the river (sites 1-3), then increase near site 4, which is at the mouth of Bunker Creek. Levels remained high up to site 6, at the mouth of Johnson Creek, suggesting that sources of contamination were present throughout this area. Levels were lowest at site 8, which is at the end of the effluent pipe from the Durham POTW. This was a function of the residual chlorine in the effluent that essentially disinfected the river at that point. This effect was also apparent at sites just upstream (site 7) and downstream (site 12), which also had low average levels. Upstream of this area, the levels increased dramatically once again, with highest levels at site 9 at the mouth of Beards Creek. High levels were also observed at Town Landing (site 10), and above the dam at site 11. These results suggest that Beards Creek and the freshwater portion of the Oyster River are both relatively contaminated compared to the well-mixed estuarine waters at the mouth of the

Oyster River. At high tide, levels were lower that at high tide at the three sites sampled, with levels increasing going upstream.

The results for *C. perfringens* in the tidal Oyster River are presented in Figure 1-2. *C. perfringens* is a spore-forming anaerobic pathogen that can survive adverse environmental conditions extremely well. Levels of this indicator increased going upstream to sites 12, 8 and 7. These sites are near the POTW outfall pipe, and these results show how *C. perfringens*, which is relatively resistant to the chlorination process, is discharged with the effluent. Other related studies have shown that *C. perfringens* is also closely associated with suspended particles in the water column, and probably sediments out of the water column with the settling particles relatively rapidly. Thus, levels this indicator appears to be related to POTW effluent, and probably any resuspension of sediments, in addition to potential direct fecal contamination sources. Levels upstream of the POTW were highest at site 9 off Beards Creek, and were quite low in the freshwater portion of the river.

Analysis of data for specific sampling dates shows that contaminant concentrations are quite variable, ranging from relatively low to high levels. In addition, comparison of levels to rainfall amounts suggests that the intermittent occurrences of elevated contaminant concentrations have not been observed necessarily in association with definable events, such as rainfall/runoff events. Average levels for samples collected during the four seasons are presented in Figures 1-3 to 1-5. It appears that for sites where one season had significantly higher levels, the typical season for this occurrence was spring for fecal coliforms and *C. perfringens*, and no season in particular for enterococci. Some of the sampling dates during spring followed significant rainfall events, but the dates with the highest levels (Table 1-1) followed relatively dry periods (Table 1).

Transect stations in the Oyster River were sampled for nutrient concentrations in FY 1994, though less frequently than in FY 1993. Stations 1, 6, and 10 were sampled on 18 occasions while most others were sampled on five occasions. Data was collected in the summer, fall and spring only, due to the heavy ice cover from late December through March. Nutrient concentrations measured at the transect sites are presented in Tables 1-3, 1-4 and 1-5. Annual and seasonal means of nutrient concentrations are presented in Figures 1-6 thru 1-11. As was the case for FY 1993, Station 8 (Durham POTW) had the highest concentrations of all the nutrients measured. It is difficult to compare NO3 and NH4 concentrations at the outfall site separately for the two years, since the ratio of these two species of nitrogen in the effluent fluctuate daily. Combined dissolved nitrogen (NO3+NH4), however, was slightly higher in FY 1993 than 1994. PO4 concentration at the outfall site and for most other sites, however, was higher in FY 1994. Concentrations of NH4 and NO3 at the other stations were similar to FY 1993, and the effect of tidal flow direction, with the POTW as a reference point, was evident. Though not illustrated in the charts, samples upstream of the POTW showed elevated levels of nutrients at high tide (Tables 1-3 thru 1-5). Besides the POTW site, highest ammonium concentrations were detected at stations 12 (Unnamed Creek), 7 (Horsehide Creek), station 3, station 6 (Johnson Creek), and the Town Landing (station 10). The elevated concentrations at stations 7 and 12 are due to their proximity to the POTW. High tide concentrations of NH4 at town landing, which were higher than at low tide, are likely influenced by the POTW (Table 1-3). Besides the POTW and adjacent stations, NO3 concentrations were highest at Johnson Creek ( station 6) and town landing (station 10).

Seasonal comparisons were difficult to make for all stations due to the unequal number of sample dates for all stations in all seasons. At the stations where all seasons were sampled somewhat equally (Stations 1, 6, and 10) highest concentrations of NH4 and NO3 were obtained in the fall. At stations where only summer and spring had a sufficient number of samples, NH4 for the most part was higher in the summer, while NO3 was higher in the spring. With the exception of Station 7, summer PO4 levels were higher than the other seasons. The higher summer concentrations of nutrients may have been due to the lack of rainfall and therefore lower dilution of the nutrients.

The effects of rainfall on nutrient concentrations was examined to determine if there was a response to rainfall within 24, 48 and 72 hours of sampling. No trends were detected, in fact, the day on which all stations had the highest concentrations of ammonium and phosphate (9/8/93) was preceded by three days with no recorded rainfall.

## Estimated loading of dissolved inorganic nitrogen, phosphate and microbial contaminants from point and non-point sources in the tidal portion of the Oyster River

### Introduction

A two part study was conducted in 1993-1994 to determine the contributions of dissolved inorganic nitrogen and phosphate from point and nonpoint sources in the Oyster River. The initial part of the study focussed on transport and dilution of these compounds from the point source origin at the outfall of the Durham Sewage Treatment Facility. The effluent plume was tracked along a five station transect in the river, and the results indicate that the treatment plant has a significant influence on dissolved nutrient concentrations at downstream sites during the ebb tide and at upstream sites during the flood tide. Analysis of the nutrient concentrations measured over a two year period at 12 sites along a transect in the river, as well as site specific studies in the sub-watersheds of the river, indicates that there are other more diffuse sources of nutrients to the river as well. In order determine the relative contribution of these diffuse sources to the dissolved nutrient concentration throughout the river, flows were measured at the mouths of the largest tributaries to the river. Mean nutrient concentrations calculated for the two year study period were then applied to the flow rates to determine loading.

## Methods

Rate of flow was measured during high (March 23, 1994) and low flow (September 17, 1994) periods in Bunker Creek, Johnson Creek, Unnamed Creek and Beards Creek using a Marsh-McBirney model 201D electromagnetic current meter attached to a custom stainless steel top setting wading rod. Stream width was measured at the location of deployment of the flow meter. Depth was measured with the wading rod, and the probe was set at 0.60 the depth of the water (Marsh-McBirney, 1988). Water flow was measured at 0.50 meter intervals across the width of the stream, and the depth of the probe was adjusted to water depth for each measurement. All measurements were made at low slack tide.

Stream dimensions and average velocity were used to calculate stream discharge for the above mentioned streams. River discharge data for the main stem of the Oyster River was obtained from the USGS flow gauge data from the Oyster River (Toppin et al. 1994). Average annual stream discharge for the tributaries was calculated by averaging the discharge during low flow and high flow conditions. Tributary flows for those two dates were then compared to the published discharge data for the main stem of the Oyster River. The relationship of the measured flow in the Oyster River to the calculated mean daily discharge was used to adjust the average stream discharges. Mean concentrations of dissolved inorganic nutrients were then used to calculate the # of kilograms per year of nitrogen and phosphate entering the river.

Nutrient loading from the Durham Sewage Treatment Plant was calculated from annual average flow measured at the plant and from the mean of values obtained for effluent nutrient concentration measured during the dispersion/dilution study referenced above.

## Results

Results of the determination of total stream discharge from the tributaries and the calculated loading of dissolved inorganic N&P from the streams (NPS) and the Durham POTW) are presented in Tables 1-6 and 1-7. For dissolved inorganic N (NH4+NO3), approximately 25,985 kg/yr comes from the POTW, approximately

28,541kg/yr from the tributaries for a total of 54,526 kg/yr. The calculated percent contribution of dissolved N from nonpoint sources was ≈ 52%, while the POTW contributed ≈ 48% (Tables 1-6, 1-7, Fig 1-12) The main stem of the Oyster River accounts for >41% of the NPS-N, and ≈22% of the total N. Of the tributaries, Johnson Creek (30% of NPS, 16% of total N), followed by Beards, Bunker and Unnamed Creeks, contributes the highest percentage of N to the river.

The situation for dissolved inorganic PO4 was quite different. Total estimated loading was ≈ 10,628 kg/yr, of which 2,421 (≈23%) came from nonpoint sources, and the remaining 77%, or 8,207 kg from the POTW. Of the nonpoint sources, Johnson Creek contributes the largest portion (34% of NPS, 7.7% of total), followed by the Oyster River, Beards and Bunker Creeks. Percent contribution of P from Unnamed creek is minimal (Tables 1-6, 1-78, Fig. 1-13).

Calculated annual stream discharge figures were applied to mean concentrations of fecal coliforms and enterococci to estimate annual loading of microbial contaminants to the river (Table 1-8, Fig. 1-14). These estimates indicate that the greatest source of both fecal coliforms and enterococci is the main stem of the Oyster River, followed by Johnson, Beards, Bunker and Unknown Creeks. The estimated loadings of fecal coliforms from the POTW and enterococci are insignificant by comparison.

## Discussion and interpretation

Though weights and percentages of nutrient and bacterial loading are reported in this study, the reader should be aware that these figures are estimates, and that there are many potential sources of error or variation in the data used to calculate the figures. To begin with, only the dissolved inorganic portions of both N and P were used in the calculations. Though these are the forms of these compounds that would be readily available to plants, they by no means represent the total picture of nitrogen and phosphorus loading. The flow from each of the tributaries was measured on only two occasions, and the river gauge data (Oyster River) was used to adjust the average flow. This averaging may also be a source of error. Concentrations of nitrogen and phosphorus in the POTW effluent were calculated from relatively few samples, though based on the results of the dilution/dispersion study and the large data set for nutrient concentrations at the outfall pipe, these concentrations seem to be a reasonable estimate. Additionally, there are other, smaller creeks that empty into the river (Horsehide Creek, Deer Meadow Creek, Smith Creek, etc.), so there is likely additional nonpoint source input, as well as natural and anthropogenic riparian sources that may have direct groundwater or surface flow connection to the river. These sources would be much more difficult to measure, though they may increase the percentage contribution of NPS nutrient contamination.

It is interesting to note that besides the main freshwater stem of the Oyster River (due to the much greater volume of water), Johnson Creek seems to be the greatest source of dissolved nutrients and bacterial indicators to the tidal portion of the Oyster River. The Johnson Creek watershed was a focus of the land use impact assessment study, and the primary land use and possible contaminant sources identified were private sewage disposal systems associated with residential development.

Dispersion and dilution of nutrients from the Durham POTW outfall

Summary

In July of 1993, a study was conducted to measure the effect of nutrient loading from the POTW effluent on the nutrient concentrations in the Oyster River. Five stations were established in a horizontal transect bracketing the outfall pipe and sampled hourly for six hours during the ebbing tide on 7/14/93 and hourly during the flooding tide on July 21, 1993. Measurements of temperature, salinity, dissolved oxygen, and pH were made at the time the samples were taken. Vertical profiles of the physical parameter measurements were done each hour at the effluent pipe. Water samples were analyzed for concentrations of $NO_3^-$, $NH_4^+$, $PO_4^{-3}$, total suspended solids, and photosynthetic pigments. Results of the study indicate that the POTW effluent has a major impact on the nutrient concentration in the River and that the effluent plume travels in the direction of the flow of tidal currents, affecting the downstream portions during ebbing tide and the upstream portions on the flooding tide. In addition, the nitrogen species in the effluent varies, with high NO3 and lower NH4 discharged on 7/14 and the reverse on 7/21.

Introduction

From July 1992 thru June 1993, the first year of a study of non-point source pollution was conducted on the tidal portion of the Oyster River. Elevated nutrient concentrations were detected at 12 stations arranged in a horizontal transect starting at the mouth of the river extending to the upper tidal limit at the dam in Durham, NH. It was determined that although some of the tributaries contribute to the overall nutrient loading in the river, the highest concentrations of nutrients (NO3, NH4 and PO4) were found at the POTW outfall site (station 8, see updated data base in another section of this report), and at those stations closest to it, indicating that

that the treatment plant was a major source of nutrients (Jones and Langan, 1993). A second year of the study was proposed and included in that study was the determination of the relative contributions of point and non-point sources to the concentration of nutrients in the tidal portions of the river. This report on the POTW study represents the point source portion of the nutrient loading study.

## Materials and Methods

Five stations were established along a horizontal transect in the Oyster River, with the middle station (station 3) located at the POTW outfall pipe; station 1 in mid-channel near the mouth of Beards Creek; station 2 midway between stations 1 and 3; station 4 in mid-channel near the mouth of unnamed creek; and station 5 in mid-channel near the mouth of Johnson Creek. The study was conducted in two parts; the ebb tide portion was done on July 14 and the flood tide portion on July 21. Replicate one liter water samples were obtained by subsurface grab hourly at each station beginning at slack high water on July 14 and at slack low water on July 21. All sample bottles were previously acid-cleaned, and samples were placed immediately on ice and out of direct sunlight. During the third hour of sampling on each date, replicate samples were obtained from inside the treatment plant to determine the nutrient concentrations of the undiluted effluent samples. Measurements of temperature, salinity, dissolved oxygen and pH were made at the time the water samples were taken. A vertical profile of temperature, salinity and dissolved oxygen at the POTW outfall was established each hour following the last sample to determine if stratification was occurring.

Samples were filtered within seven hours following the first sample collection. 500 ml of each sample was filtered through previously washed, dried and weighed glass fiber filters (1.2μ nominal pore size) and the filtrate divided into three acid cleaned containers. The containers were immediately frozen at - 20°C and analyzed for nutrient concentration within 14 days. The filter was dried for 24 hours at 80°C, weighed to obtain the suspended solid weight, then placed in a muffle oven at 450°C for 4 hours. The filter was weighed again to determine % organic content by combustion. The remaining 500 ml of sample was filtered thru an unweighed glass fiber filter of the same pore size. The filter was treated with 1 ml of MgCO3, frozen at -20°C and analyzed for photosynthetic pigments within 14 days. Ammonium and nitrate/nitrite concentrations were determined using a LACHAT nutrient autoanalyzer (Lachat Instruments, 1991). Orthophosphate concentrations were determined using colorometric methods described by Strickland and Parsons (1976), and absorbances were read on a Beckman model DU 640 single beam spectrophotometer. Chlorophyll a and phaeophytyn concentrations were determined using the acetone extraction method (Strickland and Parsons, 1976) and absorbances read on a Beckman model DU 640 single beam spectrophotometer.

## Results

Vertical profiles of temperature, salinity, and dissolved oxygen obtained hourly at the treatment plant outfall station indicate that a certain degree of stratification occurs at the slack tides (high and low) with a differential of ≈ 2-3 ppt between the surface water and a depth of 0.5 m. Salinity did not change with depth below the 0.5 m depth and stratification was reduced or eliminated as the tidal flow increased (hours 3-6 ebb tide; hours 9-12 flood tide).

Results of the nutrient analyses clearly demonstrated that the POTW effluent has a significant effect on nutrient concentrations in the river. The concentrations of the nitrogen species were quite different on the two sampling days, illustrating the variable degree of nitrification of the treatment plant effluent. On July 14, during the ebb tide portion of the study, the undiluted POTW samples had ammonium and nitrate concentrations of 132 μM and 1212 μM respectively. On July 21, during the flood tide study, the concentrations were 1281 μM for ammonium and 8.23 μM for nitrate; the reverse of the 7/14. For this reason, the data is presented as total nitrogen (NH4 + NO3) in figures 1-15 thru 1-17, as well as for the individual; nitrogen species in figures 1-18 thru 1-20.

Dilution from the plant to the outfall sampling site, estimated by comparing concentrations of nutrients from replicate samples taken within the plant at mid-falling and mid-rising tides (hours 3 and 9) to concentrations at the outfall site, were approximately 10:1. As stated, the dominant nitrogen species during the ebb tide portion of the study (hours 1-6) was nitrate (Fig. 1-18 thru 1-20). With the exception of a high ammonium concentration ( ≈ 8 μM) at station 2 during hour 4, the nitrate and ammonium concentrations (Fig. 1-18) at the two upstream stations (1 and 2) were <2μM. At stations 4 and 5, downstream of the treatment plant in the direction of the tidal flow from the effluent, nitrate and ammonium, and particularly nitrate at station 4, increased steadily to and reached a peak ( ≈ 60 μM at station 4) at hour 5 (Fig. 1-20). The concentrations of nitrogen species at the treatment plant outfall at hour 5 were: ≈ 100 μM for nitrate and ≈ 25 μM for ammonium, for a combined total nitrogen concentration of 125μM (Figs.1-16 and 1-19). Peak nitrogen (≈ 175 μM) during the ebb tide portion of the study was detected at hour 6 (slack low water) (Fig. 1-16). Concentrations had already begun to fall at downstream stations (4 and 5) at hour six when the tidal flow was no longer carrying the outfall plume in their direction (figs 1-17 and 1-20).

A similar situation was observed during the ebb tide study for phosphate. The concentration of phosphate in water taken inside the plant at mid-ebb tide was ≈ 102 µM, and samples at the outfall site at the same time were ≈ 11 µM; showing a 10:1 dilution, similar to nitrogen (Fig 1-22). Phosphate concentrations at the upstream stations (1 and 2), did not change appreciably during the ebb tide and ranged between 1.25 and 1.75 µM (Fig. 1-21). The downstream stations (4 and 5) tracked the outfall concentrations with all three stations reaching peak concentration at hour 5. The phosphate levels measured at stations 3, 4 and 5 were 23, 7 and 2.2 µM respectively, indicating a fairly rapid dilution as the distance from the outfall increases.

Very different nutrient conditions were detected on July 21 during the flood tide study. Phosphate concentration of samples taken inside the plant during hour 9 (mid-flood tide) were ≈ 267 µM, greater than twice concentration during the ebb tide. Once again, the dilution at the outfall site was ≈ 10:1, with the concentration of hour 9 samples measuring ≈ 27 µM. As previously mentioned, the concentrations of nitrogen species during the flood tide were the reverse of the ebb tide, with ammonium being dominant and nitrate levels low. At hour 9, samples taken inside the plant had levels of ammonium of ≈ 1281 µM, and nitrate of ≈ 8 µM. Ammonium concentration of the outfall site samples were ≈ 130 µM at hour 9, showing a similar 10:1 dilution (Figs. 1-16 and 1-19). Significant increases in total nitrogen were observed at the upstream stations (1 and 2) during the flooding tide, particularly during the second hour (hour 8) when concentrations peaked at ≈ 21 µM at both stations (Figs 1-15, 1-18). The peak concentration of nitrogen at the outfall site (725 µM) occurred at hour 8 as well (Figs. 1-16 and 1-19). Concentrations at stations 1 and 2 dropped at hour nine, remaining stable at ≈ 7 µM for hours 10, 11, and 12, tracking the outfall concentrations (Figs.1-15 and 1-16). Nitrogen levels at downstream stations were for the most part much lower during the flood than the ebb tide. Station 4 had an ammonium concentration of ≈ 27 µM at hour 8, and ≈ 12 µM at hour 12, while both ammonium and nitrate were ≈ 2µm throughout the flood tide at station 5 (Figs.1-17 and 1-20).

Similar patterns were observed for phosphate during the flood tide. A peak concentration of ≈ 27µM was measured at the outfall site at hour 7, and decreased steadily as greater dilution was achieved as the volume of tidal water increased (Fig. 1-22). The upstream stations (1 and 2) had peak phosphate concentrations at hour 8 of 5.7 and 5 µM respectively (Fig 1-21). Concentrations fell during the remainder of the flood tide, probably reflecting the greater dilution from incoming tidal water. The downstream stations, particularly station 5, showed steadily decreasing (to ≈ 1µM) phosphate concentration during the flood tide (Fig 1-23). Phosphate at station 4 was variable, probably due to its proximity to the outfall pipe, or perhaps an additional source.

## Discussion

The results of this study clearly illustrate the effects of point source loading of nutrients from the sewage treatment plant on the Oyster River. Stations in the direction of the tidal flow exhibited elevated nutrient concentrations during both ebb and flood tide, though the flood tide concentrations at upstream stations were rapidly diluted by incoming tidal water. Comparison of high and low tide concentrations of nutrients at station 10 (Town Landing) in the main river transect also support the results of this study (see the updated database section of this report). Several samples taken during this study, however, (station 2, $NH_4$ hour 4; station 4 $NH_4$ hours 8 and 12), as well as data from 1992 (stations 3, 5 6, 9) indicate that there are other sources in the river as well. The rapid dispersion/dilution of phosphate and nitrogen observed at station 5 during the ebb tide, also indicates that the POTW is not responsible for all of the elevated nutrient levels observed over the past 1.5 years of the Oyster River NPS study. Using data gathered in this study, along with discharge volumes at the POTW and stream flow measurements at the tributaries of the river, it will be possible to estimate the relative contributions of nutrients from point vs. nonpoint sources to the Oyster River. This estimate will make nutrient reduction strategies less difficult to identify if they are deemed necessary.

## OBJECTIVE 2

A detailed NPS assessment was focused on Johnson Creek, where a previous project indicated temporally fluctuating elevated levels of contaminants. Land uses in the Johnson Creek watershed include rural, agricultural, and non-sewered residential areas, thus providing the opportunity to determine relative impacts of these different land uses. The Strafford Regional Planning Commission provided different digitized land use maps. A parcel-based map was provided as an overlay for the other maps. A significant amount of the land use data used to generate the maps was inaccurate or dated, especially the large areas defined as agricultural lands that are simply open fields. Some of the land use data does not reflect recent residential development, as might be expected. We are currently working with SRPC to correct and update these data, based on our groundtruthing activities. The sampling stations have been located using a GPS unit and included on the parcel map overlay. The land use information that has been most useful includes the following:

-a parcel-based overlay map with building and sample site locations;
-soil suitability map;

-wetlands map;

-land use map.

More information on land cover would be useful, and groundtruthing was absolutely necessary. In fact, very little active agricultural land use is present in the watershed.

Sampling was undertaken along longitudinal transects covering the full length of Johnson Creek and its tributaries. Sites were chosen to focus on obvious, potential NPS pollution problem areas, based on presently available land use information. The focus of sampling was to document impacts on water quality from different land use areas. Routine sampling along the transect of the creek and its tributaries occurred basically on a monthly basis to establish a database for contaminant loading to the Oyster River and to allow for detection of any contamination that may not be associated with any obvious land use. The results are presented in Table 2-1, with calculated geometric means for annual and seasonal data presented in Table 2-2. Nutrient concentrations at the sites are presented in Tables 2-3 thru 2-5 and annual and seasonal means are presented in Figures 2-5 thru 2-10.

All three indicator bacteria followed similar general trends, with fecal coliforms giving the most striking differences between stations (Figure 2-1). Levels were relatively low at the mouth of the creek (sites 1&2) compared to levels at upstream sites. Along the main branch of the creek (see Figure 3), levels were higher at site 3 but increased dramatically at site 4 just downstream of a sewered trailer park in Dover. Levels were relatively low in the east branch of the creek at site 5, but were again high downstream of the confluence of these two branches at site 6. This site is just upstream of a municipal water treatment facility and the land upstream to the trailer park is vacant and undeveloped. Thus, levels at site 6 appeared to be residual from sources near site 4. Levels decreased going downstream to site 7, but were still relatively high compared to levels in the west branches of the creek. Levels at site 13 were low when sampling was possible, and are not presented. Levels at site 12 were the lowest of any of the freshwater sites, but then levels were higher at sites downstream and at the mouth of the southwest branch at site 10. Levels at the confluence of these two branches at site 9 appeared to reflect a combination of the two creek branches, while levels were slightly elevated downstream at site 8. Approximately 10 more unsewered houses could potentially influence water quality between sites 9 and 8, suggesting that one or some of these houses could be contributing contaminants to the watershed. Thus, the trailer park and other residences in the watershed appear to be sources of bacterial contamination in the Johnson Creek watershed.

Summer and autumn appeared to be the seasons with the highest levels of fecal coliforms and enterococci at most of the sites (Figures 2-2 & 2-3). High levels in summer and autumn at many sites suggest that transport of contaminants is favored under those environmental conditions. In addition, high levels in summer could reflect low water volumes in the streams, thus concentrating contaminants, or regrowth under relatively favorable conditions could also cause increased levels. The reason for relatively high levels of *C. perfringens* during winter compared to other seasons at many sites (Figure 2-4) is not known.

Elevated NO3 concentrations throughout the Johnson Creek watershed suggest that there are potentially a number of sources along the branches and main stem of the creek, particularly at sites 4 and 12A (Fig. 2-6). Probable cause for the elevated NO3 at station 4 is a trailer park and other residences in close proximity to surface water, while site 12A is influenced by a number of houses with older septic systems as well as a farm. Despite the elevated NO3 concentrations at most of the upstream sites, the tidal sites in Johnson Creek (JC 1&2) are quite low, likely due to a combination of dilution, uptake and microbial/biogeochemical activity (Figs. 2-6 and 2-9). In contrast to the high NO3 concentrations, NH4 and PO4 were quite low throughout, though site 4 was higher relative to the other sites (Figs. 2-5 and 2-7). Analysis of the seasonal means indicate that ammonium and phosphate are is highest in the summer when the water levels in the streams are the lowest. In contrast, nitrate concentrations are highest in the spring and fall when it appears that rainfall and high water table conditions mobilize nitrate from soils (or septic systems) into the surface waters (Figs 2-8 thru 2-10).

Natural processes that may influence contaminant levels are of interest for predicting the fate of contaminants to surface waters from land sources. The Johnson Creek has an extensive salt marsh at its mouth, and levels of fecal coliforms and enterococci were measured at low tide along the length of the marsh (between sites 2 and 8) to see what influence mixing of salt and freshwater could have on water column bacteria. Results show a relatively rapid decrease in bacterial levels between the freshwater head site and next 3 sites with low salinity brackish water (Figures 2-11 & 2-12). The dashed lines indicate predicted levels if the waters at each end were mixed to give the observed salinities at sites in the middle. At sites further downstream levels remained about the same. This suggests that the mixing of freshwater with low salinity brackish water could promote flocculation of colloidal and particulate material and induce sedimentation of particle-bound contaminants, as observed in other similar areas.

OBJECTIVE 3

Determination of nonpoint pollution sources based on detailed digitized information and extensive sampling can become extremely expensive, and as the geographical area of interest increases, the cost can become prohibitive. For assessing large and complex geographical areas, it is important to identify the types of data that are most effective for predicting potential NPS loading. The goal for this part of the study will be to initiate development of an effective system for predicting NPS loading in NH coastal watersheds, based on the most critical combinations of land use and watershed characteristics that result in NPS pollution.

The most important source of bacterial and nutrient contamination from a land use perspective appears to be private residential on-site sewage disposal systems. All of the Durham and Madbury areas, and much of the Dover area, of the Johnson Creek watershed are not served by municipal sewage systems. The results of our water quality analyses give some indications that these residential areas are increasing contaminant levels in nearby streams, even though there are houses near the heads of all of the streams in the watershed and thus no good pristine, upstream sections to use as background references. An in-depth study of a residential area in Durham that is unsewered was undertaken to document any impacts on the water quality of the nearby south branch of Gerrish Brook (Figure 3-1). Gerrish Brook runs at approximately 20 feet lower elevation from the back of the development, and two drainage swales, one from within the development, flow downslope to Gerrish Brook. All of the soils in the area are designated severely limited for septic tank effluent by the Strafford County Soil Survey, either because of high seasonal water table/slow permeability, or because of slope restrictions or shallowness to bedrock. Most of the houses in the development were built during 1972-76, and the septic systems were installed according to permit requirements. Most of the systems are beds with 3 lines covering areas ranging from ~500-700 ft2. Based on this information, it was expected that contamination from this development could be detected in the brook.

Results of sampling the south branch of Gerrish Brook and tributaries near the development (Table 3-1; Figure 3-3) indicate elevated levels of bacteria occur occasionally in the drainage swales (sites 3-4; Table 3-1) and consistently at site (#8) downstream of the main area of focus. $NO_3$ concentrations were also high at stations 3&4, though only $PO_4$ and $NH_4$ was elevated at site 8 (Table 3-3). This site is relatively close to a house with a sewage treatment system visible from Gerrish Brook and perched approximately 10-15 feet above and approximately only 25 feet away from the stream bed. Below this is an oxbow containing ponded, stagnant water that is obviously contaminated, based on the high levels of algal growth, color of the water, odor, and bacterial (FC = 1060/100 ml; 42,000/100 ml on 6/29/94) and nutrient ($PO_4$=256.89 µM; $NH_4$=53.46 µM on 6/29/94) levels. Phosphate concentrations this site were extremely high, with the mean for the four sampling dates (138 µM). Downstream bacterial levels were slightly higher, but not to any significant extent on the sample days (Figures 3-4 & 3-5). However, the potential for contamination following high-flow events is obvious.

Our interpretation of land use from data, maps, and groundtruthing activities shows very little active agricultural land use in the watershed. One farm with animals exists at the head of the north branch of Gerrish Brook, along with another housing development (Figure 3-4) that may have some impact on water quality. The housing development is older than the one previously described, although it is located on soils more suitable for septic systems (Figure 3-2). Detailed information on septic systems was difficult to locate, but it is expected that the systems are older than in the development near the south branch of the brook. Data on bacterial contaminants in the north branch of Gerrish Brook near these sites on three sample dates is presented in Table 3-2 and Figures 3-6 to 3-8. Nutrient data was collected on two dates ate these sites, and is presented in Table 3-4. On the last two sample dates, sites downstream near the mouth of the brook (near site 11 of Johnson Creek; see Figure 3) were included to determine the influence of ~4 unsewered houses in that area.

The results were quite variable both temporally and spatially. Geometric average levels for the different sites suggest that the houses may be sources of contamination relative to the other sites (Figure 3-6). The site furthest upstream of the housing development was always relatively clean (Figures 3-7 & 3-8). However, the next three sites had high levels of both indicators on June 6, following a dry period (Table 1). This could reflect some altered farming practices or some other influence. Levels near the houses and further downstream were lower on June 6, but fecal coliforms (but not enterococci) were high at the site nearest the houses on April 5. Neither ammonium nor phosphate concentrations appear o be a problem on the north branch of Gerrish Brook, however, NO3 concentrations were elevated on both sampling dates, and on 6/6 in particular. Based on the location of the stations with respect to sources, soil type and topography, it appears that the cow pasture (12E and 12 D) and the housing development above station 12B and 12B are influencing the nitrate concentrations in the brook (Table 3-4).

In comparison to the other housing development, there may be some potential for the older systems to be sources of bacterial contaminants (April 5 FCs), but their location on suitable soils and their setback distance from the brook probably enhance removal of contaminants. In addition, the farm may be an intermittent source of bacteria. Overall, none of the bacterial levels were very high at any sites, unlike the oxbow site in the south branch. The results from both study areas suggest that most setback distances, except for the house near the oxbow, from the stream surface waters appeared to be adequate for minimizing transport of contaminants and contamination of the surface waters. This seemed to be a more important factor than age of system of soil suitability, although the amount and variability of the data precluded any conclusive determinations of the significance of these apparently intermittently important factors. Season and rainfall did not have any discernible effects based on the limited sampling frequency of this study. Thus, it appears that private, on-site sewage disposal systems in residential areas were the most important sources of contamination in the watershed, and setback distance was the only obvious critical factor that could be confirmed from the data.

The limited area of agricultural land limits our abilities to assess potential impacts, but the data thus far suggest that runoff from pastureland can contaminate surface waters. Thus, the critical land use factors identified by this study are proximity to surface waters and soil and site characteristics as they relate to residential on-site sewage disposal systems, and site characteristics and proximity to surface waters of agricultural land. As in any NPS pollution assessment, rainfall, temperature, storm event incidence and intensity, and accurate land-use data are also critical factors. A larger and more intensive study of these areas could probably better define the significance of all potential influencing factors.

## Review of Existing Nonpoint Source Pollution Models

One objective of this project was to evaluate existing capabilities for predicting NPS pollution of coastal NH watersheds. To this end, a number of existing models and related literature on pollutant and environmental characteristics and land-use interpretation were reviewed to determine the best approaches for assessing NPS pollution. The goal was to provide a framework for potential future modification and calibration of models to accurately fit physical, chemical, and biological processes that affect the fate of target pollutants in the environment. A summary of this review is presented below. Existing water quality data have not been used in models because of the inaccuracies of existing land-use data and the time required to modify and input these data to different individual computer programs for each model.

The focus of the review was on models that described NPS loading of nutrients, fecal-borne bacteria, and sediments to relatively small watersheds. These limitations resulted in a small number of models that appeared to be potentially useful. To support the mechanistic bases of these models for describing the fate of the different pollutants, a review of related literature on the behavior of nutrients, bacteria and sediments in watersheds was also conducted. The information can be summarized in three parts: estimation of pollutant discharge loading to the watershed, pollutant transport through the watershed, and use of supporting land-use systems and other data needs. The loading information requires data on load generation from a given source relative to eventual discharge load. In addition, processes that affect transport of the pollutant from sources to the watershed need to be identified, especially relative to stormflow or baseflow conditions.

The transport of pollutants through the watershed also requires knowledge of the factors that can affect transport, such as pollutant characteristics, environmental influences, and land-use characteristics. In terms of pollutant characteristics, again we are concerned with fecal-borne bacteria, nutrients, and solids. Because the environmental incidence of actual pathogenic bacteria and viruses is relatively rare (and if they are present, it would not be appropriate to allow them to persist any longer than necessary!), most studies on fecal-borne microbial contaminants focus on fecal indicator bacteria. What has been found is that these bacteria have the capacity for regrowth under favorable conditions, thus increasing in number and potentially indicating more pollution than what is actually occurring. More often they are subject to die-off, and this is affected by starvation conditions, inhospitable Eh, pH, or oxygen tensions, irradiance in surface waters, and predation (Auer and Niehaus, 1993). To complicate their behavior even more, many of the target bacteria tend to respond to unfavorable conditions by becoming relatively dormant, and no longer can be cultured/enumerated by conventional methods, even though they may remain viable, potentially virulent, and subject to predation (Gonzalez et al., 1992). Nutrients can also be transformed to other forms that may remain or that are lost from the the system. This is especially true of nitrogen, which can be transformed to nitrogenous gases and lost from the system, or form particulate to dissolved and back to particulate forms that affect the adsorption and settling properties of this nutrient. Microbial processes such as nitrification, denitrification and nitrogen fixation all are key processes involved in the fate of nitrogen in the environment, and the significance of each process is dependent on an integration of many environmental conditions and the presence of the bacteria and fungi capable of mediating the processes. Solid particulate matter is of direct concern, but also affects the transport of bacteria and nutrients. Depending on the size and charge of particles and the forms of the other pollutants, bacteria and nutrients can adsorb to particles or remain dissolved in aqueous phases of the environment. During transport through soils, the soil texture, unsaturated zone moisture, temperature, water table and other profile characteristics can also affect subsurface transport of pollutants. Surface runoff will also be affected by whether pollutants are associated with particulate matter.

Environmental characteristics are also important considerations when predicting NPS pollution. Meteorological conditions such as precipitation (rain, snow), wind, sunshine/irradiance, and temperature regime can affect pollutant behavior. Rainfall affects transport as a function of its duration and intensity. Wind can affect evapotranspiration and cause wave action in surface waters. Sunshine/irradiance has a significant affect on plant growth and survival of microorganisms in surface waters. Whether temperatures are above or below freezing will significantly affect transport, and warmer temperatures will increase biological metabolic rates, which affect microbial survival and process rates, plant growth, and predator feeding rates. The conditions of soils, land surfaces, and aqueous environments in terms of pH, dissolved oxygen/aeration, irradiance, and charged surfaces are important factors for all pollutants, and plant uptake of nutrients can be significant (Rogers et al., 1991). The relative flow rates of water on surfaces through runoff and in the subsurface is extremely important, and is a function of soil permeability, texture, structure, existence of macropores and fractures, other profile characteristics, and water table height. The water flow characteristics for the recipient surface streams are critical for determining the fate of pollutants and their eventual loading to surface water bodies. Tidal influences can also impact pollutant characteristics and vertical mixing.

Land use characteristics are the other important aspect of NPS pollution prediction. The type of land use or cover is important, such as urban/rural, commercial, residential, agricultural (row crop, pastureland, management practices), forested, marsh, or idle/open/gravel pits/mines. Related data on the distribution of specific land types and their area within a watershed are essential, as are topographical data on slope and elevation. Most importantly, an understanding of the hydrology of the watershed is absolutely essential.

Rarely are data available for all of the above factors in a given watershed. Even if a significant amount of data is available, meaningful predictions cannot be made without integration of pertinent data into forms that are more useful. For example, a certain set of conditions at a site may predict denitrification to be a significant sink for nitrogen, but seasonal changes in those conditions could result in prediction of insignificant denitrification with plant uptake becoming the dominant sink. Thus, in New Hampshire, data should be grouped according to the seasonality of conditions. One of our other objectives, identification of critical factors that are associated with NPS pollution in the target watersheds, is an important exercise that should help to narrow data needs to allow for prediction of NPS loading from certain land uses under specific conditions (see below). Data gaps can be filled using published values from the literature, although caution is required. Dierberg (1991) found that measured nitrogen and phosphorus export coefficients for an agricultural-suburban watershed in central Florida were more similar to published values for Wisconsin, but deviated considerably from those for national averages. The next question is, 'What are the predictive needs, and which of those require use of models and which can be based on empirical relationships developed for specific land use types?'

All of the above information can be integrated and used in models to predict pollutant loading and fate in the environment. Existing data on pollutant concentrations can be used to run sensitivity analyses for different model parameters and for curve fitting to modify parameter values. Models can also be modified to represent conditions different from present conditions for predicting impacts from future development or management practices. These approaches were taken by Najarian et al. (1986) for predicting the effects of a proposed land development on water quality in a coastal New Jersey watershed. They used a modified STORM model that included infiltration of soluble pollutants (nutrients; bacteria) to groundwater. Another model that could be useful is the BROOK 6 model for small watersheds. It would require extensive modification to include the impacts of pollutant characteristics and behavior in both surface and subsurface transport. Sekine et al. (1991) developed a complicated model for predicting runoff loading of nutrients through rivers to lakes and inner sea areas of Japan. Their approach used long-term data and curve-fitting to adjust model parameter values for simulating pollutant discharge under present conditions and for predicting effects of changes in population, industrial production, and land use.

Some of the land-use data can be integrated into useful groupings such as riparian zones, impervious areas, vegetated buffer strips, soil suitabilities, etc. that are useful when going from process modelling for small areas to modeling whole watersheds. GIS can be useful for integration and manipulation of land-use data for predicting present and future impacts of development, using either models or empirical relationships. Basic data required include area and distribution of different land uses and cover, length of streams, and area of watersheds. Buffer functions in GIS software can also be used to determine areas of critical land uses surrounding water bodies that may impact water quality, and to correlate with actual pollutant measurements. This empirical approach was taken by Osborne and Wiley (1988) to explain measured nitrate and soluble reactive phosphorus levels in an Illinois watershed. As a first approximation and an approach that requires less technical training, this may be useful in New Hampshire, and can be built off the existing data collected for the Oyster River watershed.

## OBJECTIVE 4

The critical factors identified from the Johnson Creek portion of the study were applied to the Beards Creek watershed, which has a number of features in common with Johnson Creek. Digitized land use data was made available for this area, though not in the detail that was available for Johnson Creek. Again, there was little agricultural activity in the watershed, but it appeared that some high density residential areas could give similar results compared to the Johnson Creek watershed. In addition, it features portions of the urbanized district of Durham. In a few areas, houses were located quite close to the stream surface waters, so setback distances were expected to influence water quality.

Water quality at 12 sites (Figure 4) located throughout the watershed was assessed by measuring bacterial indicator and nutrient concentrations at all sites (Tables 4-1 and 4-3). Geometric annual mean fecal coliform and enterococci levels followed generally the same trends, while C. *perfringens* levels were virtually the same at all sites (Table 4-2; Figure 4-1). At the northern head of the main stem of Beards Creek (sites 6 & 5), levels of fecal coliforms and enterococci were higher than in estuarine receiving waters (site 1), but lower than at downstream sites (sites 4 & 3). Site 4 is just downstream of a high density, sewered residential neighborhood where a few unidentified pipes emptying into the stream were also located. Site 3 is on the other side of Rt. 4 near a few other houses, Thus, there is an apparent source of contamination in this area, based on the observed increased levels compared to upstream. On Littlehole Creek, levels were the highest seen in the watershed at site 12, above a small wetland. However, it appears that the wetland has a favorable impact on water quality, as levels were much lower at sites 11 and 10. Even though most of the houses in this area are on the municipal sewer system, some houses at the ends of streets are known to have on-site septic systems. These results suggest that residential areas with on-site septic systems are probably the major sources of bacterial contamination in these portions of Beards Creek watershed.

The other sampling sites were located in the urban area of Durham along Reservoir Brook. Levels of fecal coliforms and enterococci were relatively high all along this brook (sites 9,8,&7), especially near site 8 (Figure 4-1). These results suggest that some sources of fecal contamination are present even in a sewered area. Site 2 is located at the downstream end of an extensive marsh at the confluence of all the branches of the creek. It appears that contaminant levels decrease during the residence time for inflowing water into the marsh, as levels at site 2 were lower than at sites 3, 7 and 10.

Analysis of the data with respect to season showed some seasonal differences in bacteria levels, but no significant trends (Figures 4-2 to 4-4). Generally, the spatial trend observed for annual means (Figure 4-1) were consistent with season. For fecal coliforms and enterococci, it appeared that summertime gave the largest differences between sites, with less inter-site differences during autumn and spring.

With the exception of a few isolated ammonium samples, NH4 and PO4 concentrations were low at all Beards Creek watershed stations. The highest mean NH4 concentrations were measured at stations 4 and 9 (where high fecal coliforms were also measured) (Table 4-3, Fig. 4-5). NO3 concentrations were relatively high at all stations, except for the last two freshwater stations (1&2) in the Beards Pond area (Table 4-3, Fig. 4-6). Station 5, which is located near a non-sewered residential area in Madbury, had the highest mean NO3 concentration, which may be the result of the on-site sewage disposal systems associated with the residences. As was the case with fecal coliforms, NO3 concentrations at stations 7, 8, and 9 were elevated. Seasonal analysis of mean nutrient concentrations indicate that for NO3, stations with the highest annual means were highest in the summer, while those with lower concentrations were higher in the wetter spring and fall (Fig. 4-9). This same trend was also observed for NH4 (Fig 4-8) while highest PO4 concentrations were measured in the spring and fall (Fig. 4-10).

One potential source of fecal contamination in sewered and urban areas is sewer lines for the municipal system. At the mouth of Beards Creek is a mudflat area between the dam and the main stem of the Oyster River. A cement-encased sewer line crosses the mudflat just downstream of the dam. Sampling around this pipe on an outgoing tide near slack low showed a pattern of contamination that suggested the pipe may be a source of contamination. Fecal coliforms levels at three sites above the pipe were relatively low and similar, with freshwater levels being similar to the downstream tidal sites (Figure 4-11). Fecal coliform levels were much higher just below the pipe, and the salinity was lower (16.5 vs ~23 ppt upstream), suggesting that the pipe is a source of fecal coliform-contaminated freshwater. Thus, nonpoint sources that are often relatively difficult to identify and observe can include sewer system pipes in urban areas.

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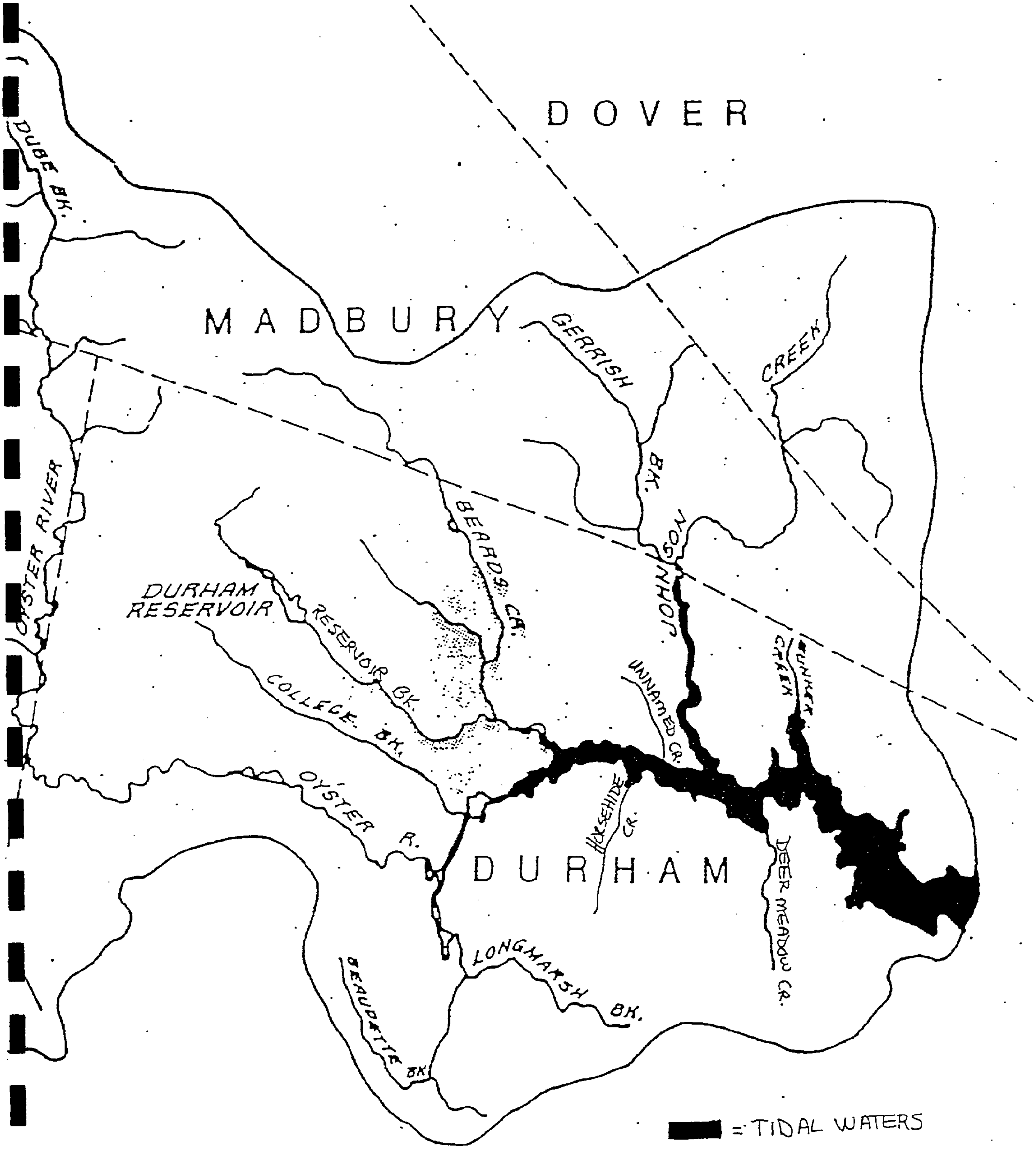
Table 1. Rainfall amounts (cumulative) on 3 days preceding sample dates.

| Sample Date | Precipitation (inches) 1 day | 2 days | 3 days |
|---|---|---|---|
| 4/7/93 | 0.00 | 0.00 | 0.06 |
| 4/12/93 | 0.84 | 1.33 | 1.33 |
| 5/25/93 | 0.00 | 0.00 | 0.05 |
| 6/1/93 | 0.00 | 0.00 | 0.00 |
| 6/29/93 | 0.00 | 0.00 | 0.00 |
| 6/30/93 | 0.13 | 0.13 | 0.13 |
| 7/7/93 | 0.00 | 0.00 | 0.00 |
| 7/8/93 | 0.00 | 0.00 | 0.00 |
| 7/12/93 | 0.00 | 0.00 | 0.00 |
| 7/13/93 | 0.00 | 0.00 | 0.00 |
| 7/15/93 | 0.00 | 0.00 | 0.00 |
| 7/20/93 | 0.00 | 0.00 | 0.00 |
| 7/21/93 | 0.21 | 0.21 | 0.21 |
| 7/27/93 | 0.00 | 0.00 | 0.00 |
| 7/28/93 | 0.61 | 0.61 | 0.61 |
| 8/3/93 | 0.11 | 0.11 | 0.16 |
| 8/10/93 | 0.28 | 0.28 | 0.28 |
| 8/11/93 | 0.00 | 0.28 | 0.28 |
| 8/12/93 | 0.00 | 0.00 | 0.28 |
| 8/16/93 | 0.00 | 0.00 | 0.00 |
| 8/17/93 | 0.00 | 0.00 | 0.00 |
| 8/18/93 | 0.00 | 0.00 | 0.00 |
| 8/24/93 | 0.00 | 0.00 | 0.00 |
| 9/8/93 | 0.00 | 0.00 | 0.00 |
| 9/22/93 | 0.00 | 0.00 | 0.00 |
| 9/29/93 | 0.50 | 1.69 | 2.66 |
| 10/18/93 | 0.00 | 0.00 | 0.00 |
| 11/2/93 | 0.60 | 1.26 | 1.32 |
| 11/9/93 | 0.00 | 0.00 | 0.14 |

| Sample Date | Precipitation (inches) 1 day | 2 days | 3 days |
|---|---|---|---|
| 11/16/93 | 0.18 | 0.18 | 0.24 |
| 11/23/94 | 0.00 | 0.00 | 0.18 |
| 12/7/93 | 0.00 | 1.55 | 1.55 |
| 12/13/93 | 0.21 | 1.15 | 1.15 |
| 1/3/94 | 0.00 | 0.00 | 0.00 |
| 1/26/94 | 0.00 | 0.07 | 0.07 |
| 2/1/94 | 0.00 | 0.00 | 0.00 |
| 2/15/94 | 0.00 | 0.90 | 0.90 |
| 2/22/94 | 0.00 | 0.00 | 0.00 |
| 3/1/94 | 0.00 | 0.00 | 0.00 |
| 3/8/94 | 0.00 | 0.00 | 0.00 |
| 3/15/94 | 0.00 | 0.00 | 0.00 |
| 3/23/94 | 1.91 | 1.91 | 1.91 |
| 4/5/94 | 0.23 | 0.23 | 0.23 |
| 4/11/94 | 0.15 | 0.15 | 0.15 |
| 4/25/94 | 0.00 | 0.00 | 0.00 |
| 5/9/94 | 1.31 | 1.37 | 1.37 |
| 5/11/94 | 0.00 | 0.00 | 1.31 |
| 5/18/94 | 0.25 | 0.85 | 0.85 |
| 5/25/94 | 0.10 | 0.10 | 0.10 |
| 5/31/94 | 0.00 | 0.00 | 0.00 |
| 6/1/94 | 0.00 | 0.00 | 0.00 |
| 6/6/94 | 0.00 | 0.00 | 0.00 |
| 6/7/94 | 0.00 | 0.00 | 0.00 |
| 6/9/94 | 0.00 | 0.00 | 0.00 |
| 6/14/94 | 0.45 | 0.80 | 0.80 |
| 6/20/94 | 0.00 | 0.00 | 0.00 |
| 6/28/94 | 0.00 | 0.00 | 0.23 |
| 6/29/94 | 0.28 | 0.28 | 0.28 |

FIGURE 1

OYSTER RIVER DRAINAGE BASIN



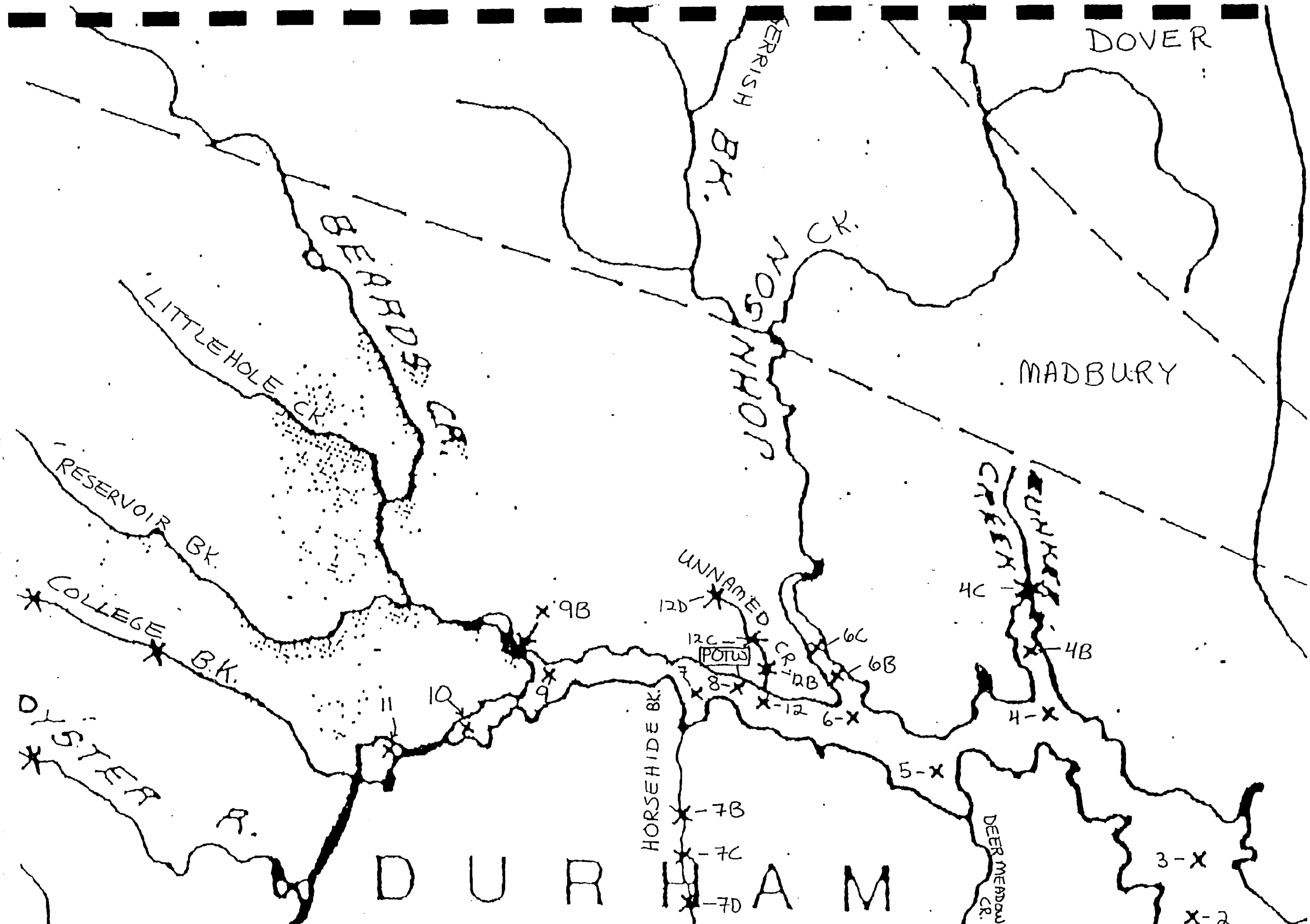
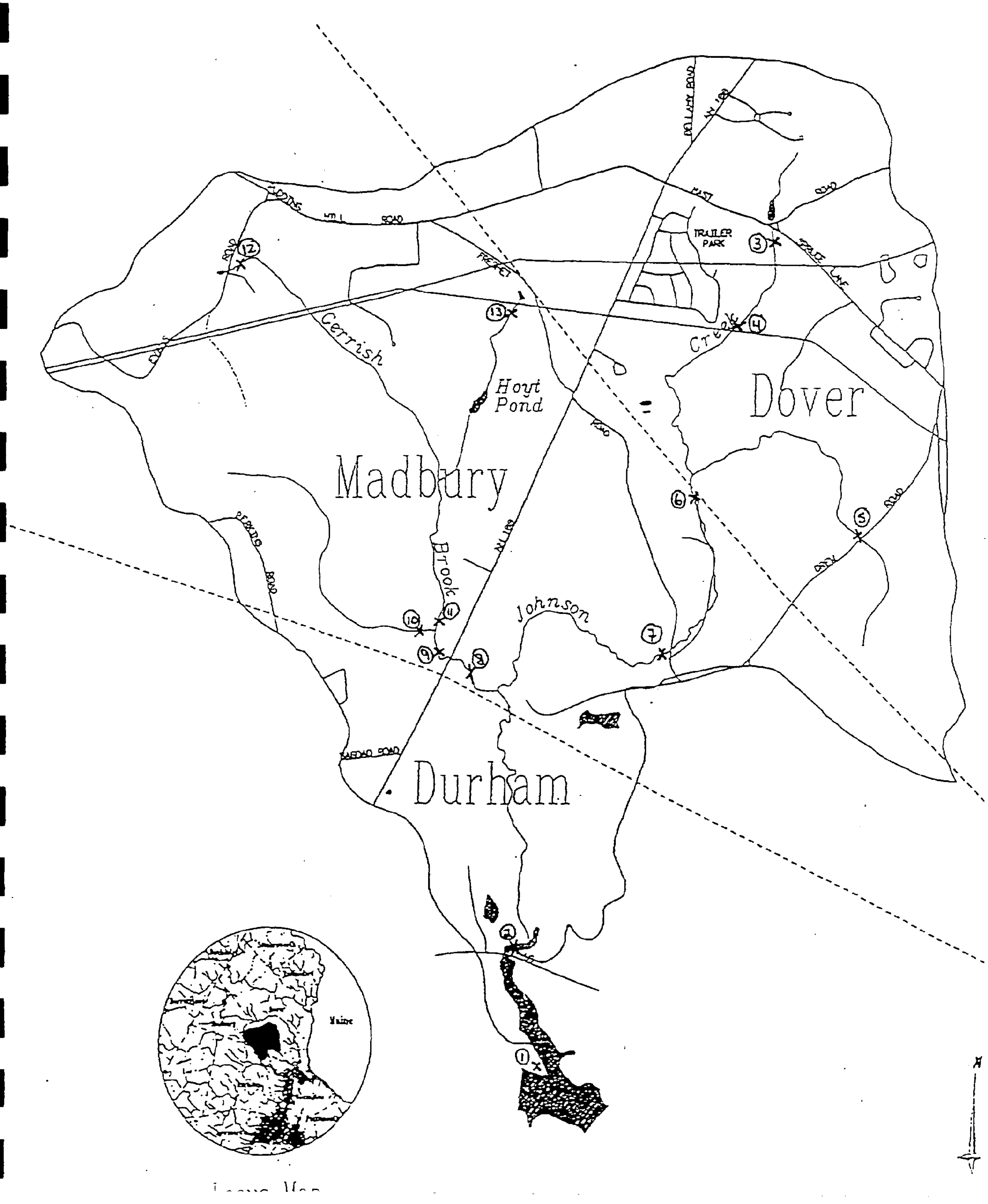



Figure 2. Sample sites in the tidal portion of the Oyster River and the major tributaries.

# Johnson Creek Watershed

Figure 3. The Johnson Creek watershed and sampling sites.



# Beards Creek Watershed

Figure 4. The Beards Creek watershed and sampling sites.

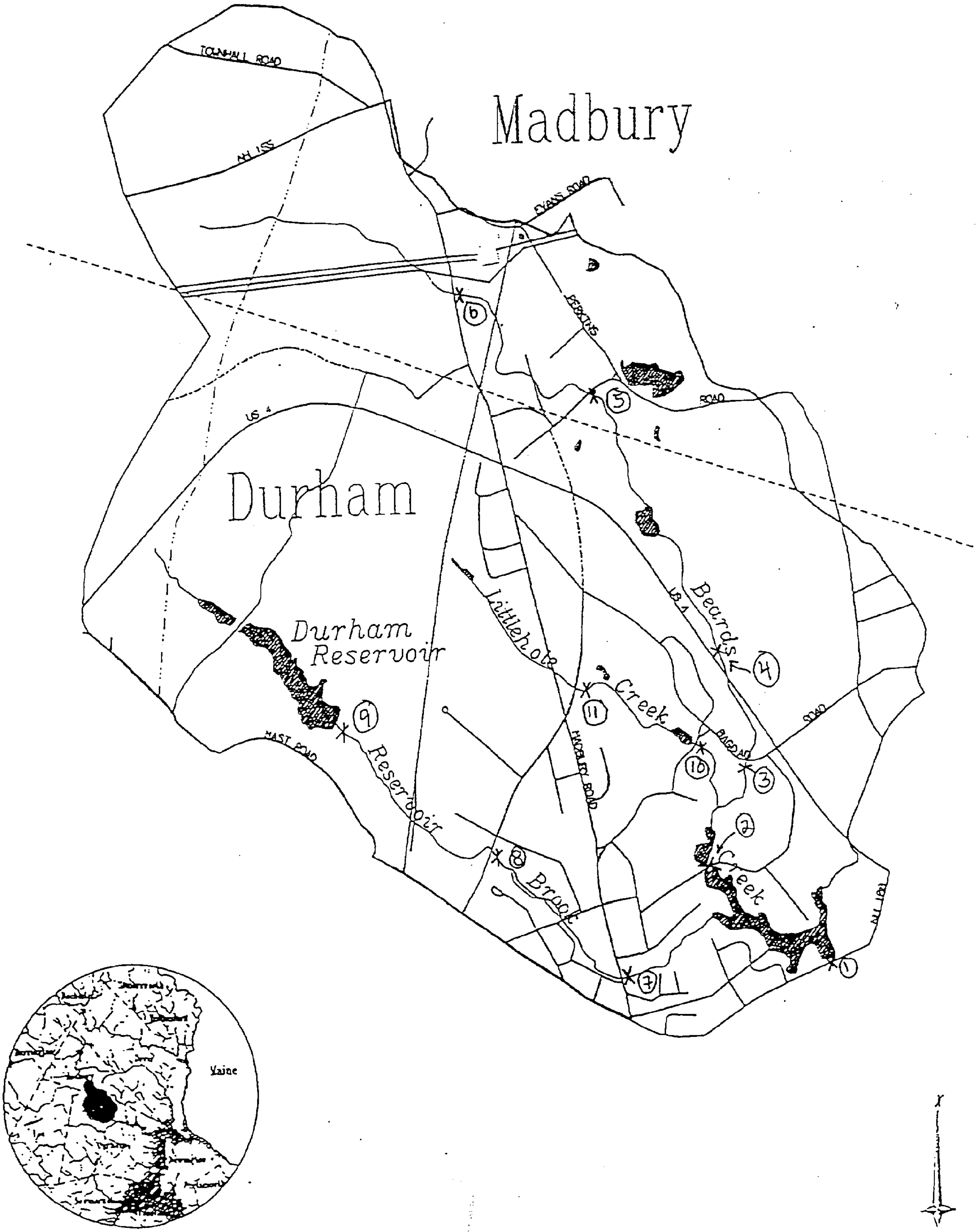
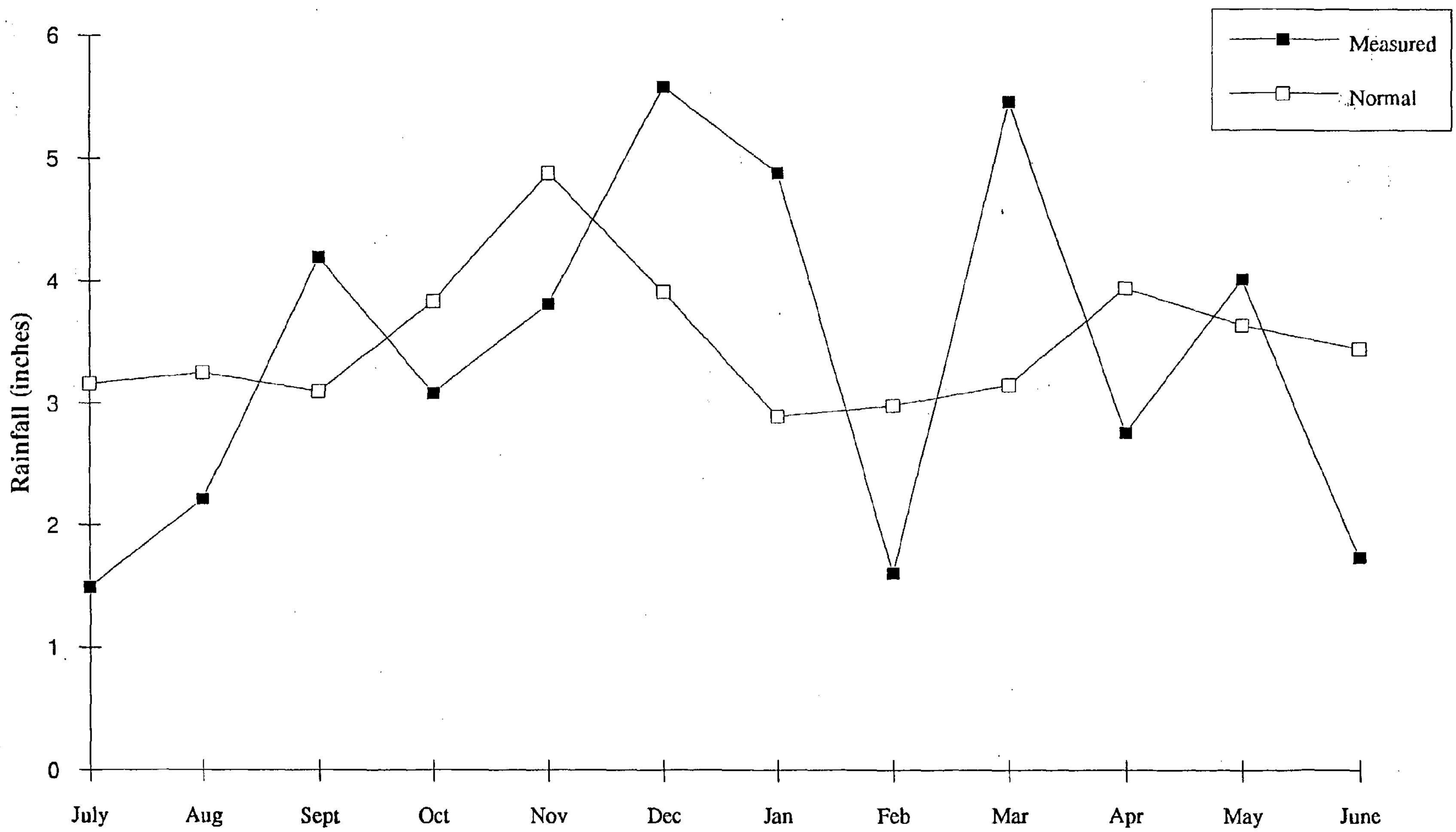


**Figure 5. Average monthly rainfall in Durham, NH: 7/1/93-6/30/94.**



# TABLES AND FIGURES

## OBJECTIVE 1

Table I-1. Bacterial indicator concentrations (per 100 ml) at sites in the Oyster River from 7/93 to 6/94.

## Fecal coliforms

| SITE # | OR1 | OR1 | OR2 | OR3 | OR4 | OR5 | OR6 | OR6 | OR7 | OR8 | OR9 | OR10 | OR10 | OR11 | OR11 | OR12 | OR13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tide | LOW | HIGH | LOW | LOW | LOW | LOW | LOW | HIGH | LOW | LOW | LOW | LOW | HIGH | LOW | HIGH | LOW | LOW |
| 7/7/93 | 7 | | | | | | 240 | | | | | 428 | | | | | |
| 7/13/93 | 1.25 | | | | | | 5 | | | | | 15 | | | | | |
| 7/27/93 | 9.25 | 6.75 | | | 49.5 | 66 | 70 | 5.5 | 54 | 14 | 78 | 22.5 | 93 | 372.5 | 11 | 91 | 0.5 |
| 8/3/93 | 29.8 | | | | | | 32.5 | | | | | | | | | | |
| 8/10/93 | 1 | | | | 15.5 | 14 | 45 | | | 8 | 52 | 30 | 1.5 | | | | 16.75 |
| 8/18/93 | 33.8 | 3 | | | | | 161 | 4 | | | | 100 | 29 | | | | |
| 8/24/93 | 1.25 | | | | | | 15 | | | | | 75 | | | | | |
| 9/8/93 | 4.25 | | 6.5 | 1 | 16.5 | 20 | 25 | | 23 | 0.75 | 32.5 | 0 | | 8 | | 2.75 | 1.25 |
| 9/22/93 | 5 | | | | | | 51.5 | | | | | 61 | | | | | |
| 10/18/93 | 5.5 | | | | | | 2.5 | | | | | 17 | | | | | |
| 11/9/93 | 4.75 | 13 | | | | | 1 | 4.25 | | | | 12 | 203 | | | | |
| 5/11/94 | 14 | | 25.5 | 27.5 | 50 | 22 | 6.3 | | 1.8 | 0.25 | 67.5 | 55 | | 65 | | 0.5 | 6.5 |
| 5/18/94 | 16 | 15.5 | | | | | 63.5 | 67 | | | | 85 | | | | | |
| 5/25/94 | 56 | | | | | | 170 | | | | | 4533 | | | | | |
| 5/31/94 | 9 | | | | | | 23 | | | | | 30 | | | | | |
| 6/9/94 | 29.5 | 2.5 | | | 235 | | 195 | 11.3 | | 0.25 | 227.5 | 55 | 98.8 | | | | 1 |
| 6/28/94 | 26 | | | | | | 190 | | | | | 85 | | | | | |
| Geom. ave. | 8.37 | 6.33 | 12.87 | 5.24 | 43.10 | 25.25 | 32.68 | 9.33 | 13.08 | 1.39 | 72.65 | 63.87 | 38.18 | 57.86 | 11.00 | 5.00 | 2.33 |
| Std. dev. | 3.38 | 2.29 | 2.63 | 10.42 | 3.02 | 1.95 | 5.12 | 3.24 | 5.87 | 6.79 | 2.05 | 4.44 | 6.95 | 6.84 | 1.00 | 14.20 | 4.27 |

## Enterococci

| SITE # | OR1 | OR1 | OR2 | OR3 | OR4 | OR5 | OR6 | OR6 | OR7 | OR8 | OR9 | OR10 | OR10 | OR11 | OR11 | OR12 | OR13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tide | LOW | HIGH | LOW | LOW | LOW | LOW | LOW | HIGH | LOW | LOW | LOW | LOW | HIGH | LOW | HIGH | LOW | LOW |
| 7/7/93 | 13 | | | | | | 19 | | | | | 10 | | | | | |
| 7/13/93 | 3.75 | | | | | | 5 | | | | | 0.25 | | | | | |
| 7/27/93 | 7.25 | 2 | | | 28 | 33.5 | 31.75 | 8.5 | 19.5 | 0.25 | 31.5 | 32 | 52 | 20 | 44 | 26.5 | 0.25 |
| 8/3/93 | 3.5 | | | | | | 8.25 | | | | | | | | | | |
| 8/10/93 | 0.25 | | | | 1.5 | 0.75 | 3 | | | 2.5 | 0.5 | 12.5 | | 32.5 | | | 0.25 |
| 8/18/93 | 12.75 | 3 | | | | | 57.25 | 4 | | | | 185.5 | 29 | | | | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/24/93 | 0.25 | 1 | | | | | 0.5 | 1 | | | | 12 | 12 | | | | |
| 9/8/93 | 1 | | 1.25 | 0.25 | 9.75 | 3.25 | 2.25 | | 3.5 | 4.75 | 16.5 | 16.75 | | 11 | | 2 | 0.25 |
| 9/22/93 | 8.5 | 11.5 | | | | | 6.5 | 9 | | | | 15.5 | 26 | | | | |
| 10/18/93 | 0.25 | 7 | | | | | 0.25 | 0.5 | | | | 146 | 19 | | | | |
| 11/9/93 | 0.25 | 4 | | | | | 5.5 | 0.25 | | | | 6 | 35 | | | | |
| 5/11/94 | 1.8 | | 2.3 | 4.5 | 11 | 5.5 | 0.25 | | 0.25 | 0.25 | 22.5 | 20 | | 15 | | 0.25 | 0.5 |
| 5/18/94 | 3 | 2.3 | | | | | 11.5 | 16 | | | | 16 | 24 | | | | |
| 1/11/04 | 56 | | | | | | 39 | | | | | 1000 | | | | | |
| 5/31/94 | 1.3 | | | | | | 1 | | | | | 5 | | | | | |
| 6/9/94 | 11.5 | 2 | | | 22 | | 16.5 | 0.5 | | 0.25 | 31 | 13 | 0.25 | | | | 0.8 |
| 6/28/94 | 14.5 | | | | | | 43 | | | | | 12.5 | | | | | |
| Geom. ave. | 2.78 | 2.56 | 1.70 | 1.06 | 9.98 | 4.60 | 5.46 | 2.33 | 2.57 | 0.71 | 11.26 | 18.18 | 10.72 | 14.89 | 44.00 | 2.37 | 0.36 |
| Std. dev. | 5.43 | 1.35 | 1.54 | 7.72 | 3.16 | 4.80 | 5.76 | 6.08 | 8.98 | 4.28 | 5.82 | 6.41 | 12.39 | 1.35 | 1.00 | 10.34 | 1.71 |

## *C. perfringens*

| SITE # | OR1 | OR1 | OR2 | OR3 | OR4 | OR5 | OR6 | OR6 | OR7 | OR8 | OR9 | OR10 | OR10 | OR11 | OR11 | OR12 | OR13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tide | LOW | HIGH | LOW | LOW | LOW | LOW | LOW | HIGH | LOW | LOW | LOW | LOW | HIGH | LOW | HIGH | LOW | LOW |
| 7/13/93 | 4 | | | | | | 15 | | | | | 2.25 | | | | | |
| 7/27/93 | 1.3 | 3.25 | | | 5 | 4 | 0.5 | 3.5 | 8 | 17.5 | 8 | 6 | 6 | 0.25 | 1.5 | 7 | 1.25 |
| 8/3/93 | 7.5 | | | | | | 14.5 | | | | | | | | | | |
| 8/10/93 | 6.25 | | | | 11 | 8 | 15.5 | | | 82 | 16 | 8.5 | | 4 | | | 4.25 |
| 8/18/93 | 6.5 | 3 | | | | | 26 | 4 | | | | 7 | 29 | | | | |
| 8/24/93 | 3.5 | 3.5 | | | | | 11.5 | 4.5 | | | | 10 | 9.5 | | | | |
| 9/8/93 | 5 | | 7 | 2 | 7.25 | 12.25 | 8.75 | | 105 | 9.75 | 14 | 24.5 | | 3 | | 36 | 2.25 |
| 9/22/93 | 2 | 1.75 | | | | | 5.5 | 1.25 | | | | 9.5 | 3.5 | | | | |
| 10/18/93 | 12 | 3.8 | | | | | 10.75 | 4.5 | | | | 7 | 9 | | | | |
| 11/9/93 | 8.25 | 5.25 | | | | | 7 | 4.5 | | | | 9 | 27 | | | | |
| 5/11/94 | 26 | | 19.8 | 31 | 30.5 | 36 | 63.5 | | 128.5 | 124 | 48.8 | 42.5 | | 30 | | 82 | 16.5 |
| 5/18/94 | 23.5 | 9.5 | | | | | 22.5 | 17.5 | | | | 60 | 12 | | | | |
| 5/25/94 | 11.5 | | | | | | 40 | | | | | 38.8 | | | | | |
| 5/31/94 | 12.5 | | | | | | 33 | | | | | 41.3 | | | | | |
| 6/9/94 | 9 | 3 | | | 11 | | 15 | 8 | | 75 | 42.5 | 12.5 | 11 | | | | 2 |
| 6/28/94 | 4.5 | | | | | | 10 | | | | | 6 | | | | | |
| Geom. ave. | 6.77 | 4.29 | 11.77 | 7.87 | 10.60 | 10.90 | 12.80 | 6.15 | 47.61 | 41.96 | 20.61 | 12.12 | 15.08 | 2.82 | 1.50 | 27.44 | 3.31 |
| Std. dev. | 2.23 | 1.65 | 2.09 | 6.95 | 1.97 | 2.51 | 2.95 | 1.94 | 4.70 | 3.01 | 2.16 | 2.59 | 2.13 | 10.96 | 1.00 | 3.50 | 2.72 |

**Table 1-2. Annual and seasonal geometric means (per 100 ml) for bacterial indicators in the Oyster River: 7/93-6/94.**

## Fecal coliforms

| SITE # | OR1 | OR1 | OR2 | OR3 | OR4 | OR5 | OR6 | OR6 | OR7 | OR8 | OR9 | OR10 | OR10 | OR11 | OR11 | OR12 | OR13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tide | LOW | HIGH | LOW | LOW | LOW | LOW | LOW | HIGH | LOW | LOW | LOW | LOW | HIGH | LOW | HIGH | LOW | LOW |
| GEO AVE | 8 | 36 | 13 | 5 | 43 | 25 | 33 | 9 | 13 | 1 | 73 | 64 | 38 | 58 | 11 | 5 | 2 |
| STD DEV | 3 | 2 | 3 | 10 | 3 | 2 | 5 | 3 | 6 | 7 | 2 | 4 | 7 | 7 | 1 | 14 | 4 |
| Summer | 5 | 5 | 7 | 1 | 23 | 26 | 41 | 5 | 35 | 4 | 51 | 56 | 16 | 55 | 11 | 16 | 2 |
| Autumn | 5 | 13 | | | | | 5 | 4 | | | | 23 | 203 | | | | |
| Spring | 21 | 6 | 26 | 28 | 108 | 22 | 62 | 28 | 2 | 0 | 124 | 120 | 99 | 65 | | 1 | 2 |

## Enterococci

| SITE # | OR1 | OR1 | OR2 | OR3 | OR4 | OR5 | OR6 | OR6 | OR7 | OR8 | OR9 | OR10 | OR10 | OR11 | OR11 | OR12 | OR13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tide | LOW | HIGH | LOW | LOW | LOW | LOW | LOW | HIGH | LOW | LOW | LOW | LOW | HIGH | LOW | HIGH | LOW | LOW |
| GEO AVE | 3 | 3 | 2 | 1 | 10 | 5 | 5 | 2 | 3 | 1 | 11 | 18 | 11 | 15 | 44 | 2 | 0 |
| STD DEV | 5 | 1 | 2 | 8 | 3 | 5 | 6 | 6 | 9 | 4 | 6 | 6 | 12 | 1 | 1 | 10 | 2 |
| Summer | 2 | 2 | 1 | 0 | 7 | 4 | 7 | 6 | 8 | 1 | 6 | 11 | 39 | 15 | 44 | 7 | 0 |
| Autumn | 1 | 4 | | | | | 2 | 0 | | | | 24 | 35 | | | | |
| Spring | 6 | 2 | 2 | 5 | 16 | 6 | 7 | 3 | 0 | 0 | 26 | 25 | 0 | 15 | | 0 | 1 |

## *Clostridium perfringens*

| SITE # | OR1 | OR1 | OR2 | OR3 | OR4 | OR5 | OR6 | OR6 | OR7 | OR8 | OR9 | OR10 | OR10 | OR11 | OR11 | OR12 | OR13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tide | LOW | HIGH | LOW | LOW | LOW | LOW | LOW | HIGH | LOW | LOW | LOW | LOW | HIGH | LOW | HIGH | LOW | LOW |
| GEO AVE | 7 | 4 | 12 | 8 | 11 | 11 | 13 | 6 | 48 | 42 | 21 | 12 | 15 | 3 | 2 | 27 | 3 |
| STD DEV | 2 | 2 | 2 | 7 | 2 | 3 | 3 | 2 | 5 | 3 | 2 | 3 | 2 | 11 | 1 | 3 | 3 |
| Summer | 4 | 3 | 7 | 2 | 7 | 7 | 9 | 4 | 29 | 24 | 12 | 6 | 13 | 1 | 2 | 16 | 2 |
| Autumn | 6 | 5 | | | | | 7 | 5 | | | | 8 | 27 | | | | |
| Spring | 12 | 5 | 20 | 31 | 18 | 36 | 26 | 12 | 129 | 96 | 46 | 26 | 11 | 30 | | 82 | 6 |

TABLE 1-3. NH4 CONCENTRATIONS FOR THE OYSTER RIVER TRANSECT STATIONS 7/93-6/94

| NH4 | OR1 H | OR1 L | OR2 L | OR3 L | OR4 L | OR5 L | OR6 H | OR6 L | OR7 L | OR8 L | OR9 L | OR10 H | OR10 L | OR11 L | OR12 L | OR13L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/7/93 | | 6.17 | | | | | | 4.58 | | | | | 3.37 | | | |
| 7/13/93 | | 1.54 | | | | | | 0.35 | | | | | 0.16 | | | |
| 7/21/93 | | 4.58 | | | | | | 7.55 | | | | | 3.09 | | | |
| 7/27/93 | 1.52 | 8.93 | | | 13.35 | 10.91 | 4.38 | 23.25 | 18.61 | 25.85 | 6.25 | 14.36 | 14.43 | 0.85 | 36.50 | 0.54 |
| 8/3/93 | | 1.44 | | | | | | 19.06 | | | | | | | | |
| 8/10/93 | | 12.36 | 0.32 | 0.59 | 0.53 | 0.14 | | 0.92 | 4.32 | 0.46 | 0.28 | | 0.02 | 3.92 | 0.51 | 4.15 |
| 8/18/93 | | 1.03 | | | | | | 19.97 | | | | | 8.94 | | | |
| 8/24/93 | 7.00 | 0.63 | | | | | 1.04 | 3.07 | | | | 10.06 | 18.37 | | | |
| 9/8/93 | | 37.68 | 11.77 | 58.83 | 30.24 | 23.48 | | 29.09 | 61.39 | 998.36 | 39.72 | | 15.06 | 2.77 | 112.04 | 11.24 |
| 9/22/93 | 3.54 | 23.45 | | | | | 16.00 | 28.56 | | | | 39.90 | 29.68 | | | |
| 10/18/93 | 9.03 | 7.45 | | | | | 2.98 | 34.65 | | | | 27.14 | 11.19 | | | |
| 11/9/93 | 2.56 | 13.73 | | | | | 7.44 | 10.44 | | | | 4.41 | 13.54 | | | |
| 5/11/94 | | 6.28 | 5.22 | 5.84 | 6.67 | 6.95 | | 8.74 | 40.74 | 106.63 | 5.71 | | 3.59 | 7.62 | 12.34 | 9.30 |
| 5/18/94 | 4.43 | 7.50 | | | | | 8.25 | 5.15 | | | | 5.13 | 12.80 | | | |
| 5/25/94 | | 14.60 | | | | | | 7.84 | | | | | 11.43 | | | |
| 5/31/94 | | 12.04 | | | | | | 9.53 | | | | | 5.83 | | | |
| 6/9/94 | 6.86 | 9.60 | | | 13.80 | | 3.71 | 14.77 | | 186.39 | 6.67 | 15.77 | 9.34 | | | 2.28 |
| 6/28/94 | | 6.52 | | | | | | 7.28 | | | | | 9.32 | | | |
| | | | | | | | | | | | | | | | | |
| MEAN | 4.99 | 9.75 | 5.77 | 21.75 | 12.92 | 10.37 | 6.26 | 13.04 | 31.26 | 263.54 | 11.73 | 16.68 | 10.01 | 3.79 | 40.35 | 5.50 |

TABLE 1-4. NO3 CONCENTRATIONS FOR THE OYSTER RIVER TRANSECT STATIONS 7/93-6/94

| NO3 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE | OR1 H | OR1 L | 0R2 L | OR3 L | OR4 L | OR5 L | OR6 H | OR6 L | OR7 L | OR8 L | OR9 L | OR10 L | OR11 L | OR12 L | OR13 L |
| 7/7/93 | | 1.40 | | | | | | 8.67 | | | | 2.08 | | | |
| 7/13/93 | | 0.17 | | | | | | 1.06 | | | | 0.06 | | | |
| 7/21/93 | | 1.75 | | | | | | 1.42 | | | | 0.58 | | | |
| 7/27/93 | 0.00 | 0.64 | | | 1.77 | | 0.77 | 2.14 | | 1.25 | 2.91 | 1.37 | | | 1.19 |
| 8/3/93 | | 2.35 | | | | | | 3.44 | | | | | | | |
| 8/10/93 | | 0.97 | 0.70 | 0.60 | 6.79 | 3.81 | | 9.24 | 11.20 | 304.67 | 0.00 | 0.71 | 2.16 | 25.23 | 0.00 |
| 8/18/93 | | 1.61 | | | | | | 6.23 | | | | 1.46 | | | |
| 8/24/93 | 1.21 | 1.91 | | | | | 1.19 | 3.65 | | | | 2.92 | | | |
| 9/8/93 | | 1.28 | 1.06 | 0.03 | 1.75 | 0.53 | | 1.13 | 2.70 | 0.92 | 2.87 | 1.36 | 3.80 | 1.26 | 0.95 |
| 9/22/93 | 1.32 | 2.05 | | | | | 1.91 | 3.11 | | | | 5.33 | | | |
| 10/18/93 | 3.51 | 6.79 | | | | | 6.16 | 10.71 | | | | 6.76 | | | |
| 11/9/93 | 6.78 | 4.66 | | | | | 4.70 | 5.90 | | | | 7.97 | | | |
| 5/11/94 | | 2.02 | 2.89 | 1.63 | 2.40 | 2.34 | | 5.59 | 9.29 | 71.58 | 9.05 | 7.95 | 8.04 | 8.74 | 1.84 |
| 5/18/94 | 2.30 | 4.68 | | | | | 8.91 | 6.75 | | | | 7.48 | | | |
| 5/25/94 | | 4.41 | | | | | | 2.89 | | | | 14.16 | | | |
| 5/31/94 | | 8.79 | | | | | | 9.96 | | | | 11.55 | | | |
| 6/9/94 | 3.36 | 0.16 | | | 5.08 | | 1.51 | 4.89 | | 82.25 | 3.23 | 7.32 | | | 4.25 |
| 6/28/94 | | 0.28 | | | | | | 3.31 | | | | 3.65 | | | |
| | | | | | | | | | | | | | | | |
| MEAN | 2.64 | 2.55 | 1.55 | 0.76 | 3.56 | 2.23 | 3.59 | 5.00 | 7.73 | 92.14 | 3.61 | 4.86 | 4.66 | 11.74 | 1.65 |

TABLE 1-5. PO4 CONCENTRATIONS AT THE OYSTER RIVER TRANSECT STATIONS 7/93-6/94

| DATE | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PO4 | OR1 H | OR1 L | OR2 L | OR3 L | OR4 L | OR5 L | OR6 H | OR6 L | OR7 L | OR8 L | OR9 L | OR10 H | OR10 L | OR11 H | OR11 L | OR12 L | OR13L |
| 7/7/93 | | 1.06 | | | | | | 1.70 | | | | | 1.22 | | | | |
| 7/13/93 | | 1.12 | | | | | | 1.55 | | | | | 1.40 | | | | |
| 7/21/93 | | 1.21 | | | | | | 3.40 | | | | | 1.32 | | | | |
| 7/27/93 | 0.82 | 1.76 | | | 2.89 | 2.96 | 1.47 | 4.16 | 4.65 | 3.35 | 1.73 | 2.95 | 2.43 | 0.33 | 0.43 | 6.34 | 1.12 |
| 8/3/93 | | 1.75 | | | | | | 2.36 | | | | | | | | | |
| 8/10/93 | | 1.32 | 1.63 | 1.57 | 1.94 | 1.79 | | 1.92 | 2.75 | 17.15 | 1.93 | | 1.82 | | 0.30 | 3.21 | 1.03 |
| 8/18/93 | | 1.82 | | | | | | 2.75 | | | | | 1.95 | | | | |
| 8/24/93 | 1.06 | 1.80 | | | | | 1.57 | 2.93 | | | | 3.26 | 2.94 | | | | |
| 9/8/93 | | 2.36 | 2.87 | 1.88 | 4.71 | 4.64 | | 5.14 | 7.25 | 79.24 | 5.36 | | 3.57 | | 0.26 | 10.36 | 1.41 |
| 9/22/93 | 1.26 | 1.80 | | | | | 1.61 | 2.51 | | | | 3.15 | 3.15 | | | | |
| 10/18/93 | 1.11 | 1.28 | | | | | 1.03 | 1.91 | | | | 2.57 | 1.90 | | | | |
| 11/9/93 | 0.92 | 1.91 | | | | | 1.32 | 1.63 | | | | 0.96 | 1.64 | | | | |
| 5/11/94 | | 0.57 | 0.67 | 0.76 | 0.95 | 1.08 | | 1.60 | 10.13 | 37.60 | 1.13 | | 0.58 | | 0.52 | 2.95 | 0.23 |
| 5/18/94 | 0.58 | 1.00 | | | | | 1.29 | 0.79 | | | | 0.50 | 0.53 | | | | |
| 5/25/94 | | 0.80 | | | | | | 1.32 | | | | | 0.84 | | | | |
| 5/31/94 | | 0.84 | | | | | | 1.86 | | | | | 0.60 | | | | |
| 6/9/94 | 0.85 | 1.15 | | | 1.38 | | 0.68 | 0.97 | | 24.16 | 1.34 | 1.23 | 1.10 | | | | 0.83 |
| 6/28/94 | | 1.27 | | | | | | 0.60 | | | | | 2.04 | | | | |
| | | | | | | | | | | | | | | | | | |
| MEAN | 0.94 | 1.38 | 1.72 | 1.40 | 2.37 | 2.62 | 1.28 | 2.17 | 6.19 | 32.30 | 2.30 | 2.09 | 1.71 | 0.33 | 0.38 | 5.71 | 0.92 |

Table 1-6. Calculated loading of dissolved inorganic N and P from the Tributaries to the Oyster River and the Durham POTW

| Beards Creek | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | low Flow m3/yr | high flow m3/yr | average m3/yr | Adj Average m3/yr | avg liters/yr | Mean mg/L N | kg N/yr | POTW- T N kg/yr | Mean PO4 mg/L | kg P/yr | POTW Total kg/yr P |
| | 1261.44 | 4257360.00 | 21293107.20 | 18921055.06 | 18921055057.92 | 0.31 | 5865.53 | | 0.036 | 681.16 | |
| Unnamed Creek | | | | | | | | | | | |
| | 630.72 | 256703.04 | 1286668.80 | 1143333.90 | 1143333895.68 | 0.74 | 846.07 | | 0.0194 | 22.18 | |
| Johnson Creek | | | | | | | | | | | |
| | 200884.32 | 7221744 | 37113141.6 | 32988387.04 | 32988387043 | 0.26 | 8576.98 | | 0.0248 | 818.11 | |
| Bunker Creek | | | | | | | | | | | |
| | 38158.56 | 1302436.80 | 6702976.80 | 5956265.18 | 5956265184.48 | 0.23 | 1369.94 | | 0.0355 | 211.45 | |
| Oyster River (main stem) | | | | | | | | | | | |
| | | | | 49511520 | 49511520000.00 | 0.24 | 11882.76 | | 0.0139 | 688.21 | 8207.27 |
| | | | | | | Total N from tributaries | 28541.28 | 25985 | Total kg/yr P NPS | 2421.11 | |
| | | | | Tl kg/yr N-NPS | Tl kg/yr N-POTW | Tl kg/yr N-all sources | | | | | |
| | | | | 28541.28 | 25985.00 | 54526.28 | | | | | |
| | | | | % N-NPS | % N-POTW | | | | | | |
| | | | | 52.34 | 47.66 | | | | | | |
| | | | | Tl kg/yr P-NPS | Tl kg/yr P-POTW | Total kg/yr P-all sources | | | | | |
| | | | | 2421.11 | 8207.27 | 10628.38 | | | | | |
| | | | | % P-NPS | % P-POTW | | | | | | |
| | | | | 22.78 | 77.22 | | | | | | |

Table 1-7. Estimated amount and % contribution of dissolved inorganic N and P to the Oyster River

| | kg N/yr | % N of NPS | % N of Total* | kg P/yr | % P of NPS | % P of Total |
|---|---|---|---|---|---|---|
| **Beards Creek** | 5865.53 | 20.55% | 10.76% | 681.16 | 28.13% | 6.41% |
| **Unnamed Creek** | 846.07 | 2.96% | 1.55% | 22.18 | 0.92% | 0.21% |
| **Johnson Creek** | 8576.98 | 30.05% | 15.73% | 818.11 | 33.79% | 7.70% |
| **Bunker Creek** | 1369.94 | 11.53% | 2.51% | 211.45 | 8.73% | 1.99% |
| **Oyster River (main stem)** | 11882.76 | 41.63% | 21.79% | 688.21 | 28.43% | 6.48% |
| **Total kg/yr NPS** | 28541.28 | | 52.34% | 2421.11 | | 22.78% |
| **kg/yr POTW** | 25985 | | 47.66% | 8207.27 | | 77.22% |
| **Total kgN/yr** | 54526.28 | | | 10628.38 | | |

TABLE 1-8. ESTIMATED ANNUAL LOADING OF FECAL COLIFORMS AND ENTEROCOCCI FROM THE OYSTER RIVER TRIBUTARIES AND THE DURHAM POTW

| | FC x one billion/yr | ENT x one billion /yr | % OF TOTAL FC | % OF TOTAL ENT |
|---|---|---|---|---|
| Beards Creek | 4,940 | 1,306 | 9.56% | 4.30% |
| Unnamed Creek | 72 | 348 | 0.14% | 1.15% |
| Johnson Creek | 11,600 | 10,556 | 22.44% | 34.78% |
| Bunker Creek | 2,690 | 774 | 5.20% | 2.55% |
| Oyster River | 32,300 | 17,329 | 62.49% | 57.09% |
| POTW | 86 | 41 | 0.17% | 0.14% |

**Figure 1-1. Geometric average fecal coliform and enterococci concentrations along a transect in the Oyster River from 7/93 to 6/94. High tide samples are site #s followed by H.**

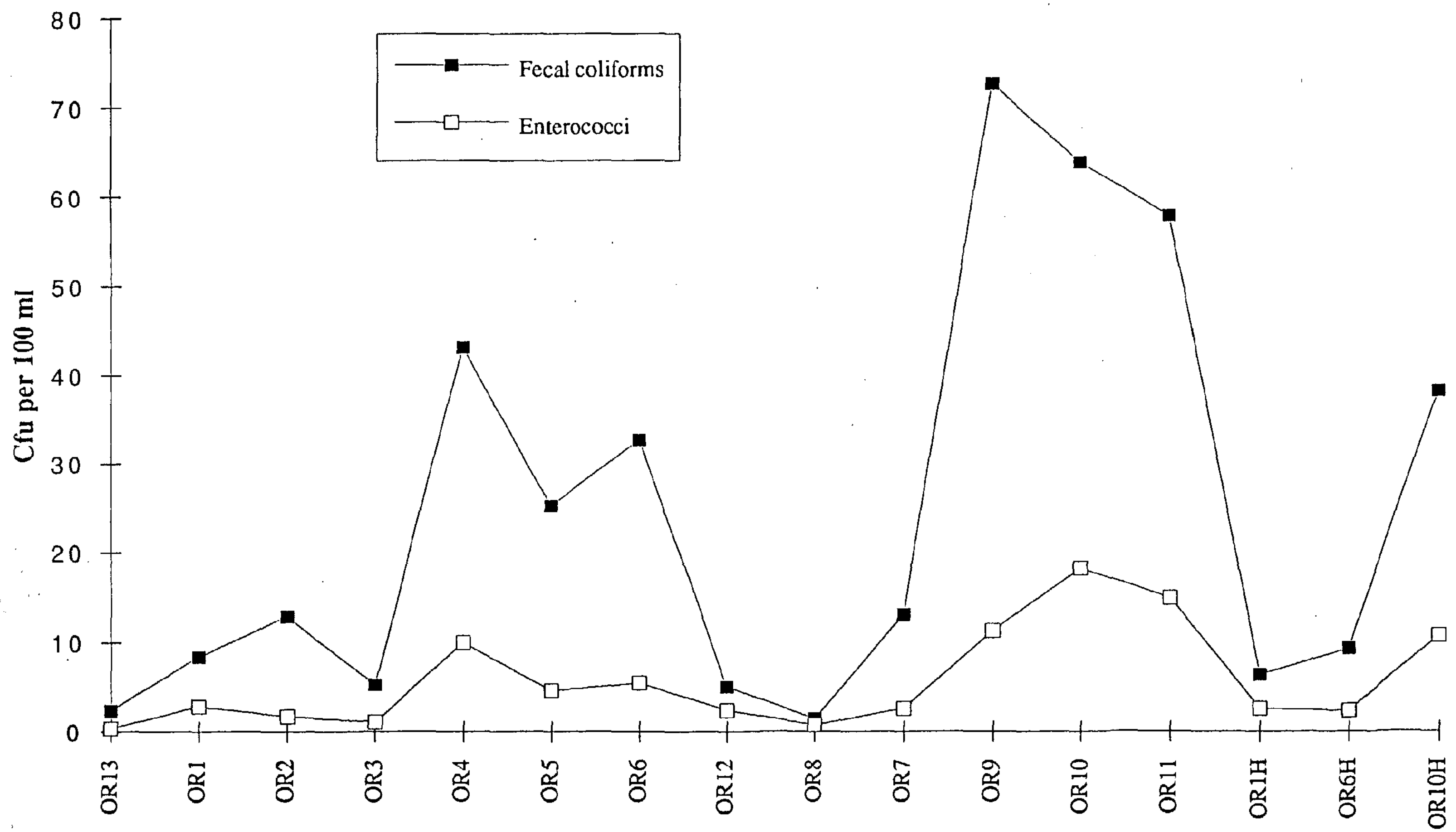


Figure 1-2. Geometric average C. perfringens concentrations along a transect in the Oyster River from 7/93 to 6/94. High tide samples are site #s followed by H.

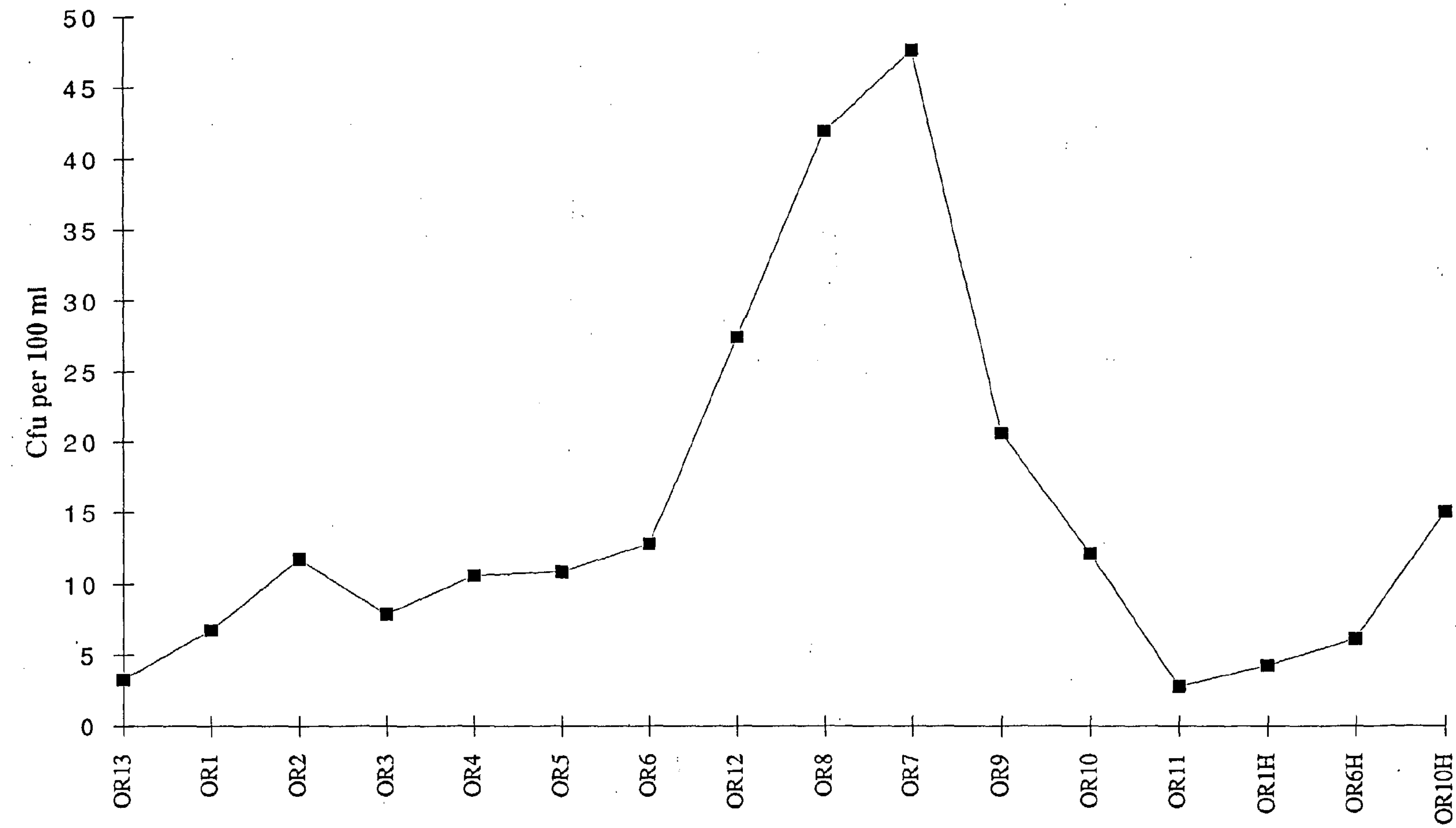


**Figure 1-3. Seasonal geometric average fecal coliform concentrations along a transect in the Oyster River from 7/93 to 6/94. High tide samples are site #s followed by H.**

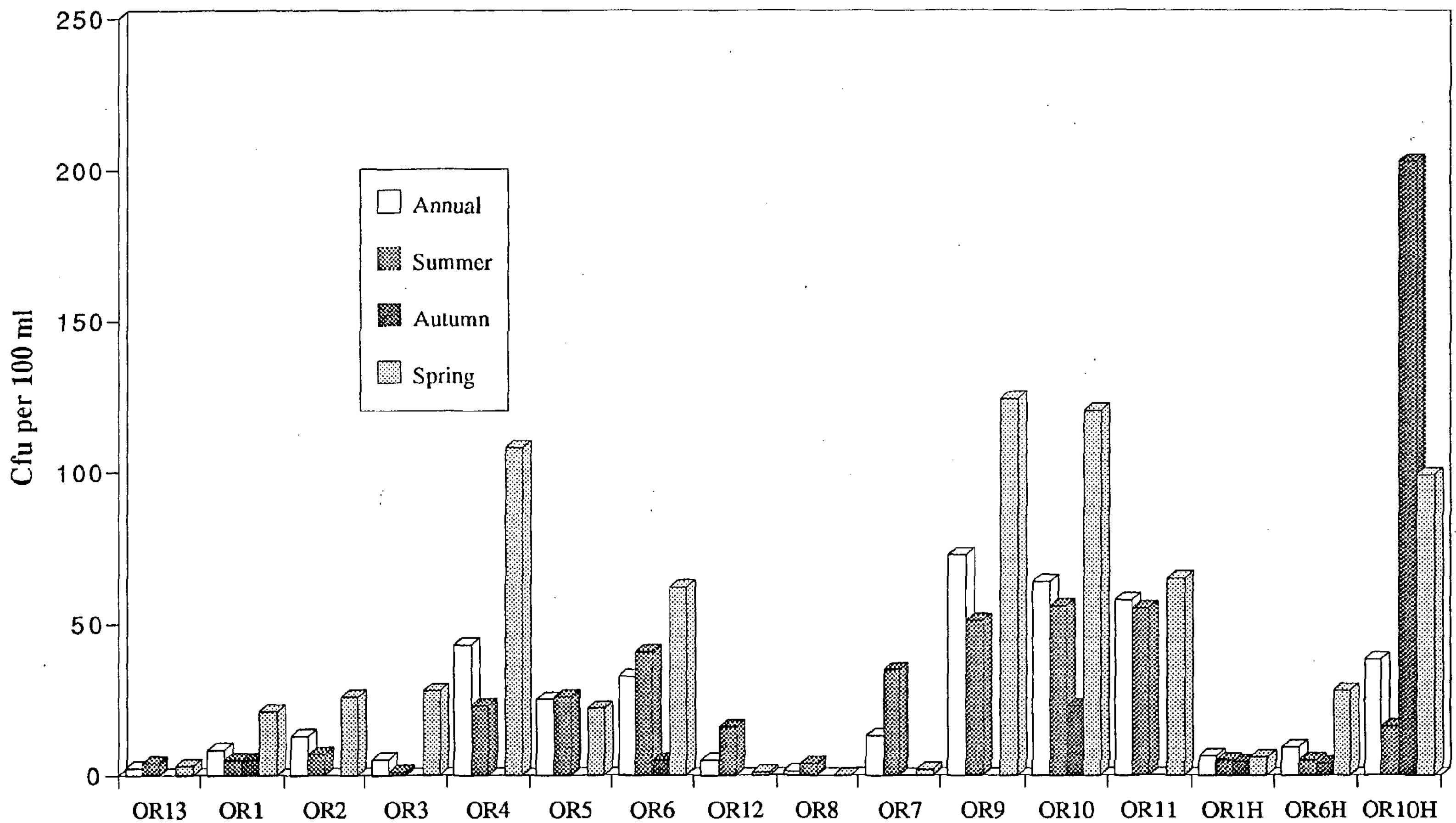


Figure 1-4. Seasonal geometric average enterococci concentrations along a transect in the Oyster River from 7/93 to 6/94. High tide samples are site #s followed by H.

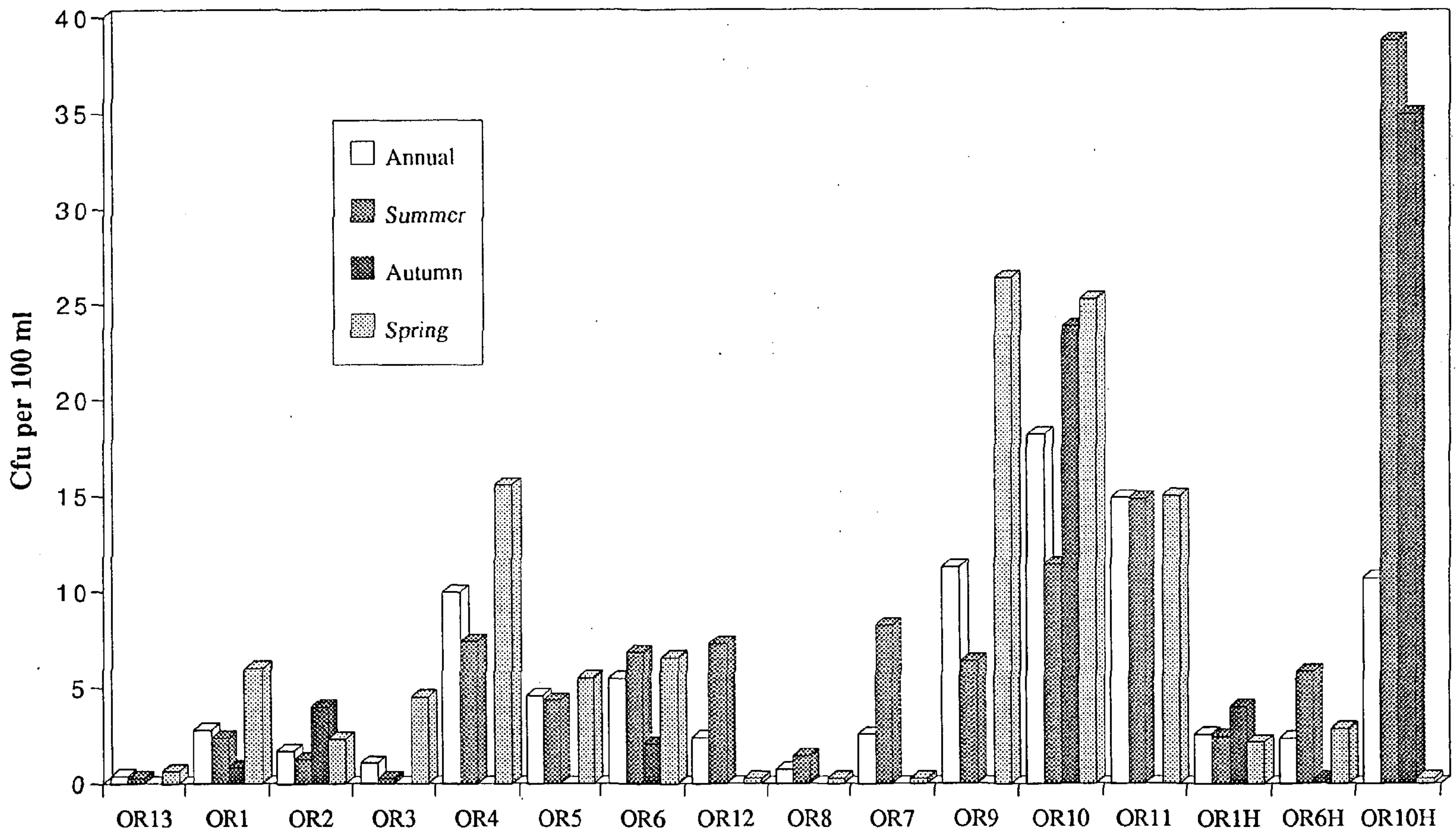


Figure 1-5. Seasonal geometric average C. perfringens concentrations along a transect in the Oyster River from 7/93 to 6/94. High tide samples are site #s followed by H.

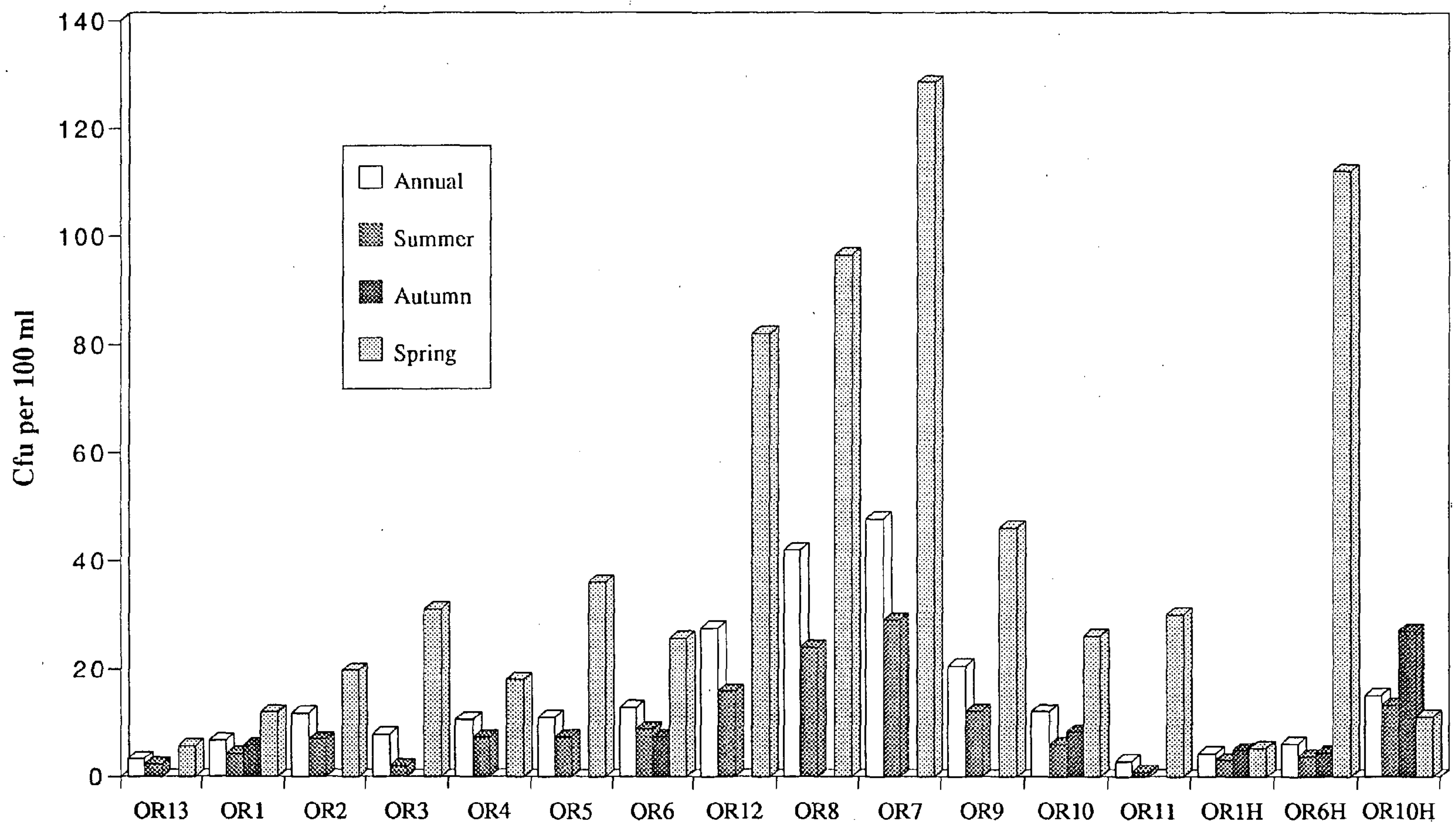


FIGURE 1-6. MEAN NH4 CONCENTRATIONS FOR THE OYSTER RIVER TRANSECT STATIONS 7/93-6/94

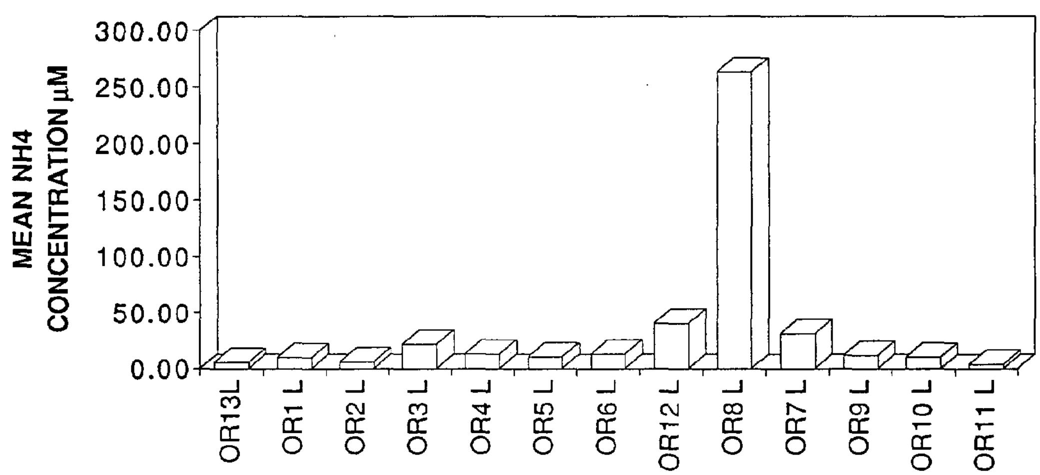


FIGURE 1-7. MEAN NO3 CONCENTRATIONS FOR THE OYSTER RIVER TRANSECT STATIONS 7/93-6/94

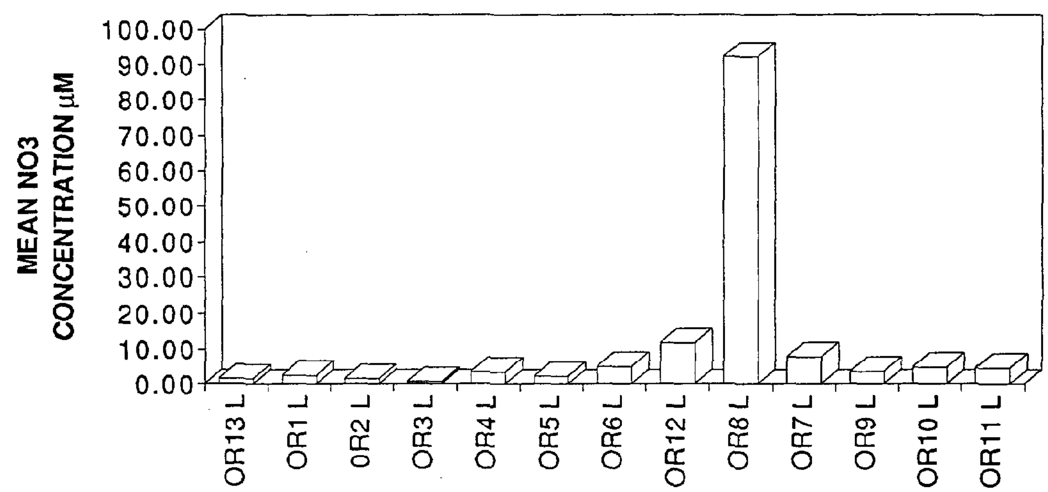


FIGURE 1-8. Mean PO4 Concentrations at the Oyster Riv Transect Stations 7/93- 6/94

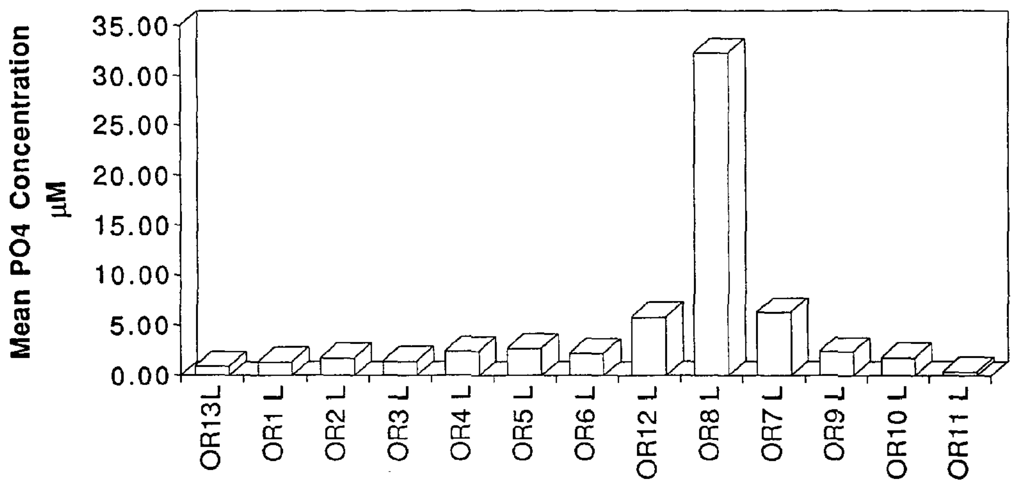


**FIGURE 1-9. SEASONAL MEAN NH4 CONCENTRATIONS FOR THE OYSTER RIVER TRANSECT STATIONS**

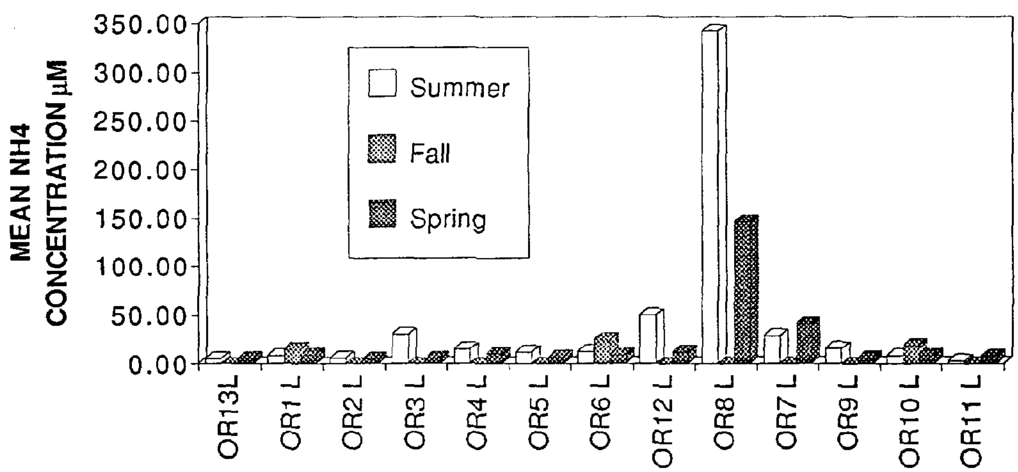


FIGURE 1-10. SEASONAL MEAN NO3 CONCENTRATIONS FOR TYHE OYSTER RIVER TRANSECT STATIONS 7/93-6/94

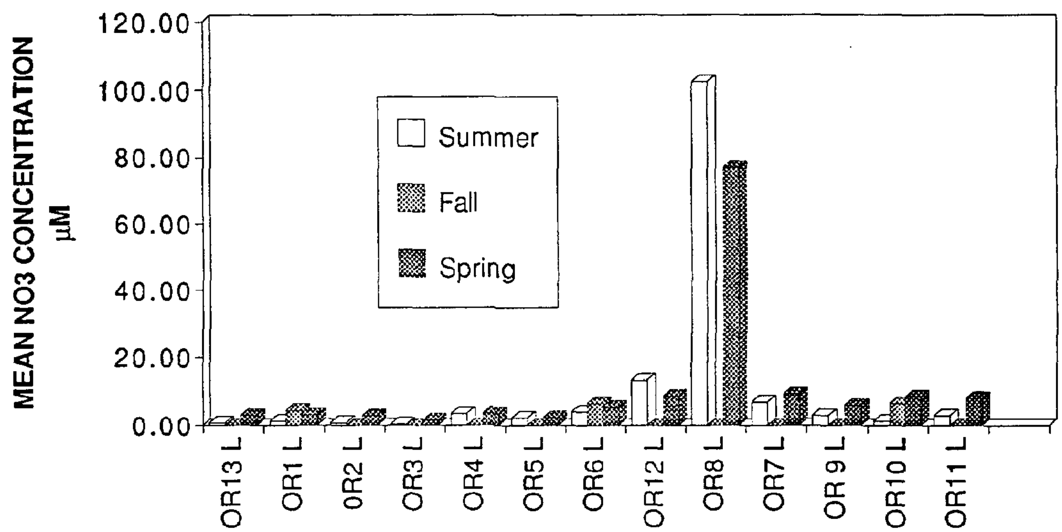


FIGURE 1-11. Seasonal Mean Po4 Concentrations for Oyst
River Transect Stations 7/93-6/94

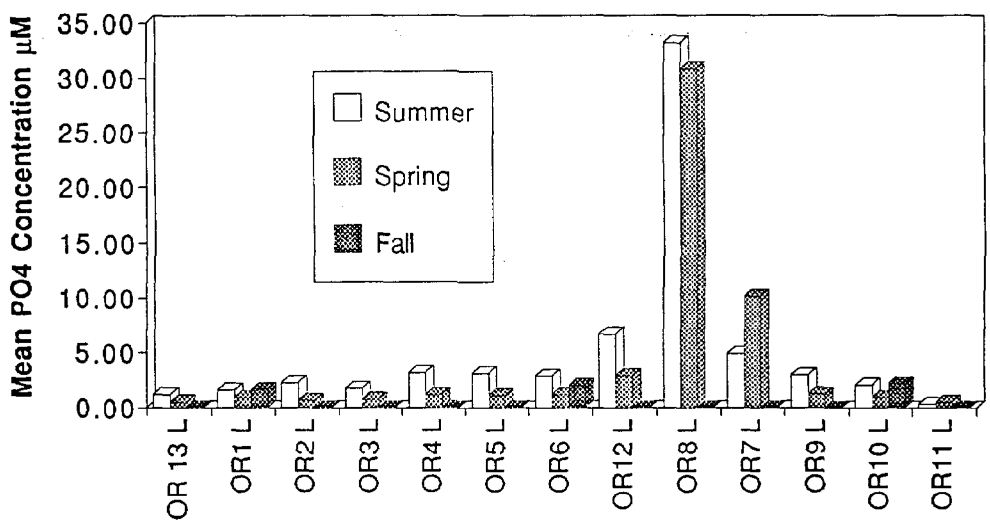


FIGURE 1-12. ESTIMATED ANNUAL CONTRIBUTION OF DISSOLVED INORGANIC N IN THE OYSTER RIVER

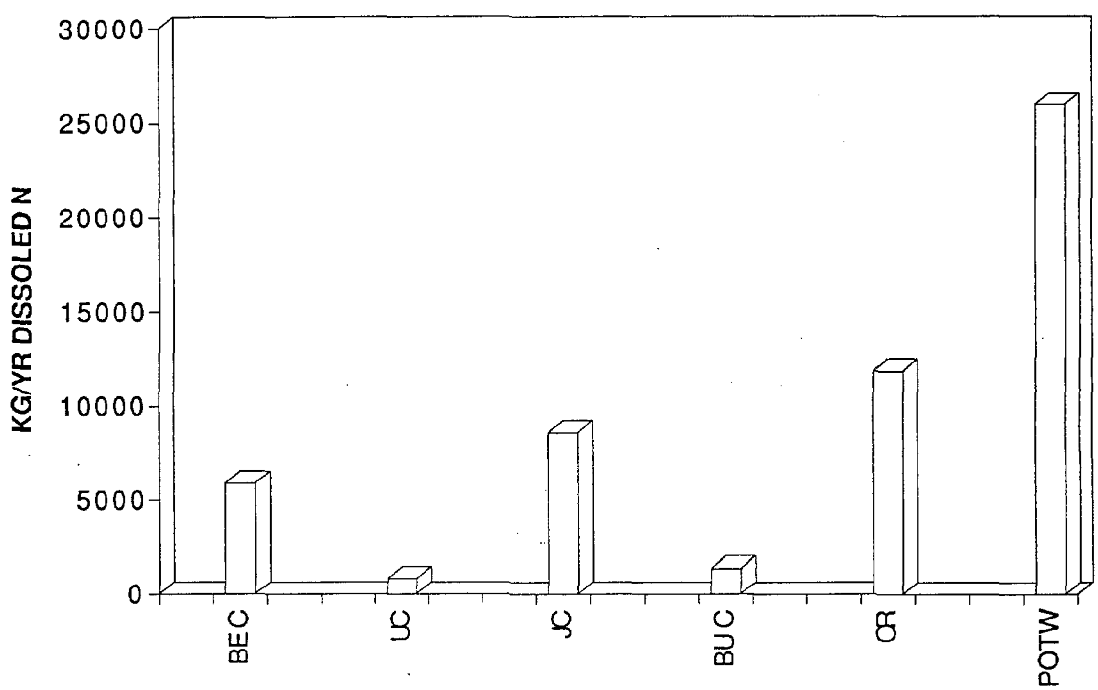


FIGURE 1-13. ESTIMATED ANNUAL CONTRIBUTION OF DISSOLVED INORGANIC P IN THE OYSTER RIVER

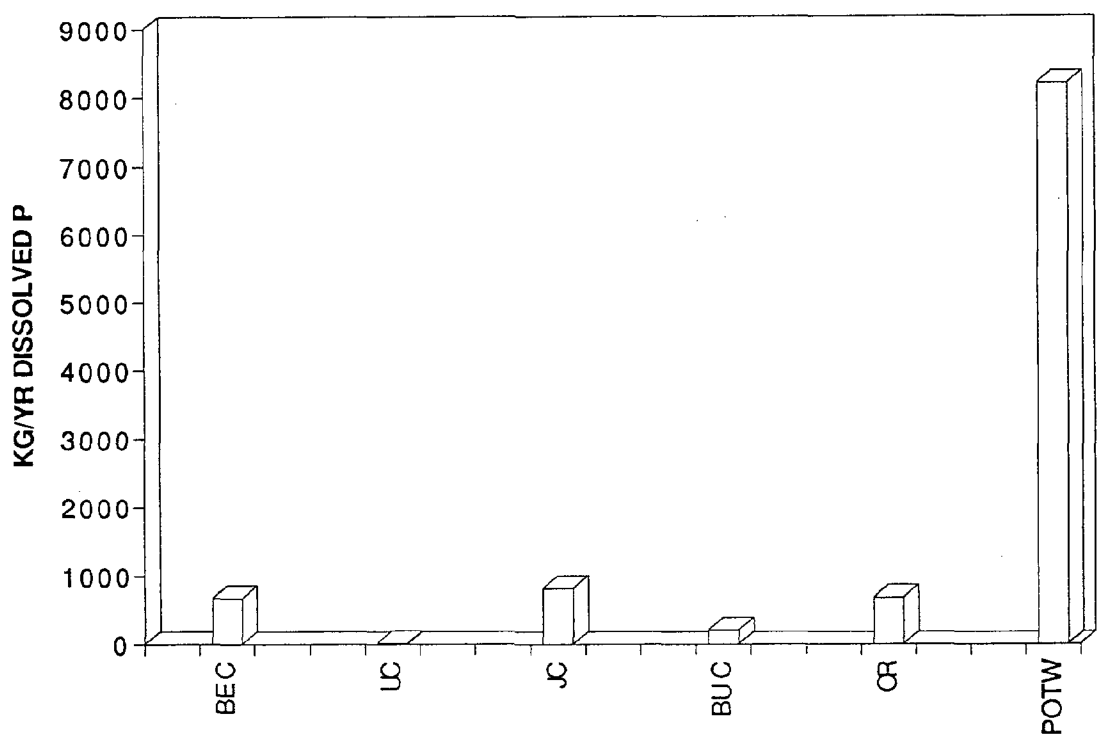
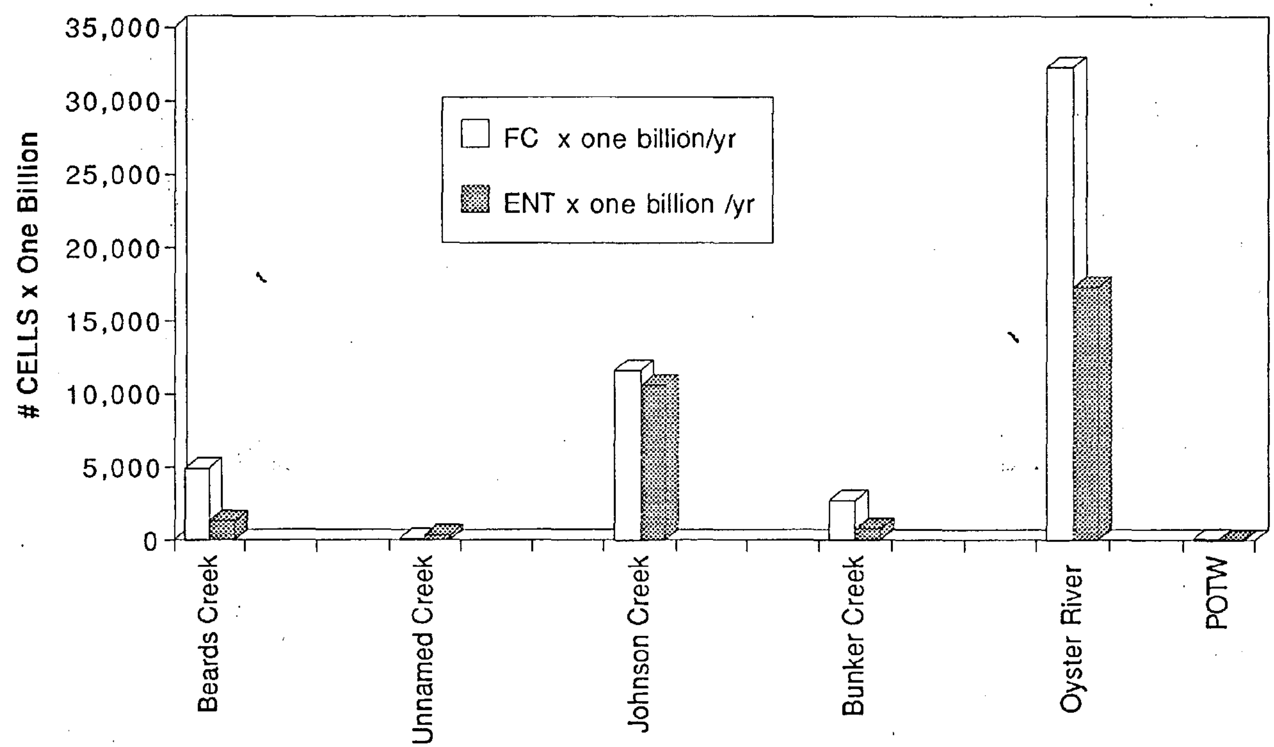


FIGURE 1-14. ESTIMATED ANNUAL LOADING OF FECAL COLIFORMS ANI ENTEROCOCCI IN THE OYSTER RIVER



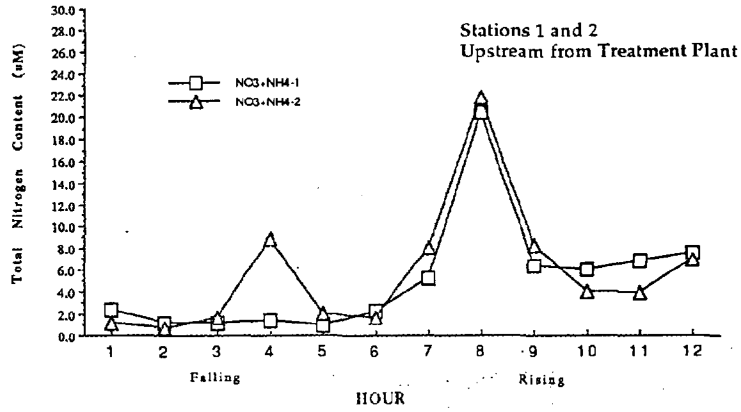



Figure 1-15. Total nitrogen content (ammonium and nitrate concentrations (uM)) at Stations 1 and 2, upstream from the Sewage Treatment Plant.

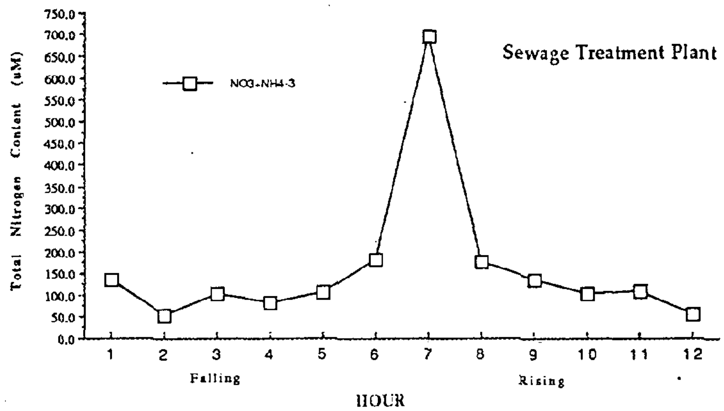



Figure 1-16. Total nitrogen content (ammonium and nitrate concentrations (uM)) at Station 3, the Sewage Treatment Plant.

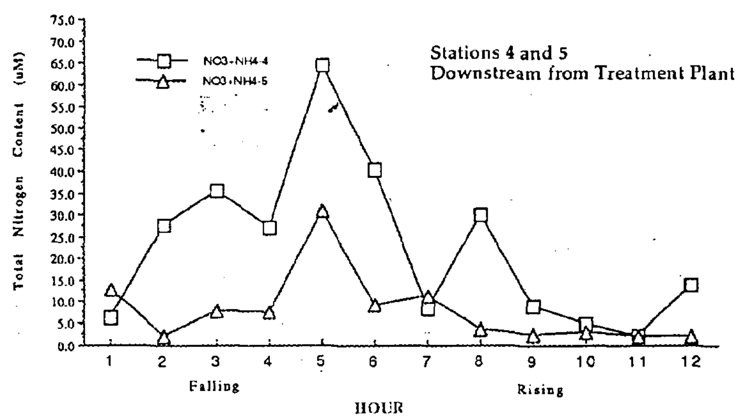



Figure 1-17. Total nitrogen content (ammonium and nitrate concentrations (uM)) at Stations 4 and 5, downstream from the Sewage Treatment Plant.

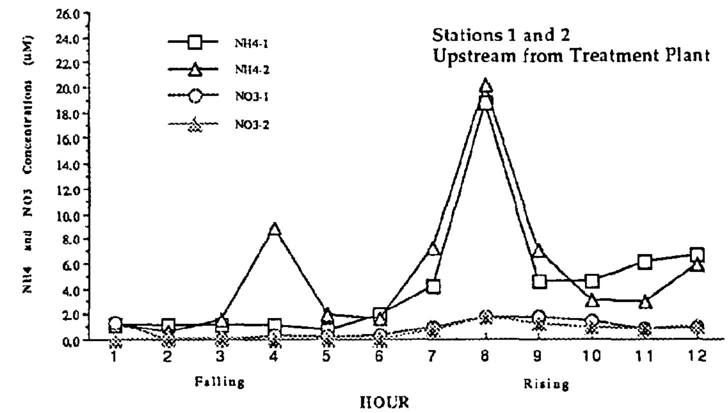



Figure 1-18. Ammonium and nitrate concentrations (uM) at Stations 1 and 2, upstream of the Sewage Treatment Plant.

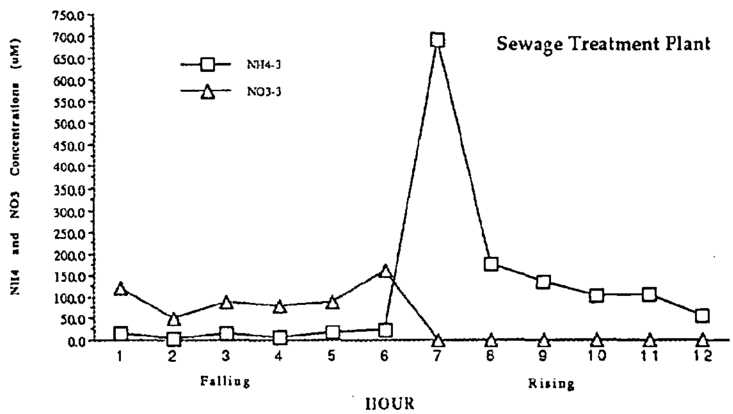



Figure 1-19. Ammonium and nitrate concentrations (uM) at Station 3, the Sewage Treatment Plant.

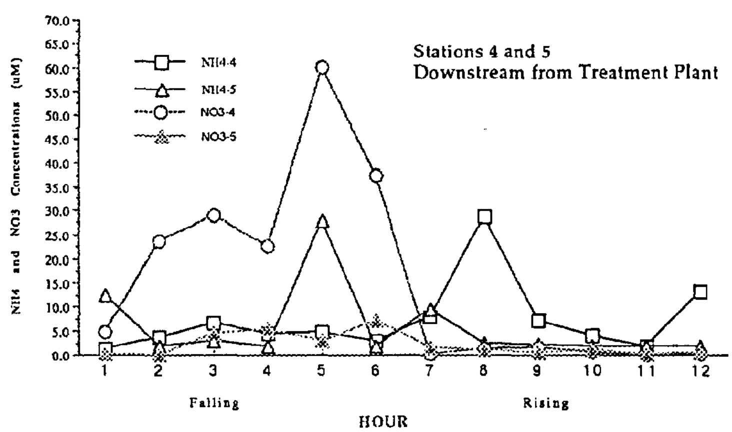



Figure 1-20. Ammonium and nitrate concentrations (uM) at Stations 4 and 5, downstream from the Sewage Treatment Plant.

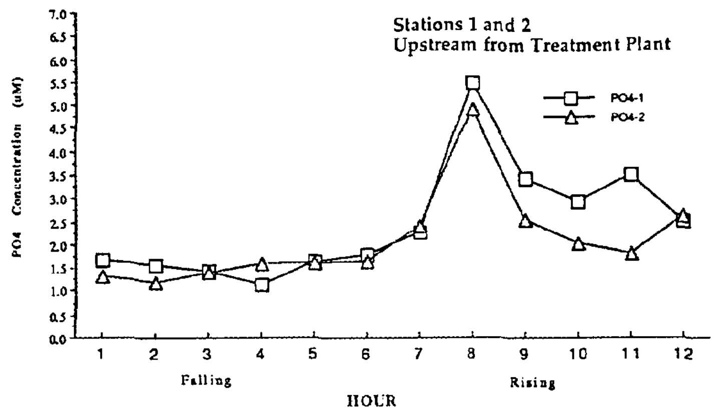



Figure 1-21. Phosphate concentrations (uM) for Stations 1 and 2, upstream from the Sewage Treatment Plant.

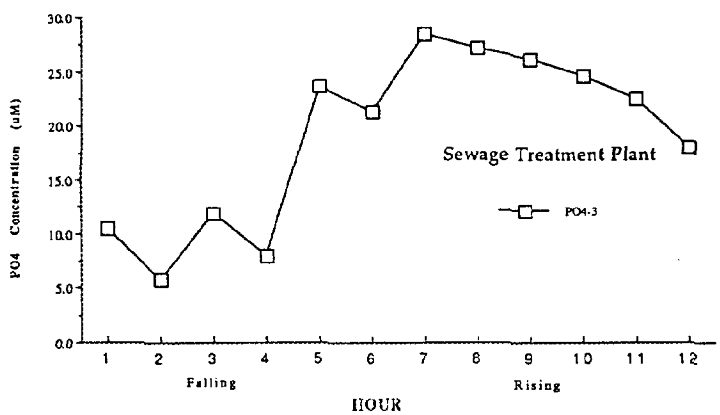



Figure 1-22. Phosphate Concentrations (uM) at Station 3, the Sewage Treatment Plant.

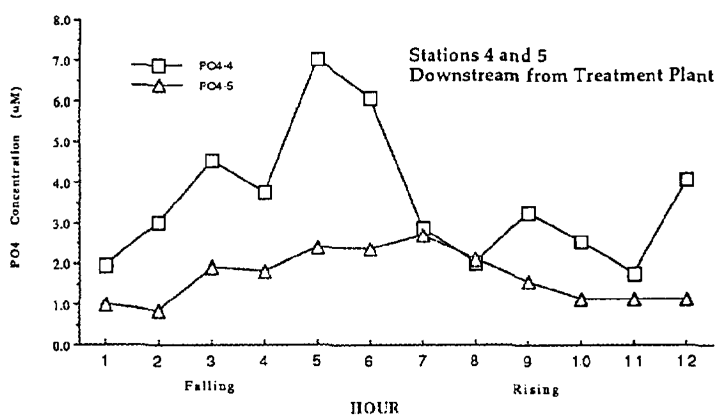



Figure 1-23. Phosphate concentrations (uM) at Stations 4 and 5, downstream of the Sewage Treatment Plant.

# TABLES AND FIGURES

## OBJECTIVE 2

**Table 2-1. Indicator concentrations and geometric means (per 100 ml) in Johnson Creek: 7/93-6/94.**

### Fecal coliforms

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12A | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/7/93 | | 85 | 745 | 1250 | | 495 | 400 | 550 | 590 | | | | | |
| 7/12/93 | 13 | 28 | 2420 | 1400 | | 450 | 475 | 205 | 815 | 795 | 550 | | | |
| 7/20/93 | 23 | 14 | 780 | 7890 | | 4640 | 2405 | 385 | 460 | 230 | | | | |
| 7/28/93 | | 60 | | | | | | 445 | | | | | | |
| 8/12/93 | | 190 | 850 | 300 | | 600 | 390 | 60 | 110 | 215 | 105 | | | |
| 8/16/93 | 5 | 25 | 100 | 700 | | 600 | 570 | 60 | 175 | 85 | 113 | | | |
| 9/29/93 | | | 412 | 210 | 4000 | 400 | 245 | 236 | 328 | 234 | 733 | 420 | | |
| 11/2/93 | 85 | 264 | 70 | 160 | 80 | 111 | 120 | 365 | 35 | 43 | 45 | 60 | 120 | |
| 1/26/94 | | | 3.0 | | | | | | | | | | | |
| 2/1/94 | | | 5.0 | | | | | | | | | | | |
| 2/22/94 | | | 22.8 | | | | | | 26.0 | | | | 27.5 | |
| 3/1/94 | | | 30.5 | | | | 42.5 | | | | | | 105.0 | |
| 3/8/94 | | | 126.3 | | | | 75.0 | | 53.5 | | | | 85.0 | |
| 3/15/94 | | | 22.5 | 14.0 | 5.0 | 20.0 | 115.0 | 26.0 | 45.0 | | 59.0 | 0.5 | 117.5 | |
| 4/11/94 | 35.5 | 9.0 | 93.8 | 1.0 | 3.5 | 13.8 | 6.0 | 9.5 | 10.0 | 4.0 | 54.0 | | 35.0 | 0 |
| 6/1/94 | 28.0 | 105.0 | 50.0 | 1500.0 | 53.0 | 318.0 | 55.0 | 61.0 | 68.0 | 31.5 | 85.0 | 23.5 | 1.3 | 0 |
| GEO AVE | 22.25 | 51.04 | 95.20 | 269.83 | 49.49 | 260.70 | 163.36 | 122.14 | 106.30 | 89.82 | 124.58 | 23.33 | 39.55 | 0.00 |
| STD DEV | 2.62 | 3.19 | 6.96 | 13.44 | 16.77 | 5.57 | 4.71 | 3.76 | 3.98 | 5.11 | 2.88 | 16.93 | 5.13 | |

### Enterococci

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12A | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/7/93 | | 15 | 240 | 585 | | 845 | 330 | 160 | 155 | | | | | |
| 7/12/93 | 28 | 59 | 890 | 1220 | | 1170 | 1530 | 235 | 508 | 400 | 293 | | | |
| 7/20/93 | 35 | 70 | 1330 | 12700 | | 8050 | 132 | 400 | 460 | 175 | | | | |
| 7/28/93 | | 16 | | | | | | 300 | | | | | | |
| 8/12/93 | 23 | 26 | 150 | | | 1 | 230 | 85 | 90 | 70 | 48 | | | |
| 8/16/93 | 57 | 7 | 60 | 1000 | | 100 | 720 | 50 | 65 | 35 | 55 | | | |
| 9/29/93 | | | 265 | 135 | 336 | 84 | 108 | 160 | 36 | 64 | 78 | 55 | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/2/93 | 23 | 144 | 110 | 150 | 80 | 138 | 165 | 200 | 40 | 8 | 50 | 179 | 59 | |
| 1/26/94 | | | 0.5 | | | | 3.8 | | | | | | | |
| 2/1/94 | | | 8.8 | | | | | | | | | | | |
| 2/22/94 | | | 55.0 | | | | | | 6.5 | | | | 9.0 | |
| 3/1/94 | | | 7.3 | | | | | | | | | | 95.5 | |
| 3/8/94 | | | 109.0 | | | | 83.0 | | 37.5 | | | | 42.5 | |
| 3/15/94 | | | 20.0 | 1.5 | 45.0 | 3.8 | 2.5 | 18.5 | 14.5 | | 22.0 | 1.0 | 47.5 | |
| 4/11/94 | 3.5 | 6.5 | 3.8 | 1.0 | 1.3 | 2.5 | 0.5 | 4.5 | 5.5 | 2.0 | 13.0 | 0.5 | 7.0 | |
| 6/1/94 | 3.8 | 61.5 | 80.0 | 35.5 | 29.0 | 65.8 | 25.8 | 25.5 | 19.5 | 27.7 | 7.0 | 3.0 | 7.0 | 173.0 |
| GEO AVE | 16.8 | 27.9 | 53.6 | 128.8 | 33.8 | 70.1 | 59.5 | 83.1 | 47.0 | 38.2 | 39.5 | 6.8 | 24.3 | 173.0 |
| STD DEV | 3.0 | 3.0 | 8.3 | 22.6 | 7.9 | 20.2 | 11.3 | 4.0 | 4.3 | 5.4 | 3.2 | 12.9 | 3.1 | |

*Clostridium perfringens*

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12A | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/12/93 | 6.00 | 18.00 | 1.25 | 7.50 | | 3.50 | 4.50 | 5.50 | 12.50 | 10.50 | 8.50 | | | |
| 7/20/93 | 7.50 | 8.00 | 0.75 | 2.00 | | 5.50 | 45.00 | 6.50 | 7.50 | 8.00 | | | | |
| 8/12/93 | 5.50 | 2.00 | 52.50 | 9.50 | | 2.50 | 0.50 | 8.00 | 5.50 | 5.00 | 4.00 | | | |
| 8/16/93 | 1.50 | 2.00 | 4.00 | 7.00 | | 3.75 | 0.50 | 1.50 | 2.00 | 0.50 | 2.00 | | | |
| 11/2/93 | 10.50 | 10.50 | 12.00 | 1.00 | 16.00 | 7.00 | 10.50 | 17.50 | 21.00 | 25.00 | 5.50 | 4.00 | | |
| 1/26/94 | | | 16.0 | | | | | | | | | | | 2.0 |
| 2/1/94 | | | 14.0 | | | | | | | | | | | |
| 2/22/94 | | | 29.5 | | | | | | 38.0 | | | | 36.8 | |
| 3/1/94 | | | 46.7 | | | | 21.0 | | | | | | 20.0 | |
| 3/8/94 | | | 102.5 | | | | 60.0 | | 0.5 | | | | 0.5 | |
| 3/15/94 | | | 36.3 | 7.0 | 46.3 | 42.5 | 27.5 | 13.0 | 8.8 | | 20.5 | 3.0 | 21.3 | |
| 4/11/94 | 9.5 | 11.5 | 8.0 | 7.5 | 12.5 | 15.0 | 2.5 | 1.3 | 5.0 | 1.5 | 18.5 | 2.5 | 2.0 | 14.0 |
| 6/1/94 | 0.5 | 7.5 | 5 | 11.5 | 5.0 | 15.0 | 5.5 | 4.5 | 8.0 | 1.5 | 16.0 | 0.5 | 14.0 | 1.0 |
| GEO AVE | 4.1 | 6.6 | 12.0 | 5.3 | 14.7 | 7.7 | 6.9 | 5.2 | 6.5 | 3.8 | 8.1 | 2.0 | 7.8 | 3.0 |
| STD DEV | 3.1 | 2.4 | 4.3 | 2.3 | 2.5 | 2.6 | 5.6 | 2.6 | 3.3 | 3.9 | 2.4 | 2.5 | 5.3 | 3.9 |

**Table 2-2. Annual and seasonal geometric means (per 100 ml) for bacterial indicators in Johnson Creek: 7/93-6/94.**

## Fecal coliforms

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GEO AVE | 22 | 51 | 95 | 270 | 49 | 261 | 163 | 122 | 106 | 90 | 125 | 23 |
| STD DEV | 3 | 3 | 7 | 13 | 17 | 6 | 5 | 4 | 4 | 5 | 3 | 17 |
| Summer | 11 | 46 | 654 | 1237 | | 821 | 633 | 203 | 336 | 240 | 187 | |
| Autumn | 85 | 264 | 170 | 183 | 566 | 211 | 171 | 293 | 107 | 100 | 182 | 159 |
| Winter | | | 18 | 14 | 5 | 20 | 72 | 26 | 40 | | 59 | 1 |
| Spring | 32 | 31 | 68 | 39 | 14 | 66 | 18 | 24 | 26 | 11 | 68 | 24 |

## Enterococci

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GEO AVE | 17 | 28 | 54 | 129 | 34 | 70 | 60 | 83 | 47 | 38 | 40 | 7 |
| STD DEV | 3 | 3 | 8 | 23 | 8 | 20 | 11 | 4 | 4 | 5 | 3 | 13 |
| Summer | 34 | 24 | 303 | 1735 | | 209 | 406 | 164 | 184 | 114 | 91 | |
| Autumn | 23 | 144 | 171 | 142 | 164 | 108 | 133 | 179 | 38 | 22 | 62 | 99 |
| Winter | | | 13 | 2 | 45 | 4 | 9 | 19 | 15 | | 22 | 1 |
| Spring | 4 | 20 | 17 | 6 | 6 | 13 | 4 | 11 | 10 | 7 | 10 | 1 |

## *Clostridium perfringens*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GEO AVE | 4 | 7 | 12 | 5 | 15 | 8 | 7 | 5 | 7 | 4 | 8 | 2 |
| STD DEV | 3 | 2 | 4 | 2 | 2 | 3 | 6 | 3 | 3 | 4 | 2 | 3 |
| Summer | 4 | 5 | 4 | 6 | | 4 | 3 | 5 | 6 | 4 | 4 | |
| Autumn | 11 | 11 | 12 | 1 | 16 | 7 | 11 | 18 | 21 | 25 | 6 | 4 |
| Winter | | | 32 | 7 | 46 | 43 | 33 | 13 | 5 | | 21 | 3 |
| Spring | 2 | 9 | 6 | 9 | 8 | 15 | 4 | 2 | 6 | 2 | 17 | 1 |

TABLE 2-3. AMMONIUM CONCENTRATIONS AT THE JOHNSON CREEK STATIONS 4/93-6/94

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12A | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/7/93 | 5.12 | 8.61 | 5.95 | | | 3.95 | | | 3.13 | | | 3.80 | | |
| 4/12/93 | 4.44 | 4.06 | 7.15 | | | 7.53 | | | 2.99 | | | 2.35 | | |
| 5/25/93 | 6.50 | 12.35 | 10.29 | 6.27 | 3.22 | 5.82 | | 4.26 | 3.11 | | | | | |
| 6/1/93 | 14.30 | 16.11 | 1.79 | | 2.31 | 4.94 | 2.49 | 4.05 | 2.67 | 5.95 | 10.12 | | | |
| 6/29/93 | 1.98 | 2.73 | 5.29 | 6.56 | 36.52 | 3.98 | 5.76 | 4.84 | 6.56 | 5.03 | 3.92 | 15.14 | | |
| 7/7/93 | | 4.35 | 4.96 | 28.54 | | 4.40 | 5.87 | 5.11 | 5.82 | | | | | |
| 7/20/93 | 1.00 | 2.38 | 1.91 | 6.93 | | 4.02 | 7.70 | 5.72 | 2.78 | 1.19 | | | | |
| 9/29/93 | | | 2.70 | 5.30 | 3.58 | 2.74 | 6.49 | | 6.79 | 9.05 | 5.13 | | 2.84 | |
| 11/2/93 | 15.70 | 5.69 | 0.49 | 2.27 | 0.46 | 0.90 | 0.51 | 2.37 | 0.65 | 0.66 | 0.60 | 0.46 | | |
| 12/13/93 | | | | | | | | | 2.18 | | 1.99 | | | |
| 3/15/94 | | | 3.67 | 2.43 | 3.06 | 2.54 | 4.80 | 8.79 | 7.99 | | 1.10 | 4.61 | 0.65 | |
| 4/5/94 | | | | | | | | | | 1.97 | 2.18 | 1.53 | 0.41 | |
| 4/11/94 | 2.93 | 5.38 | 3.11 | 2.08 | 0.53 | 3.61 | 6.76 | 2.68 | 4.48 | 0.78 | 1.11 | 2.54 | 0.81 | 1.03 |
| 4/25/94 | | | | | | | | | 1.50 | 1.17 | 1.20 | | | |
| 6/1/94 | 5.42 | 11.67 | 4.236 | 7.649 | 1.90 | 5.49 | 2.16 | 4.63 | 2.78 | 1.91 | 2.73 | 2.06 | 2.49 | 3.13 |
| 6/29/94 | | | | | | | | | | 3.25 | 4.31 | | | |
| | | | | | | | | | | | | | | |
| MEAN | 6.38 | 7.33 | 4.29 | 7.56 | 6.45 | 4.16 | 4.72 | 4.72 | 3.82 | 3.10 | 3.12 | 4.06 | 1.44 | 2.08 |

TABLE 2-4. NITRATE C0NCENTRATIONS AT THE JOHNSON CREEK STATIONS 4/93-6/94

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12A | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/7/93 | 9.93 | 11.64 | 15.76 | | | 15.07 | | | 15.58 | | | 3.44 | | |
| 4/12/93 | 9.97 | 10.03 | 10.41 | | | 10.81 | | | 11.92 | | | 0.69 | | |
| 5/25/93 | 4.56 | 6.99 | 9.28 | 79.71 | 0.84 | 24.67 | | 26.49 | 29.39 | | | | | |
| 6/1/93 | 5.31 | 5.25 | 3.48 | | 1.90 | 7.80 | 9.79 | 11.85 | 12.65 | 20.16 | 12.20 | | | |
| 6/29/93 | 4.09 | 1.95 | 13.58 | 33.97 | 4.96 | 35.28 | 49.79 | 34.82 | 35.63 | 32.62 | 30.65 | 1.08 | | |
| 7/7/93 | | 4.84 | 29.99 | 53.60 | | 53.18 | 37.80 | 13.91 | 39.01 | | | | | |
| 7/20/93 | 1.70 | 0.74 | 7.32 | 15.60 | | 45.04 | 37.88 | 12.33 | 18.91 | 2.85 | | | | |
| 9/29/93 | | | 5.96 | 54.52 | 37.40 | 24.94 | 8.51 | | 25.09 | 1.18 | 29.87 | | 79.72 | |
| 11/2/93 | 3.32 | 12.18 | 3.80 | 8.57 | 0.69 | 10.47 | 11.35 | 14.12 | 13.85 | 114.54 | 15.15 | 3.59 | | |
| 12/13/93 | | | | | | | | | 22.74 | | 16.62 | | | |
| 3/15/94 | | | 21.23 | 52.42 | 16.33 | 20.84 | 16.61 | 19.92 | 17.63 | | 17.91 | 33.10 | 27.37 | |
| 4/5/94 | | | | | | | | | | 15.24 | 15.41 | 0.00 | 28.72 | |
| 4/11/94 | 21.80 | 9.06 | 21.12 | 86.59 | 2.16 | 17.16 | 20.88 | 50.38 | 17.31 | 13.46 | 40.11 | 0.00 | 50.12 | 4.58 |
| 4/25/94 | | | | | | | | | 14.15 | 4.65 | 26.68 | | | |
| 6/1/94 | 2.58 | 9.58 | 21.415 | 96.786 | 0.21 | 30.66 | 21.06 | 17.77 | 24.25 | 18.04 | 30.64 | 67.56 | 57.60 | 0.03 |
| 6/29/94 | | | | | | | | | | 18.47 | 20.80 | | | |
| mean | 7.03 | 7.23 | 13.61 | 53.53 | 8.06 | 24.66 | 23.74 | 22.40 | 21.29 | 24.12 | 23.28 | 13.68 | 48.70 | 2.31 |

TABLE 2-5. PHOSPHATE CONCENTRATIONS AT THE JOHNSON CREEK STATIONS 4/93-6/94

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12A | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/7/93 | 0.24 | 0.29 | 0.20 | | | 0.25 | | | 0.30 | | | 0.25 | | |
| 4/12/93 | 0.38 | 0.32 | 0.25 | | | 0.44 | | | 0.46 | | | 0.29 | | |
| 5/25/93 | 0.58 | 0.66 | 0.16 | 0.10 | 0.35 | 0.30 | | 0.42 | 0.43 | | | | | |
| 6/1/93 | 0.84 | 0.87 | 0.23 | | 0.36 | 0.22 | 0.20 | 0.39 | 0.36 | 0.23 | 0.41 | | | |
| 6/29/93 | 0.46 | 0.18 | 0.45 | 0.38 | 2.10 | 0.52 | 0.30 | 0.63 | 0.57 | 0.50 | 0.50 | 0.39 | | |
| 7/7/93 | | 1.46 | 0.38 | 0.50 | | 0.42 | 0.27 | 0.69 | 0.69 | | | | | |
| 7/20/93 | 1.57 | 1.55 | 0.14 | 4.64 | | 0.44 | 0.24 | 0.62 | 0.51 | 0.63 | | | | |
| 9/29/93 | | | 0.58 | 0.37 | 1.46 | 0.34 | 0.27 | | 0.82 | 0.46 | 0.57 | | 0.48 | |
| 11/2/93 | 1.13 | 0.49 | 0.30 | 0.38 | 0.41 | 0.30 | 0.31 | 0.55 | 0.44 | 0.35 | 0.64 | 0.49 | | |
| 12/13/93 | | | | | | | | | 0.62 | 0.61 | | | | |
| 3/15/94 | | | 0.24 | 0.26 | 0.22 | 0.39 | 0.31 | 0.39 | 0.46 | | 0.37 | 0.46 | 0.46 | |
| 4/5/94 | | | | | | | | | | 0.38 | 0.31 | 0.31 | 0.37 | |
| 4/11/94 | 0.16 | 0.22 | 0.17 | 0.15 | 0.23 | 0.22 | 0.25 | 0.29 | 0.37 | 0.45 | 0.41 | 0.33 | | 0.10 |
| 4/25/94 | | | | | | | | | 0.36 | 0.38 | 0.29 | | | |
| 6/1/94 | 0.26 | 0.40 | 0.23 | 0.22 | 0.44 | 0.49 | 0.25 | 0.27 | 0.45 | 0.69 | 0.34 | 0.35 | 0.44 | 0.60 |
| 6/29/94 | | | | | | | | | | 1.60 | 0.70 | | | |
| | | | | | | | | | | | | | | |
| MEAN | 0.62 | 0.64 | 0.28 | 0.78 | 0.70 | 0.36 | 0.27 | 0.47 | 0.49 | 0.57 | 0.45 | 0.36 | 0.44 | 0.35 |

Figure 2-1. Geometric average bacterial indicator concentrations in the Johnson Creek watershed from 7/93 to 6/94.

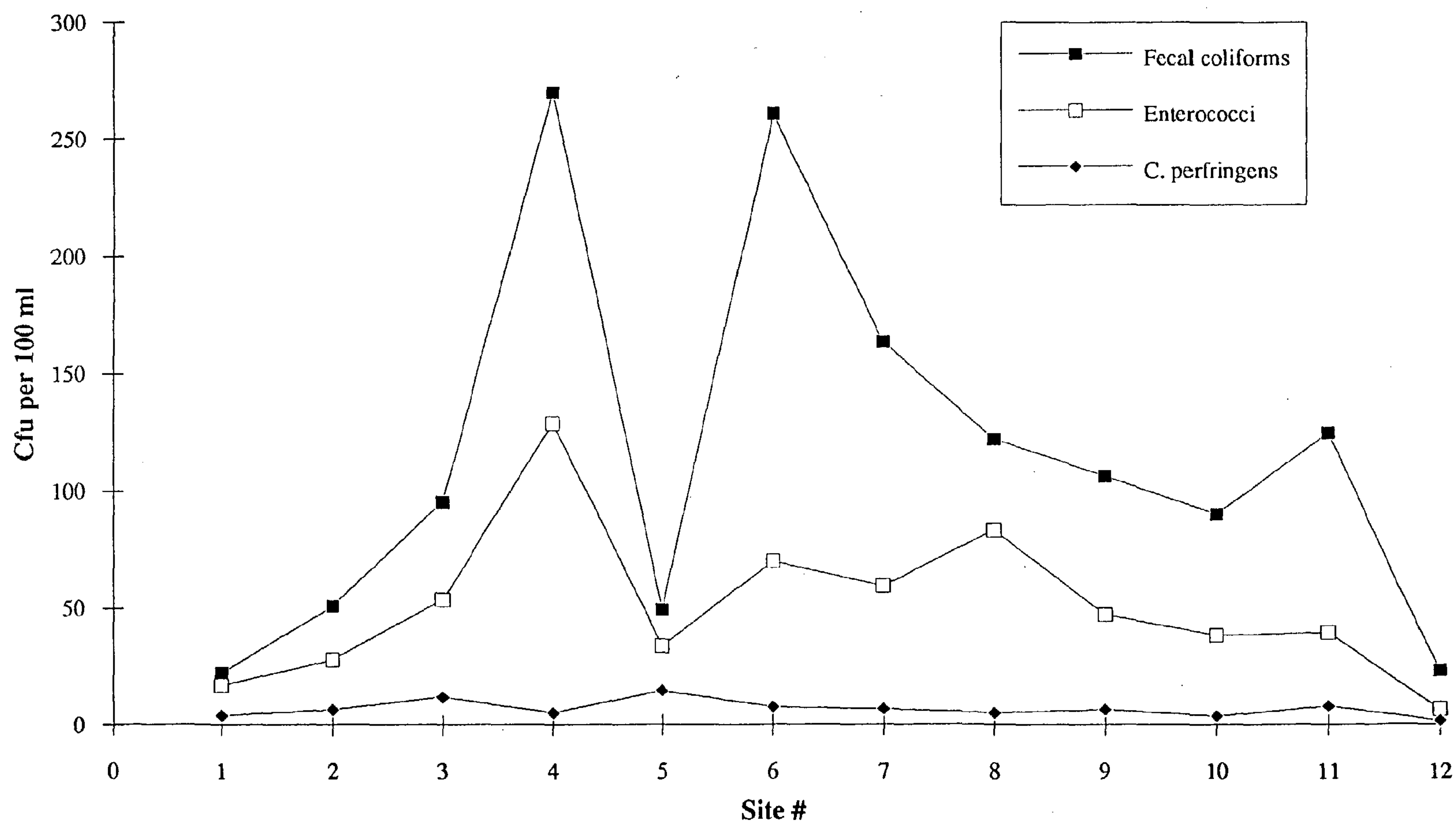


**Figure 2-2. Seasonal geometric average fecal coliform concentrations in the Johnson Creek watershed from 7/93 to 6/94.**

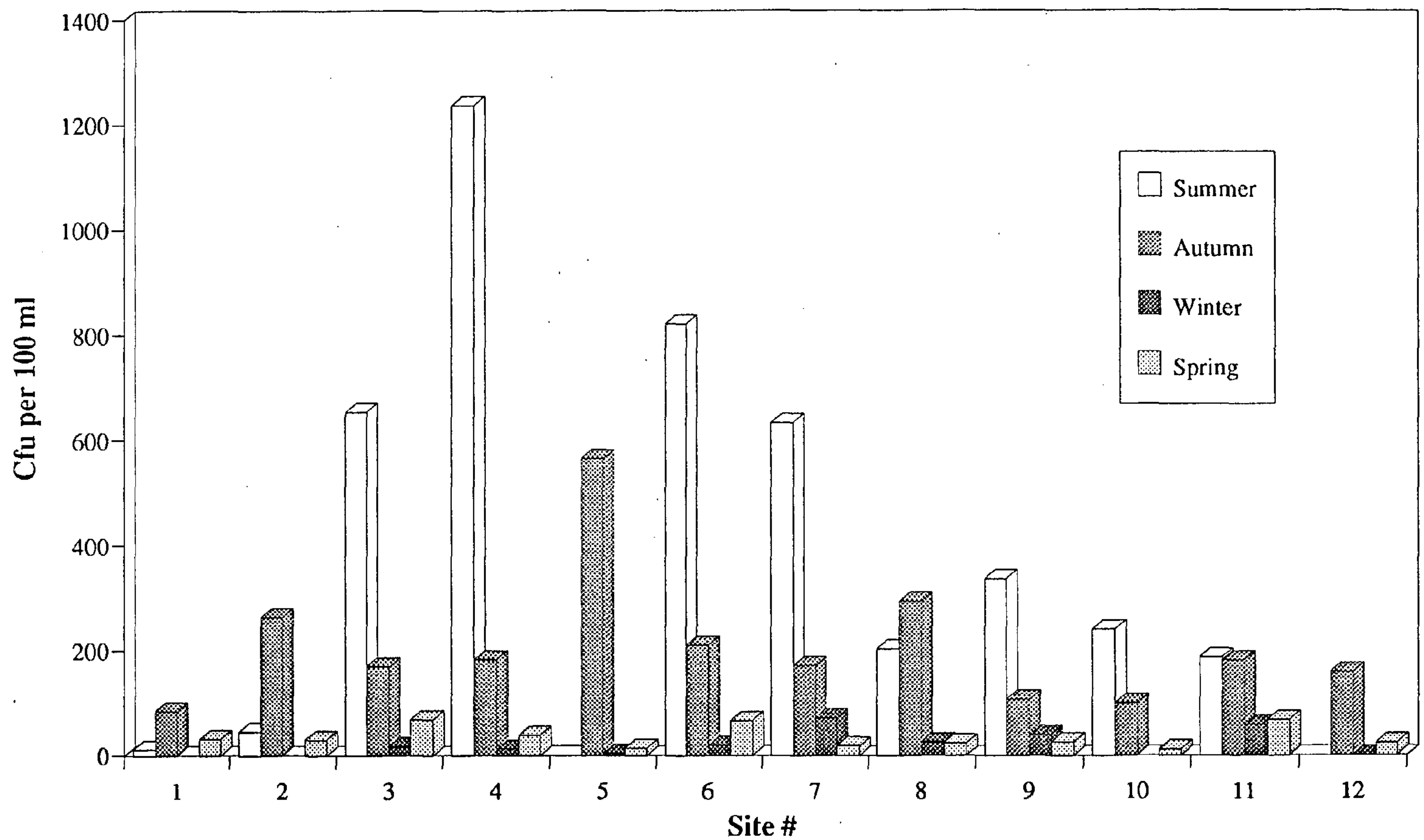


Figure 2-3. Seasonal geometric average enterococci concentrations in the Johnson Creek watershed from 7/93 to 6/94.

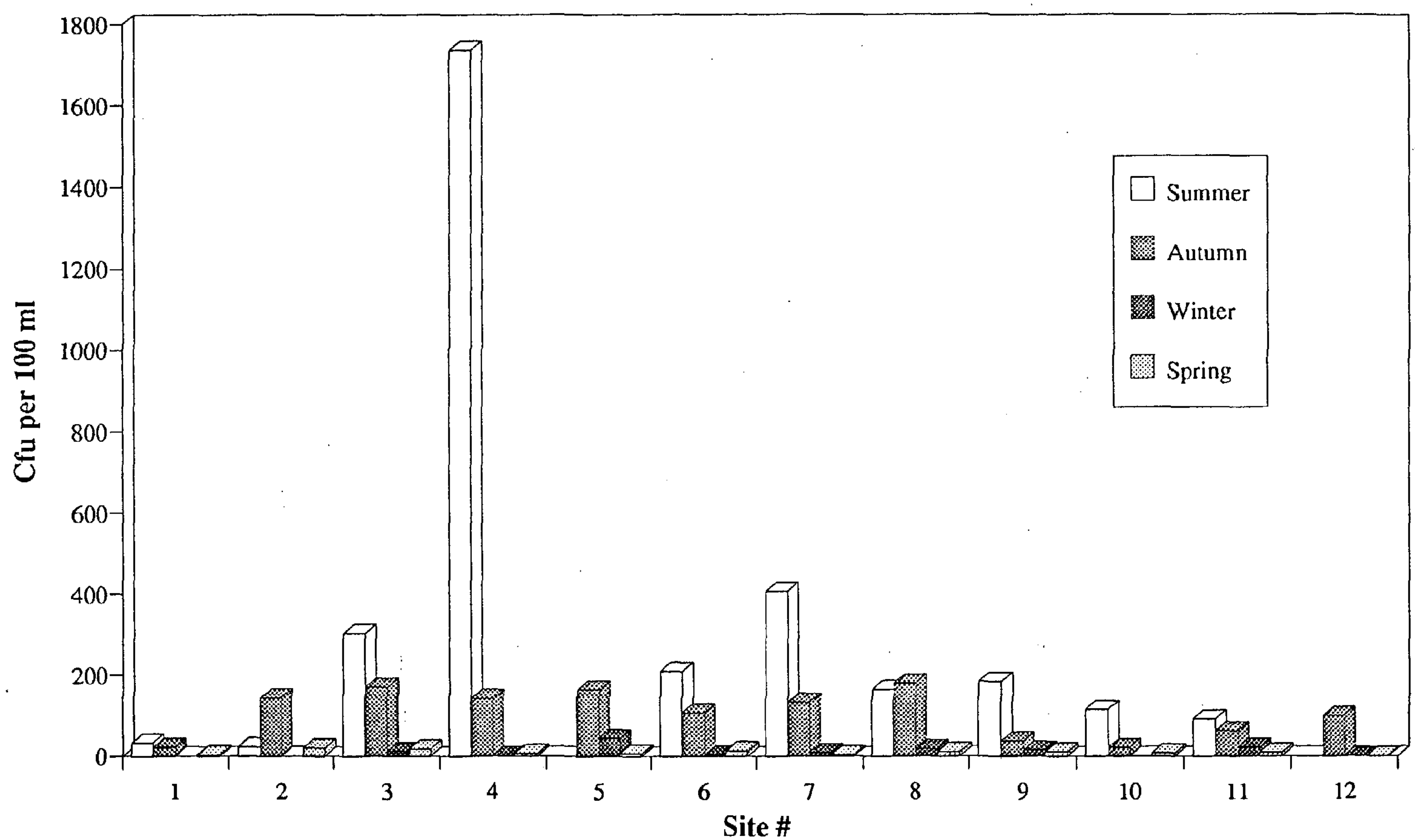


Figure 2-4. Seasonal geometric average C. perfringens concentrations in the Johnson Creek watershed from 7/93 to 6/94.

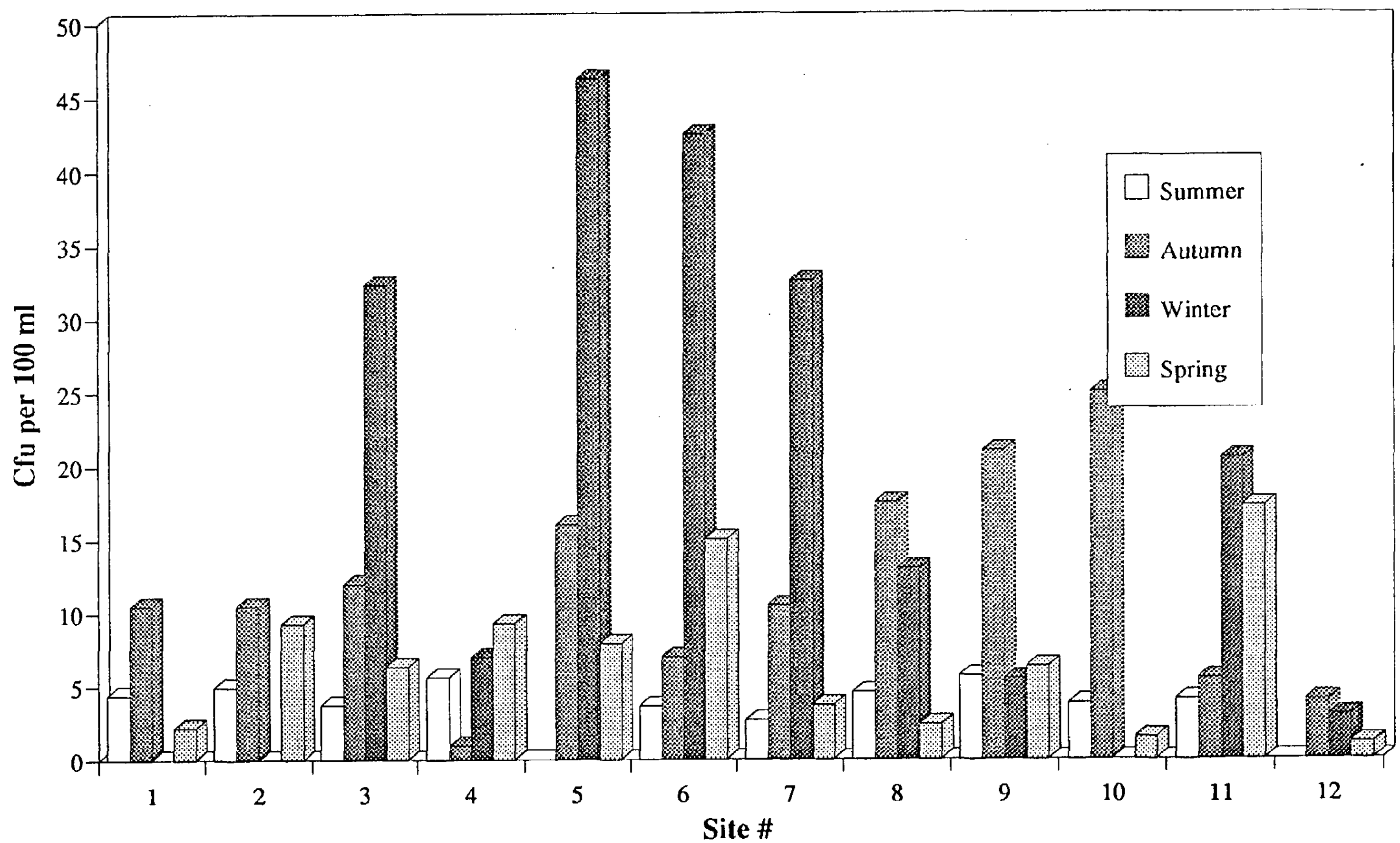


FIGURE 2-5. MEAN NH4 CONCENTRATION FOR THE JOHNSON CREEK STATIONS 4/93-6/94

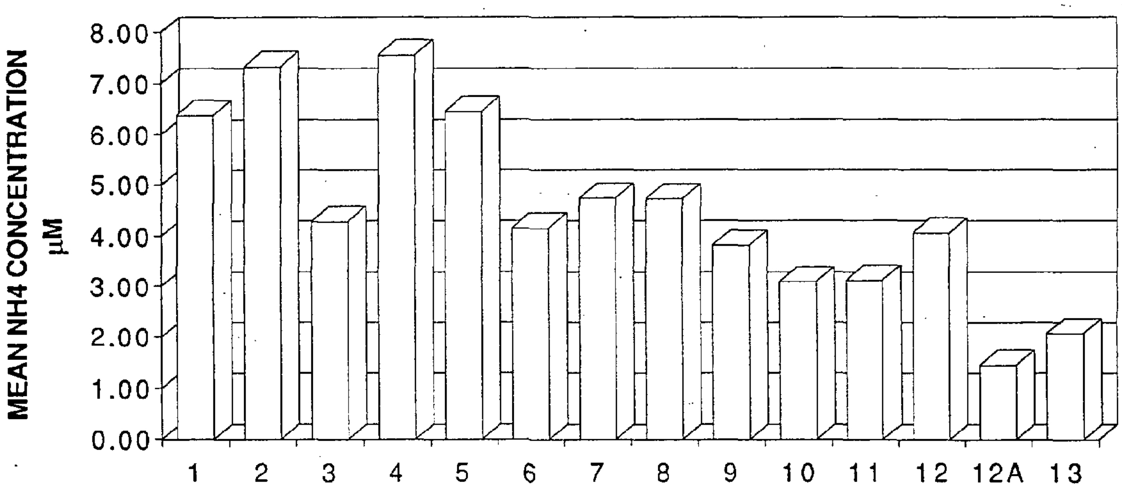


FIGURE 2-6. MEAN NO3 CONCENTRATION FOR THE JOHNSON CREEK STATIONS 4/93-6/94

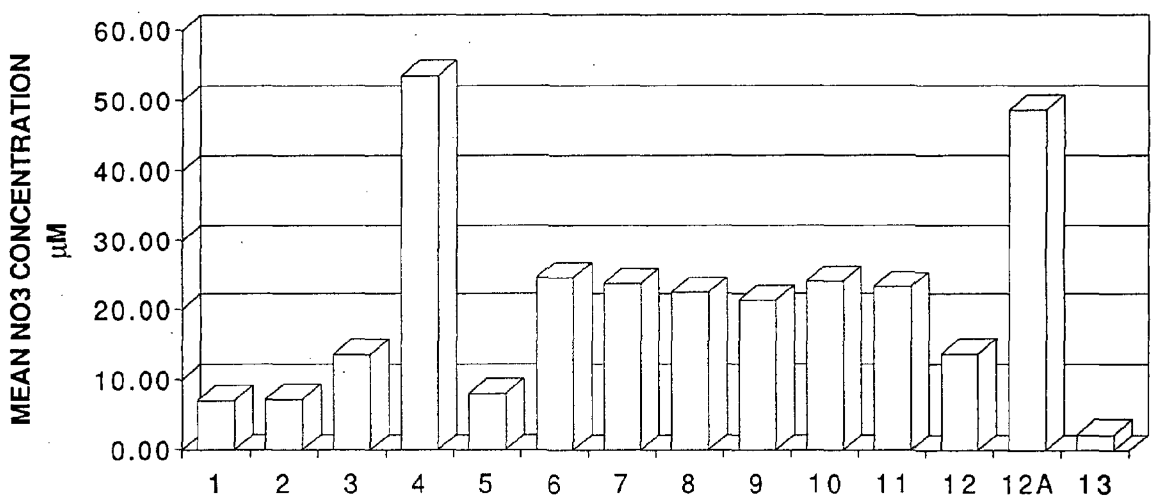


FIGURE 2-7. MEAN PO4 CONCENTRATION FOR THE JOHNSON CREEK STATIONS 4/93-6/94

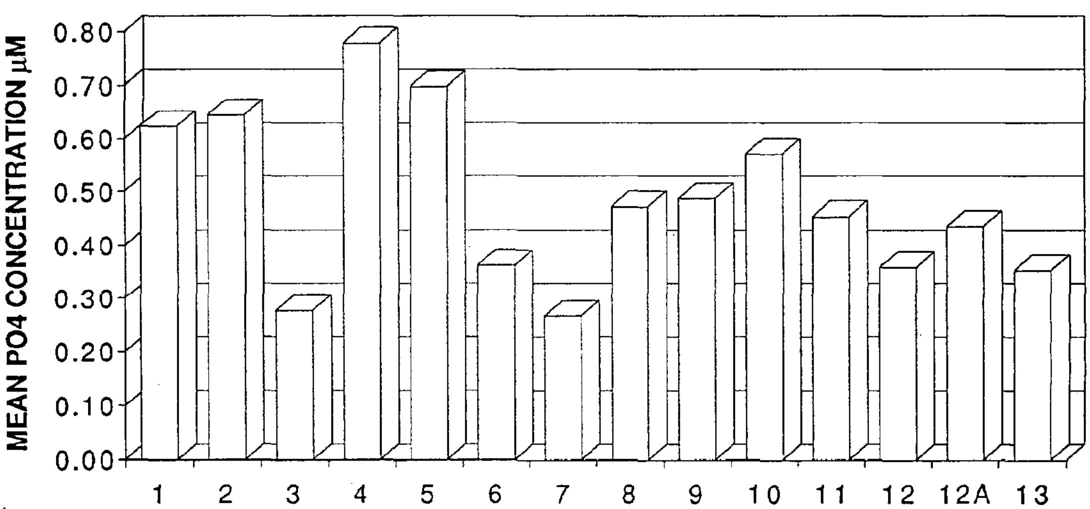


FIGURE 2-8. SEASONAL MEAN NH4 CONCENTRATION FOR JOHNSON CREEK STATIONS 4/93-6/94

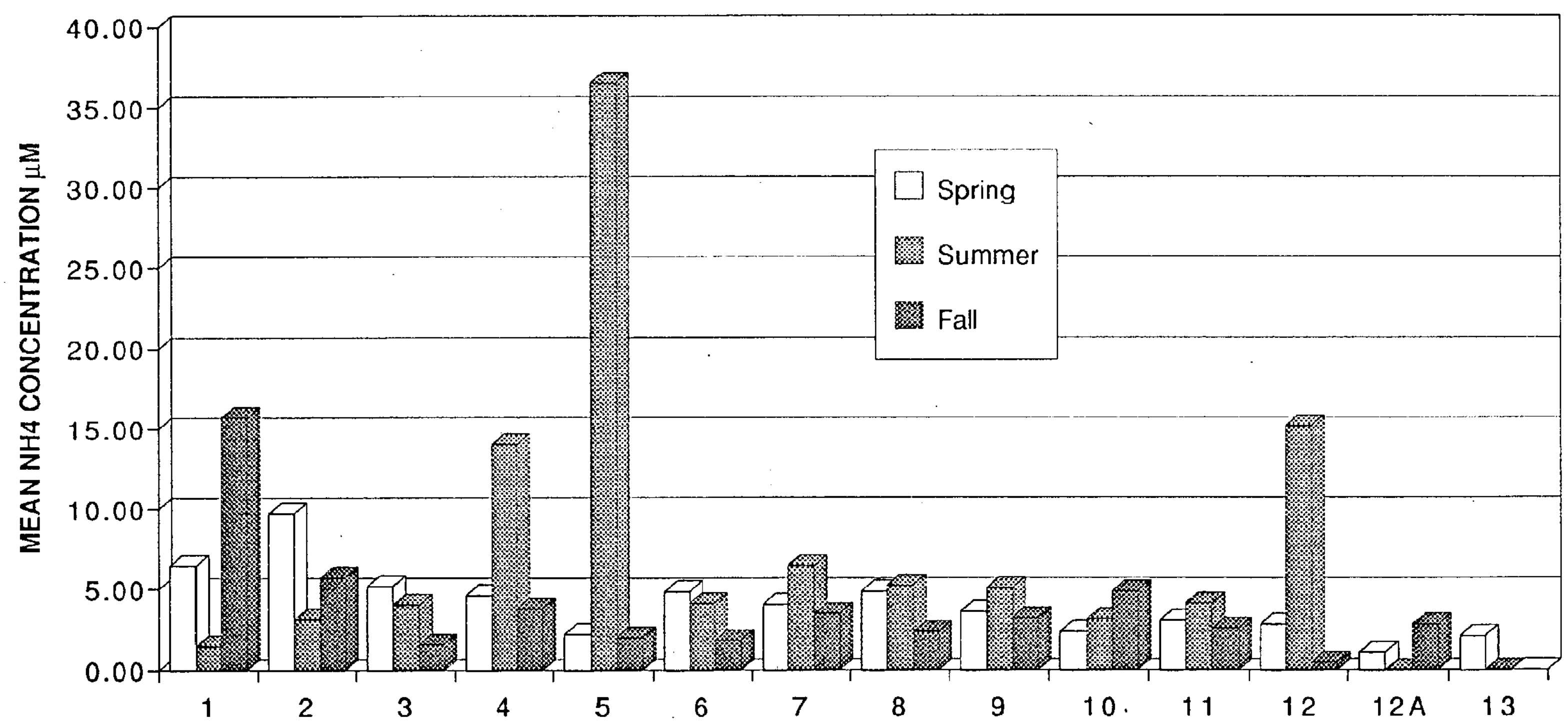


FIGURE 2-9. SEASONAL MEAN NO3 CONCENTRATION FOR JOHNSON CREEK STATIONS 4/93-6/94

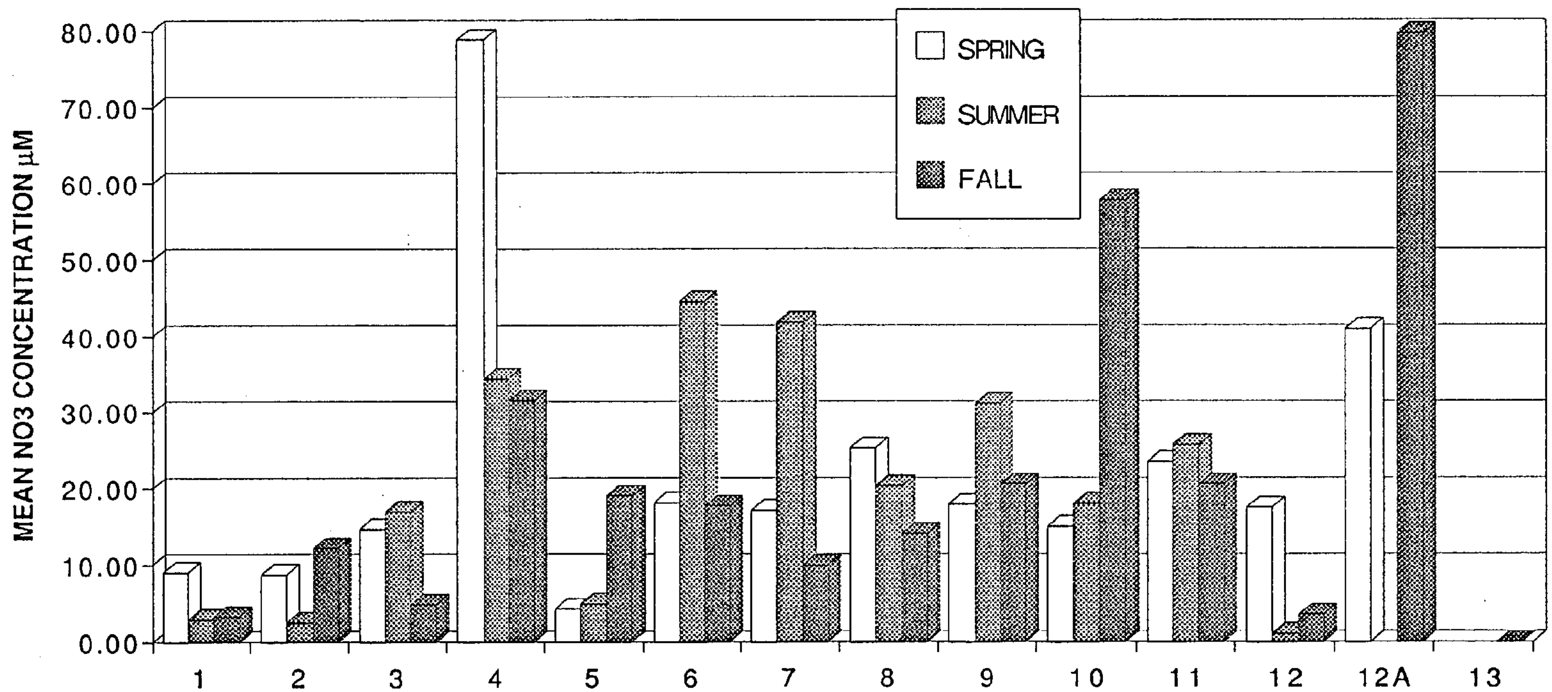


FIGURE 2-10. SEASONAL MEAN PO4 CONCENTRATION FOR JOHNSON CREEK STATIONS 4/93-6/94

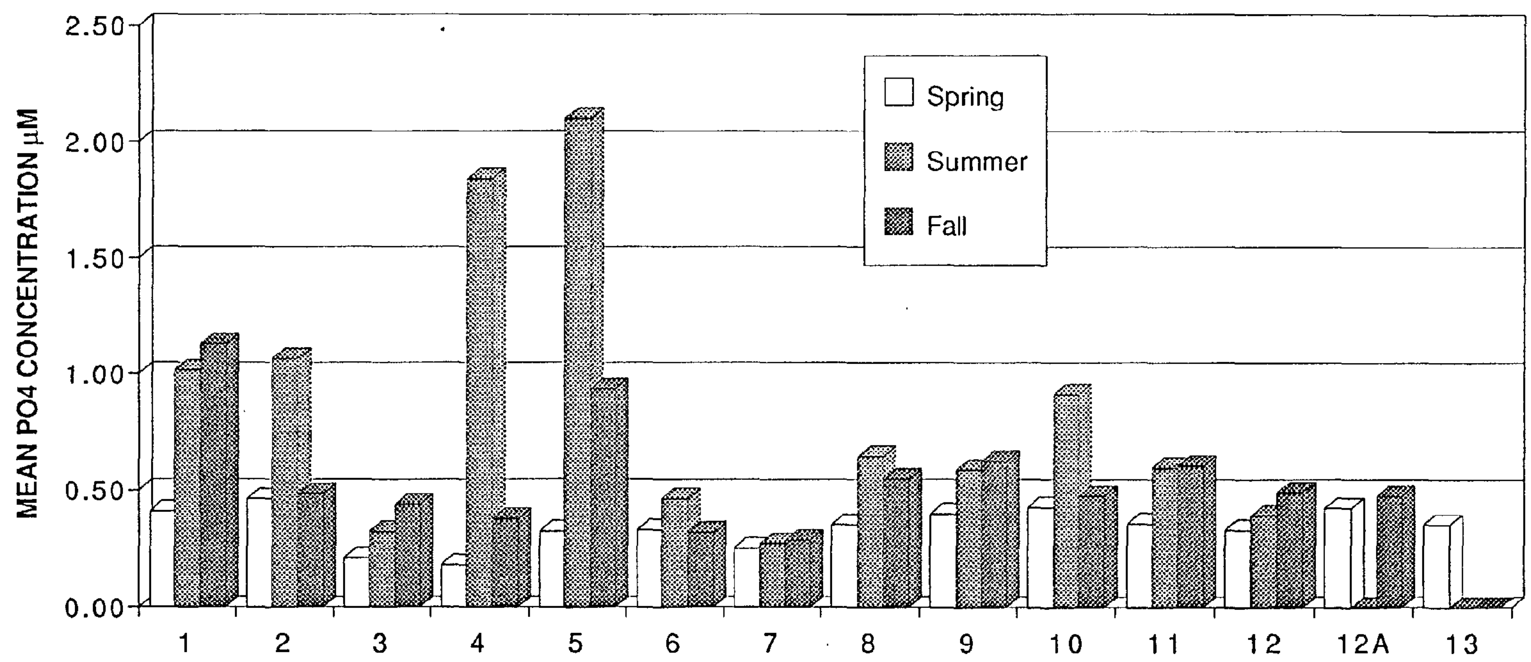


Figure 2-11. **Fecal coliform concentrations compared to salinity levels at sites along a freshwater-tidal transect on Johnson Creek.**

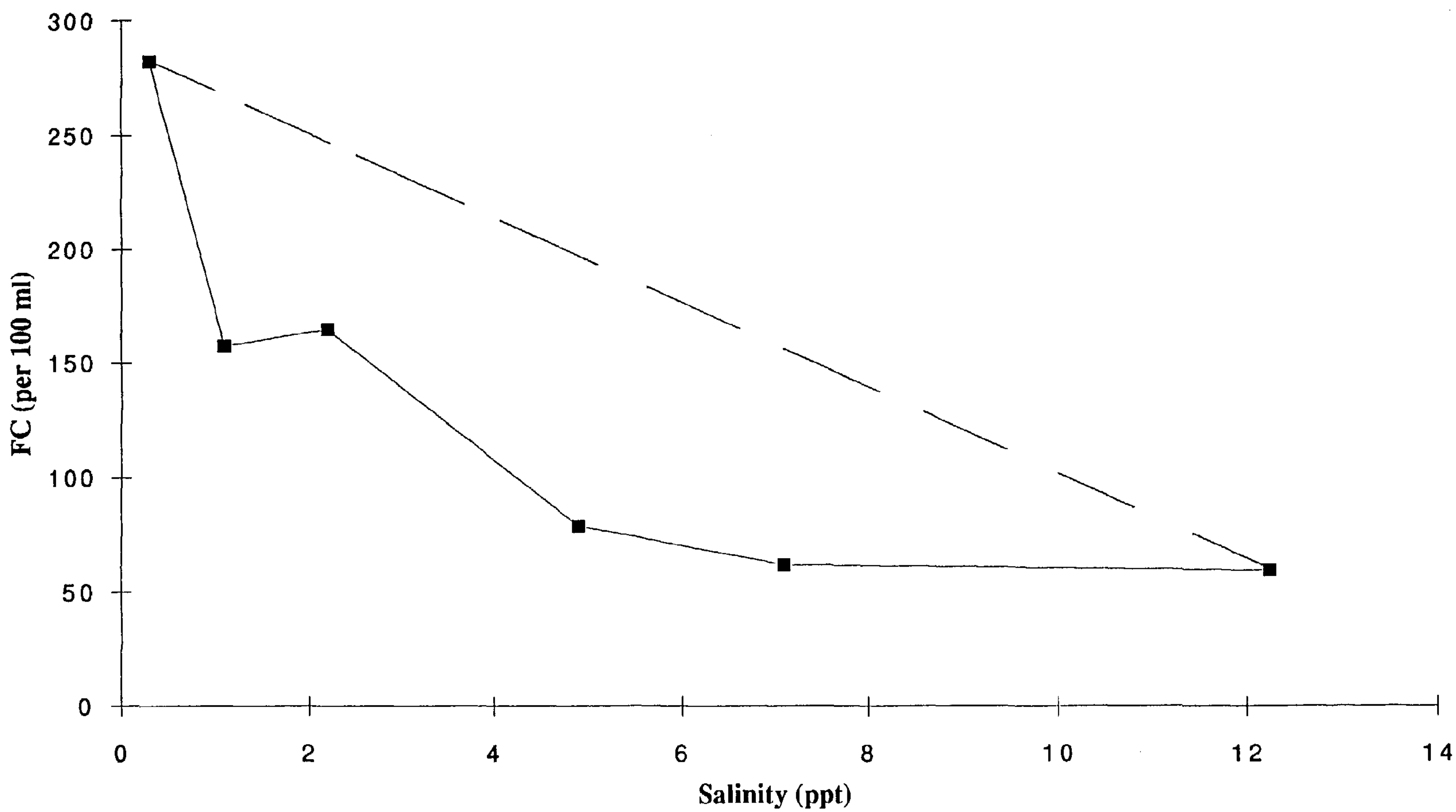
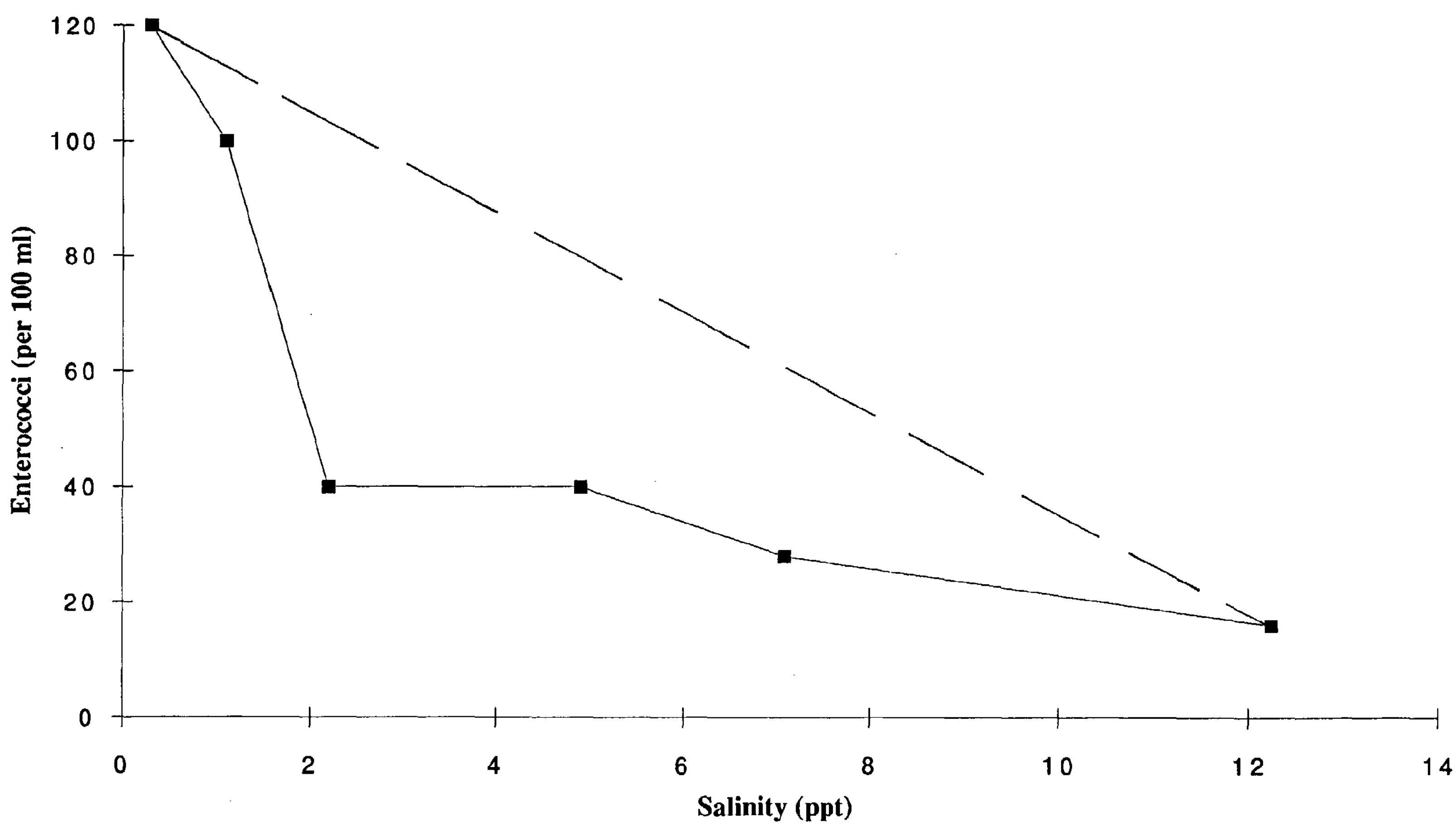


Figure 2-12. **Enterococci concentrations compared to salinity levels at sites along a freshwater-tidal transect on Johnson Creek.**



# TABLES AND FIGURES

## OBJECTIVE 3

**Table 3-1. Bacteria (per 100 ml) at sites in Gerrish Brook (south branch) near a housing development.**

CANNEY LANE (South branch Gerrish Brook)

Fecal coliforms

| SITE # | Far upstream CF1 | Near upstream CF2 | Upstream swale #1 CF3 | Downstream swale #1 CF4 | Swale #2 CF5 | Downstream of swales CF6 | Upstream of oxbow CF7 | Oxbow CF8 | Near mouth CF9 | At mouth CF10 | GB north branch JC11 | Below confluence JC9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE | | | | | | | | | | | | |
| 11/23/93 | 5.0 | 6.0 | 5.0 | 30 | 38 | 13 | 43 | 1000 | 36 | 52 | 70 | 80 |
| 12/13/93 | 13 | 7.0 | 230 | 114 | 8.0 | 4.0 | 18 | 360 | 16 | 16 | 34 | 30 |
| 4/25/94 | 32 | 32 | 3 | 16 | 11 | 32 | 31 | 28 | | 99 | 20 | 8.0 |
| 6/7/94 | 74 | 46 | 875 | 1800 | 7.5 | 33 | 15 | 3200 | | 18 | | 95 |
| 6/29/94 | 450 | 498 | 105 | 155 | 9.0 | 465 | 143 | 42000 | | 270 | 103 | 710 |
| GEO AVE | 37.0 | 31.4 | 50 | 109 | 12 | 30.1 | 35 | 1063 | 24 | 52 | 47 | 66 |
| STD DEV | 5.6 | 6.0 | 12 | 6.2 | 1.9 | 5.8 | 2.4 | 14.9 | 1.8 | 3.3 | 2.2 | 5.1 |

Enterococci

| SITE # | Far upstream CF1 | Near upstream CF2 | Upstream swale #1 CF3 | Downstream swale #1 CF4 | Swale #2 CF5 | Downstream of swales CF6 | Upstream of oxbow CF7 | Oxbow CF8 | Near mouth CF9 | At mouth CF10 | GB north branch JC11 | Below confluence JC9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/23/93 | 7.0 | 9.0 | 2.0 | 10 | 32 | 13 | 8 | 200 | 10 | 25 | 23 | 10 |
| 12/13/93 | 16 | 10 | 153 | 60 | 36 | 16 | 16 | 90 | 14 | 30 | 14 | 12 |
| 4/25/94 | 24 | 21 | 3.5 | 58 | 17 | 31 | 54 | 43 | | 40 | 16 | 9.5 |
| 6/7/94 | 48 | 38 | 544 | 1680 | 23 | 19 | 63 | 118 | | 36 | | 9.0 |
| 6/29/94 | 606 | 534 | 190 | 990 | 122 | 560 | 430 | 328 | | 602 | 135 | 80 |
| GEO AVE | 38 | 33 | 41 | 142 | 35 | 37 | 44 | 125 | 12 | 58 | 22 | 18 |
| STD DEV | 5.5 | 5.3 | 13 | 8.6 | 2.1 | 4.8 | 4.7 | 2.2 | 1.3 | 3.8 | 3.4 | 2.4 |

**Table 3-2. Bacterial concentrations (per 100 ml) at sites in Gerrish Brook (north branch) near a housing development and farm.**

**Fecal coliforms**

| Site description | Stream source | Upstream of farm | Wetland near farm | Between farm and houses | Near houses | Downstream of houses | Downstream above Rt. 108 farms | Below houses on Rt. 108 | Below barn | At mouth of stream | At mouth of other branch |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Site # | 12 | 12E | 12D | 12C | 12A | 12B | 11C | 11B | 11A | 11 | 10 |
| 1/3/94 | 4.0 | 2.5 | 13.0 | 12.0 | 13.0 | 8.0 | | | | | |
| 4/5/94 | 26.5 | 25 | 17.5 | 22.5 | 276 | 7.5 | 4.3 | 5.5 | 2.8 | 5 | 0.5 |
| 6/6/94 | 0.5 | 600 | 161 | 110 | 65 | 69 | 73.3 | 113.5 | 104 | 94.5 | 17.5 |
| GEO AVE | **3.8** | **33.5** | **33.2** | **31.0** | **61.6** | **16.1** | **17.8** | **25.0** | **17.1** | **21.7** | **3.0** |
| STD DEV | 7.3 | 15.7 | 4.0 | 3.1 | 4.6 | 3.5 | 7.4 | 8.5 | 12.9 | 8.0 | 12.4 |

**Enterococci**

| Site # | 12 | 12E | 12D | 12C | 12A | 12B | 11C | 11B | 11A | 11 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/3/94 | 2.5 | 0.5 | 3.0 | 3.0 | 2.0 | 2.5 | | | | | |
| 4/5/94 | 0.5 | 0.5 | 1.25 | 0.5 | 3.8 | 5 | 5 | 6.5 | 4 | 2.5 | 1 |
| 6/6/94 | 5.3 | 108 | 27.5 | 67.5 | 13 | 6 | 9.5 | 8.5 | 11 | 9 | 35.5 |
| GEO AVE | **1.9** | **3.0** | **4.7** | **4.7** | **4.6** | 4.2 | **6.9** | **7.4** | **6.6** | **4.7** | **6.0** |
| STD DEV | 3.3 | 22.3 | 4.9 | 12.0 | 2.6 | 1.6 | 1.6 | 1.2 | 2.0 | 2.5 | 12.5 |

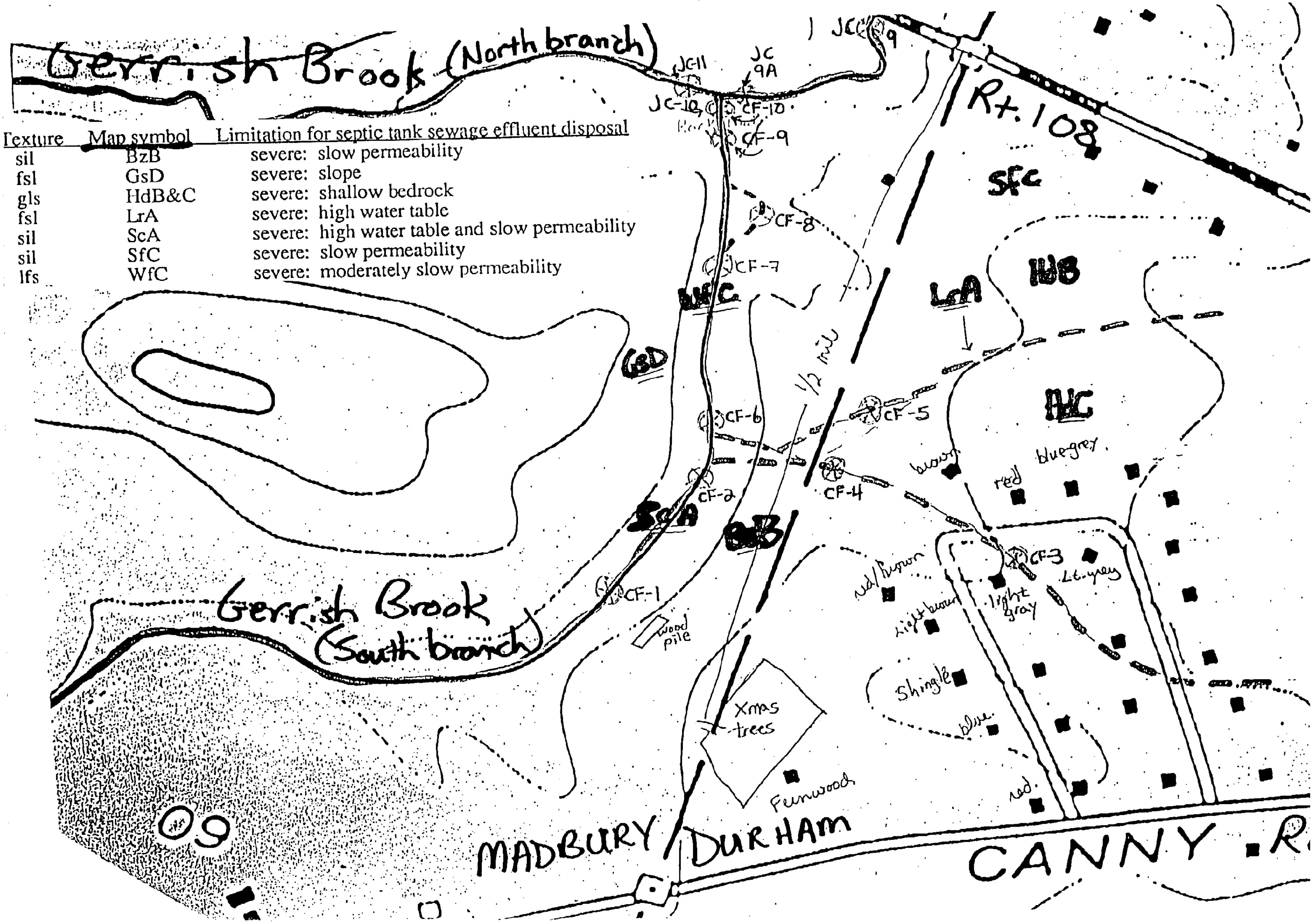
TABLE 3-3. NUTRIENT CONCENTRATIONS AT SITES IN GERRISH BROOK (SOUTH BRANCH) NEAR A HOUSING DEVELOPMENT

| CANNEY LANE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| µm NO3 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | JC 11 | JC 9 |
| | 12/13/93 | 10.68 | | | | | | 23.89 | 51.78 | 14.73 | 16.62 | 22.74 |
| | 4/25/94 | 6.40 | 0.58 | 88.07 | 80.10 | 22.65 | 9.94 | 10.05 | 14.66 | | 26.68 | 14.15 |
| | 6/7/94 | 6.53 | 8.20 | 48.05 | 45.87 | 23.77 | 16.49 | 16.74 | 0.00 | | 30.64 | 24.25 |
| | 6/29/94 | 8.40 | 9.62 | 50.18 | 45.56 | 35.40 | 16.72 | 20.12 | 6.31 | | 20.8 | |
| | **MEAN** | **8.00** | **6.13** | **62.10** | **57.18** | **27.27** | **14.38** | **17.70** | **18.19** | **14.73** | **23.69** | **20.38** |
| µM NH4 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | JC 11 | JC 9 |
| | 12/13/93 | 0.66 | | | | | | 1.00 | 9.45 | 2.75 | 1.99 | 2.18 |
| | 4/25/94 | 3.11 | 1.64 | 1.21 | 2.98 | 1.71 | 0.83 | 1.77 | 1.02 | | 1.2 | 1.5 |
| | 6/7/94 | 2.67 | 2.06 | 7.59 | 1.55 | 3.24 | 2.12 | 21.23 | 1.12 | | 2.73 | 2.78 |
| | 6/29/94 | 4.71 | 2.73 | 4.50 | 2.40 | 2.84 | 2.51 | 3.36 | 53.46 | | 4.31 | |
| | **MEAN** | **2.79** | **2.14** | **4.43** | **2.31** | **2.60** | **1.82** | **6.84** | **16.26** | **2.75** | **2.56** | **2.15** |
| µM PO4 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | JC 11 | JC 9 |
| | 12/13/94 | 0.72 | | | | | | 0.84 | 77.98 | 1.10 | | 0.62 |
| | 4/25/94 | 0.37 | 0.38 | 0.39 | 0.31 | 0.20 | 0.36 | 0.40 | 0.37 | | 0.29 | 0.36 |
| | 6/7/94 | 0.65 | 0.62 | 0.56 | 0.60 | 0.22 | 0.52 | 0.63 | 220.24 | | 0.34 | 0.45 |
| | 6/29/94 | 1.17 | 1.09 | 0.73 | 0.83 | 0.48 | 1.18 | 1.16 | 256.89 | | 0.7 | |
| | **MEAN** | **0.73** | **0.70** | **0.56** | **0.58** | **0.30** | **0.69** | **0.76** | **138.87** | **1.10** | **0.44** | **0.48** |

TABLE 3-4. NUTRIENT CONCENTRATIONS AT SITES IN GERRISH BROOK (NORTH BRANCH) NEAR A HOUSING DEVELOPMENT.

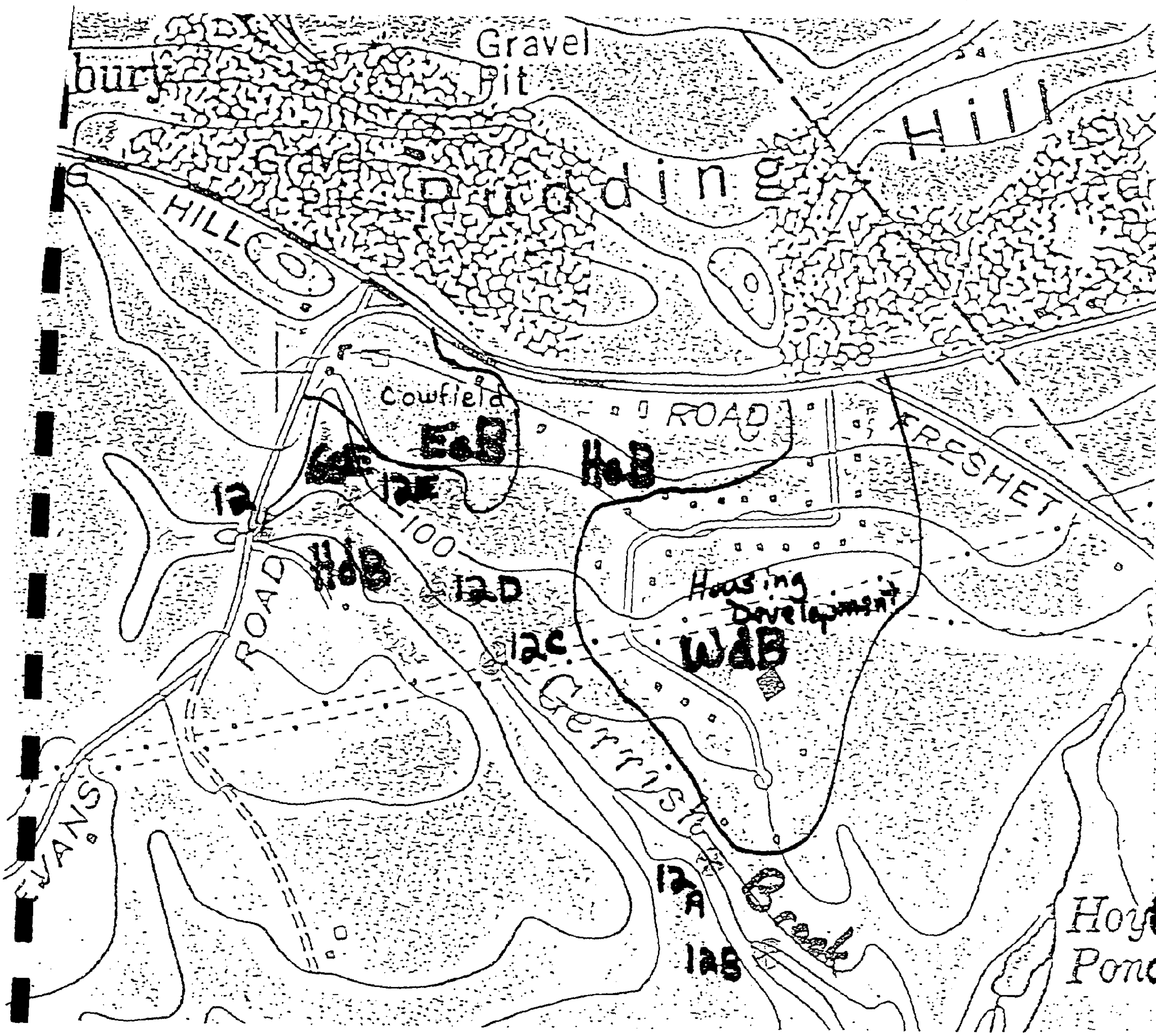
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH4 | | | | | | | | | | | |
| | 12 | 12e | 12d | 12c | 12a | 12b | 11c | 11b | 11a | 11 | 10 |
| 4/5/94 | 1.53 | 1.65 | 27.43 | 1.26 | 0.41 | 0.21 | 0.88 | 1.88 | 31.92 | 1.11 | 1.17 |
| 6/6/94 | 12.38 | 0.87 | 1.31 | 1.74 | 1.78 | 4.70 | 3.66 | 2.52 | 3.02 | 2.57 | 4.02 |
| NO3 | | | | | | | | | | | |
| | 12 | 12e | 12d | 12c | 12a | 12b | 11c | 11b | 11a | 11 | 10 |
| 4/25/94 | | 29.13 | 31.73 | 30.17 | | 27.07 | 13.15 | 14.34 | 18.31 | 26.68 | 4.65 |
| 6/6/94 | 2.18 | 108.04 | 132.15 | 114.80 | 69.15 | 71.54 | 32.20 | 31.96 | 30.91 | 28.86 | 19.14 |
| PO4 | | | | | | | | | | | |
| | 12 | 12e | 12d | 12c | 12a | 12b | 11c | 11b | 11a | 11 | 10 |
| 4/25/94 | | 0.31 | 0.35 | 0.33 | | 0.38 | 0.32 | 0.29 | 0.34 | 0.29 | 0.38 |
| 6/6/94 | 0.32 | 0.44 | 0.43 | 0.49 | 0.52 | 0.42 | 0.44 | 0.40 | 0.36 | 0.36 | 0.60 |

Fi[redacted] 3-1 [redacted]h B[redacted]h o[redacted]rish [redacted]ok [redacted] Can[redacted] Lan[redacted]usin[redacted]velo[redacted] w[redacted] sam[redacted]
sites (CF 1-10; JC9-11) and soil mapping units.




| Texture | Map symbol | Limitation for septic tank sewage effluent disposal |
|---|---|---|
| sil | BzB | severe: slow permeability |
| fsl | GsD | severe: slope |
| gls | HdB&C | severe: shallow bedrock |
| fsl | LrA | severe: high water table |
| sil | ScA | severe: high water table and slow permeability |
| sil | SfC | severe: slow permeability |
| lfs | WfC | severe: moderately slow permeability |

Figure 3-2. North Branch of Gerrish Brook, farm/cowfield and Madbury housing development with sample sites (12, 12 A-E) and soil mapping units.




| Texture | Map symbol | Limitation for septic tank sewage effluent disposal |
|---|---|---|
| sl | EaB | severe: seasonal high water table |
| gls | HdB | severe: shallow bedrock |
| sl | GsE | severe: slope |
| ls | HaB | slight: possible hazard of pollution |
| ls | WdB | slight: possible hazard of pollution |

**Figure 3-3. Geometric mean fecal coliform and enterococci concentrations in Gerrish Brook (south branch): 11/93-6/94.**

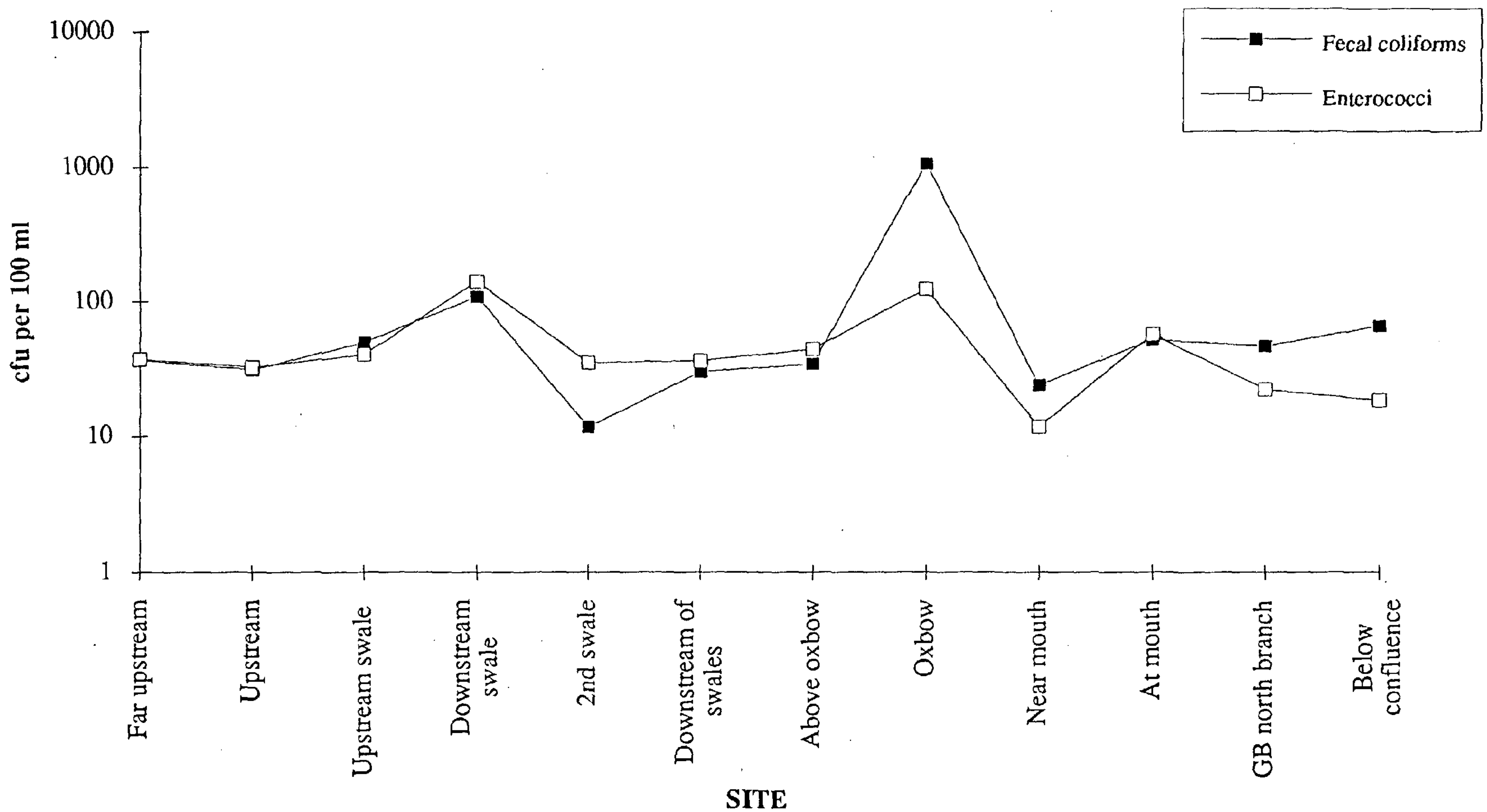


**Figure 3-4. Fecal coliform concentrations in Gerrish Brook (south branch): 1/94-6/94.**

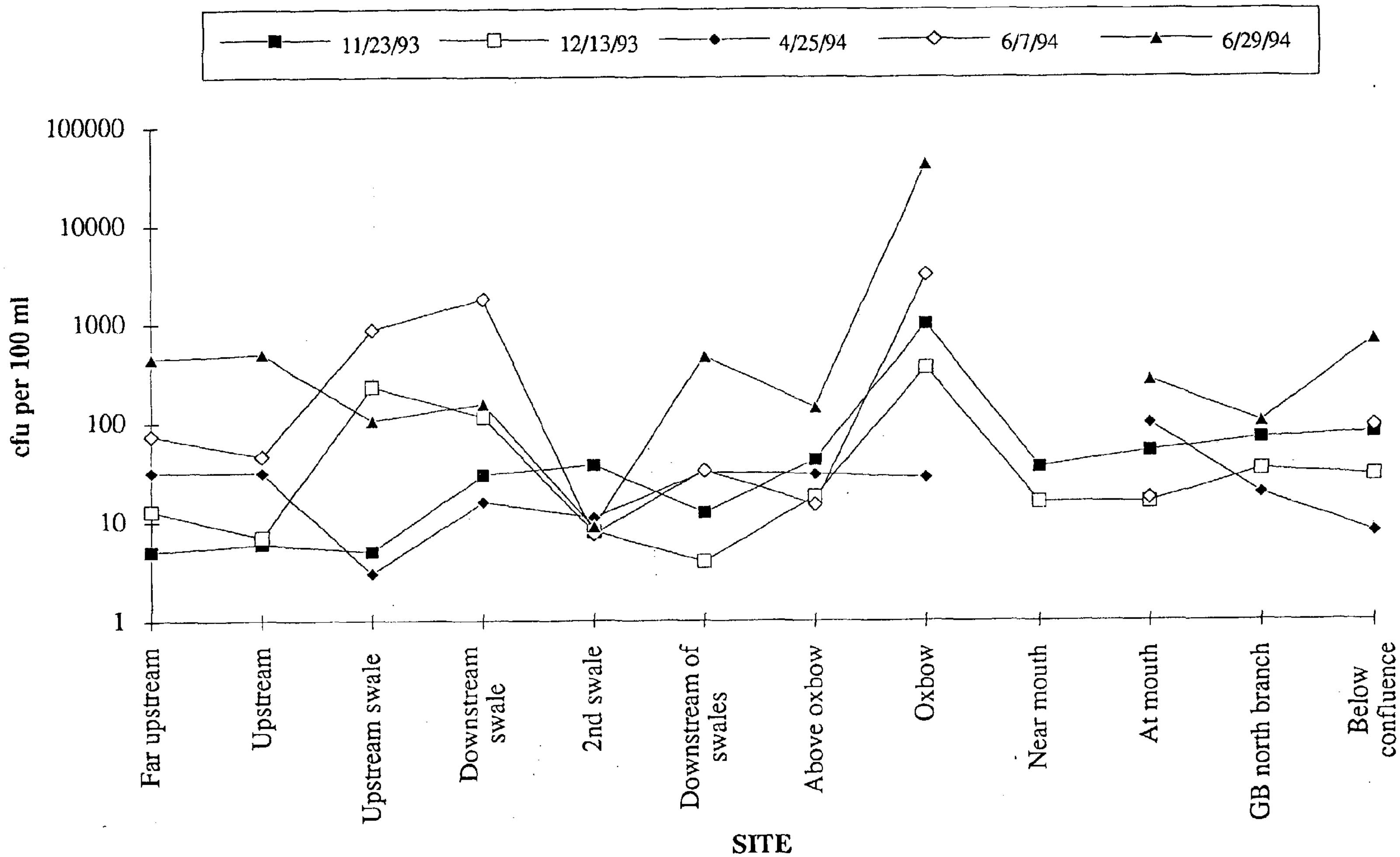


**Figure 3-5. Enterococci concentrations in Gerrish Brook (south branch): 1/94-6/94.**

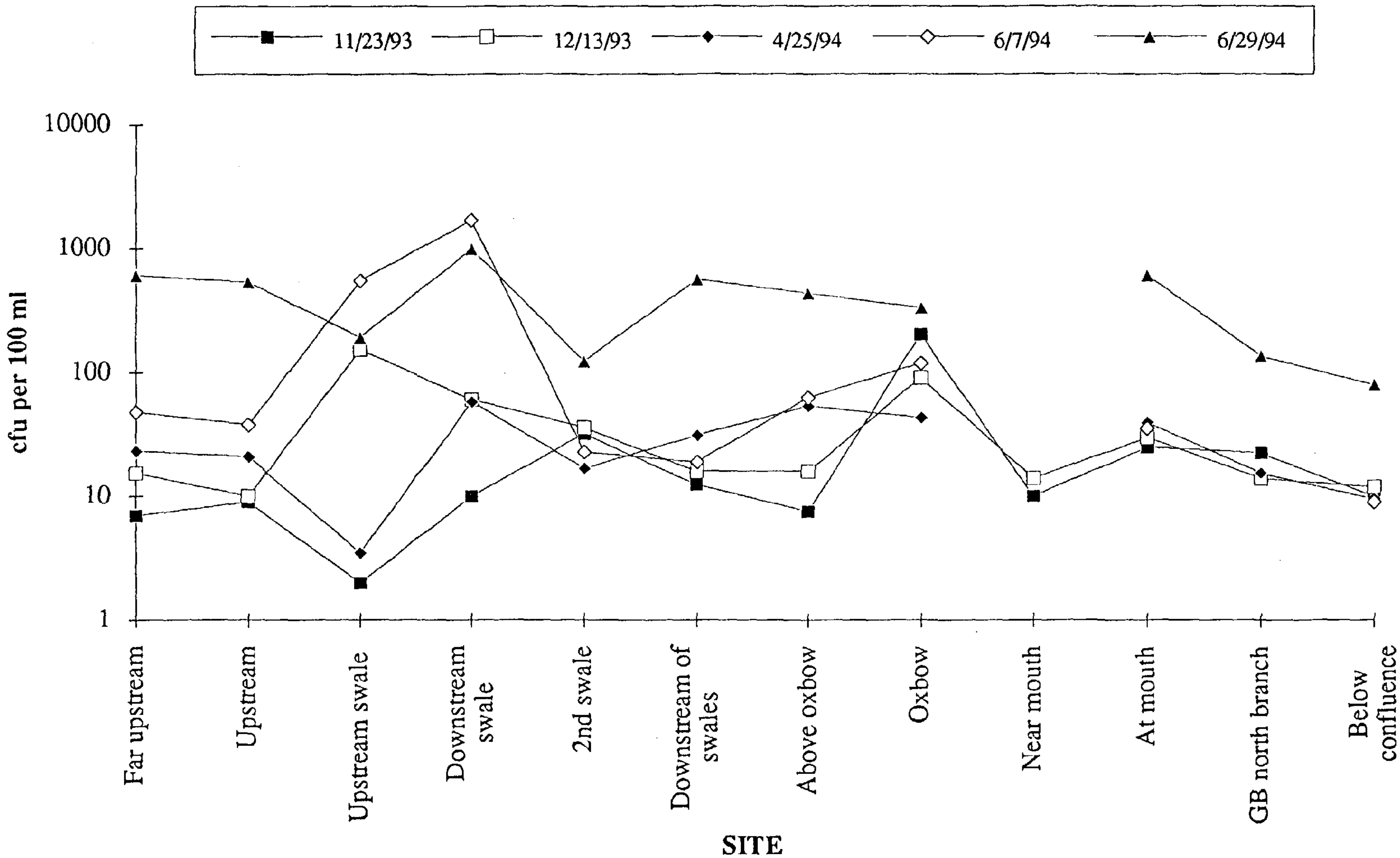


**Figure 3-6. Geometric mean fecal coliform and enterococci concentrations in Gerrish Brook (north branch): 1/94-6/94.**

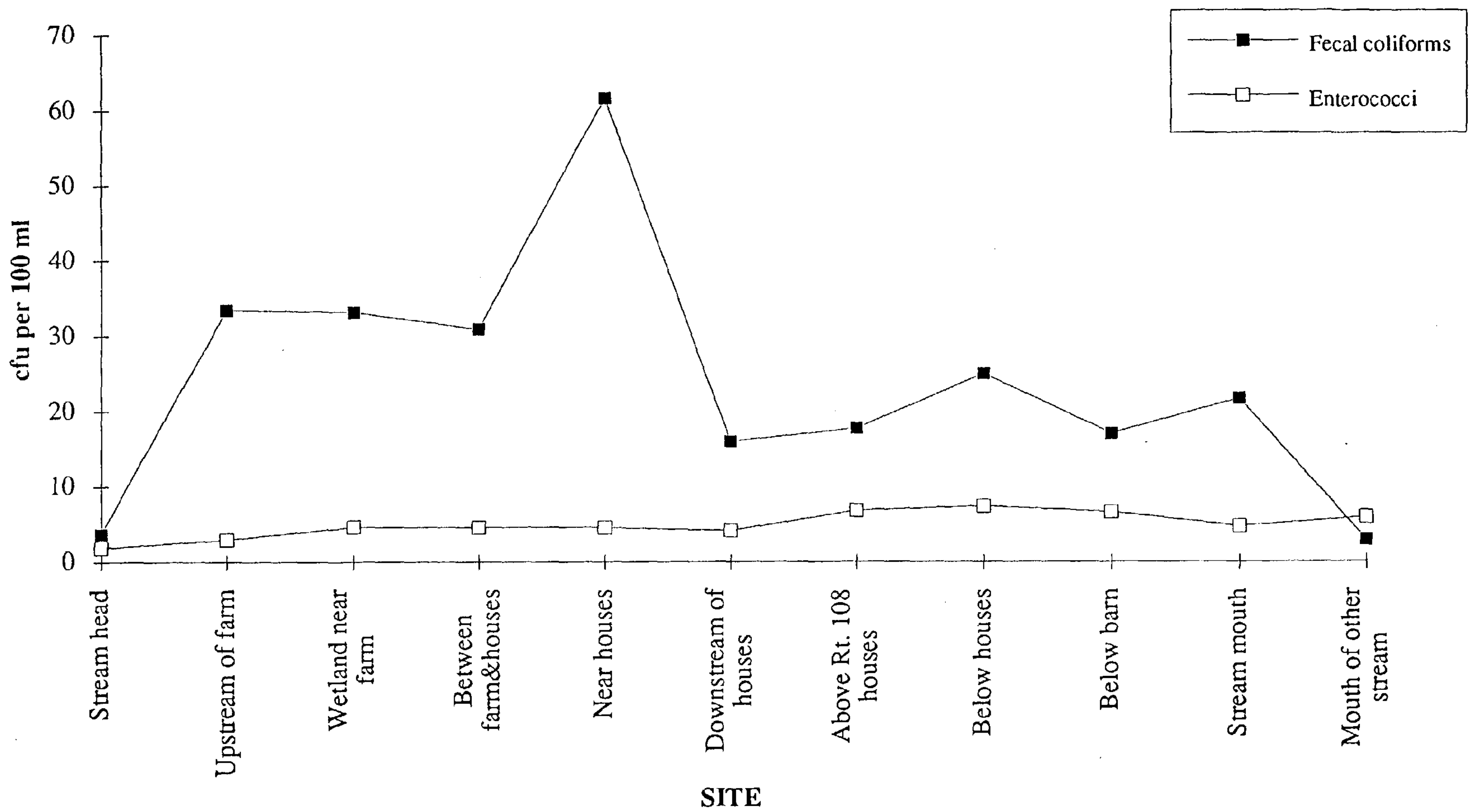


Figure 3-7. Fecal coliform concentrations in Gerrish Brook (north branch): 1/94-6/94.

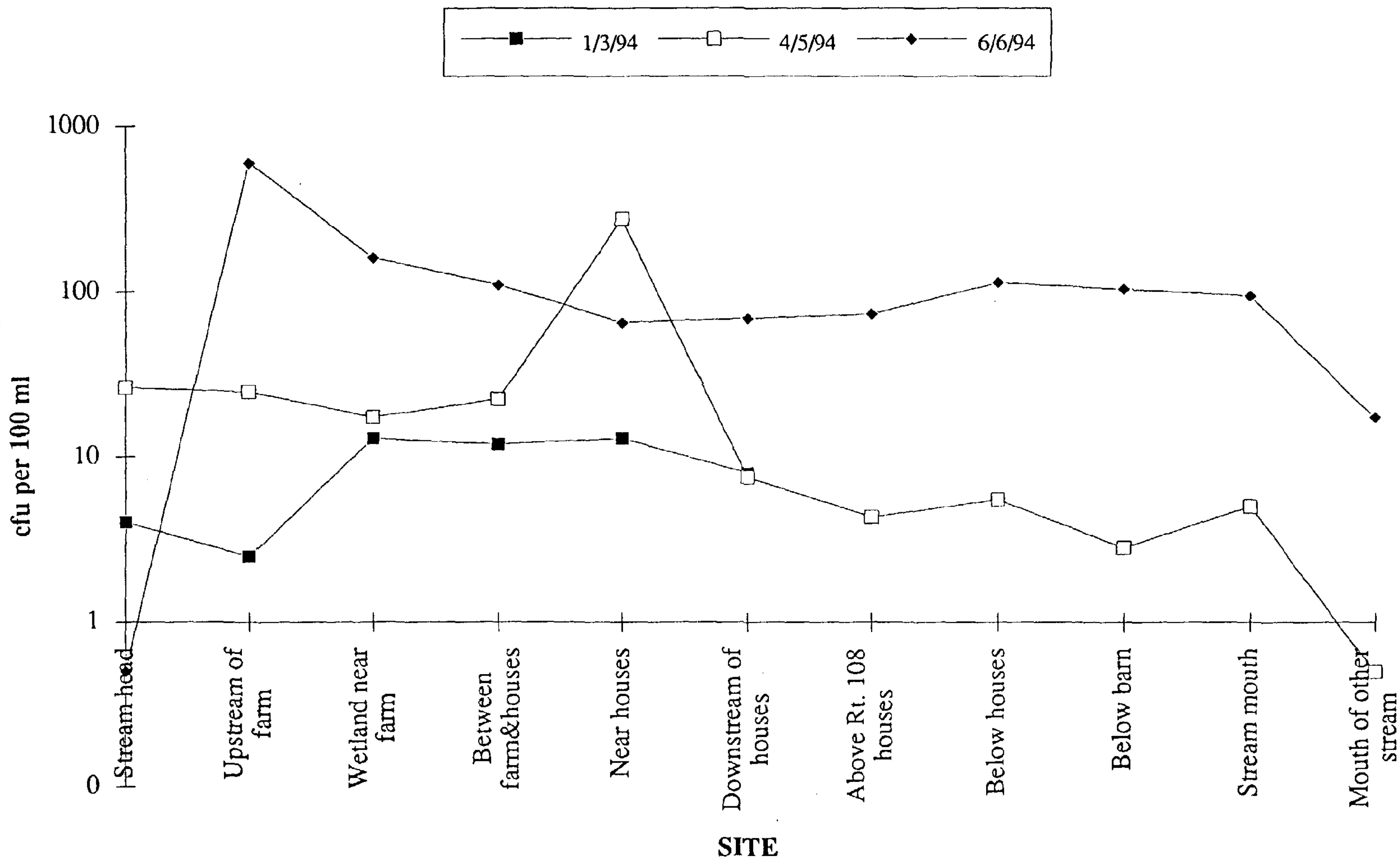
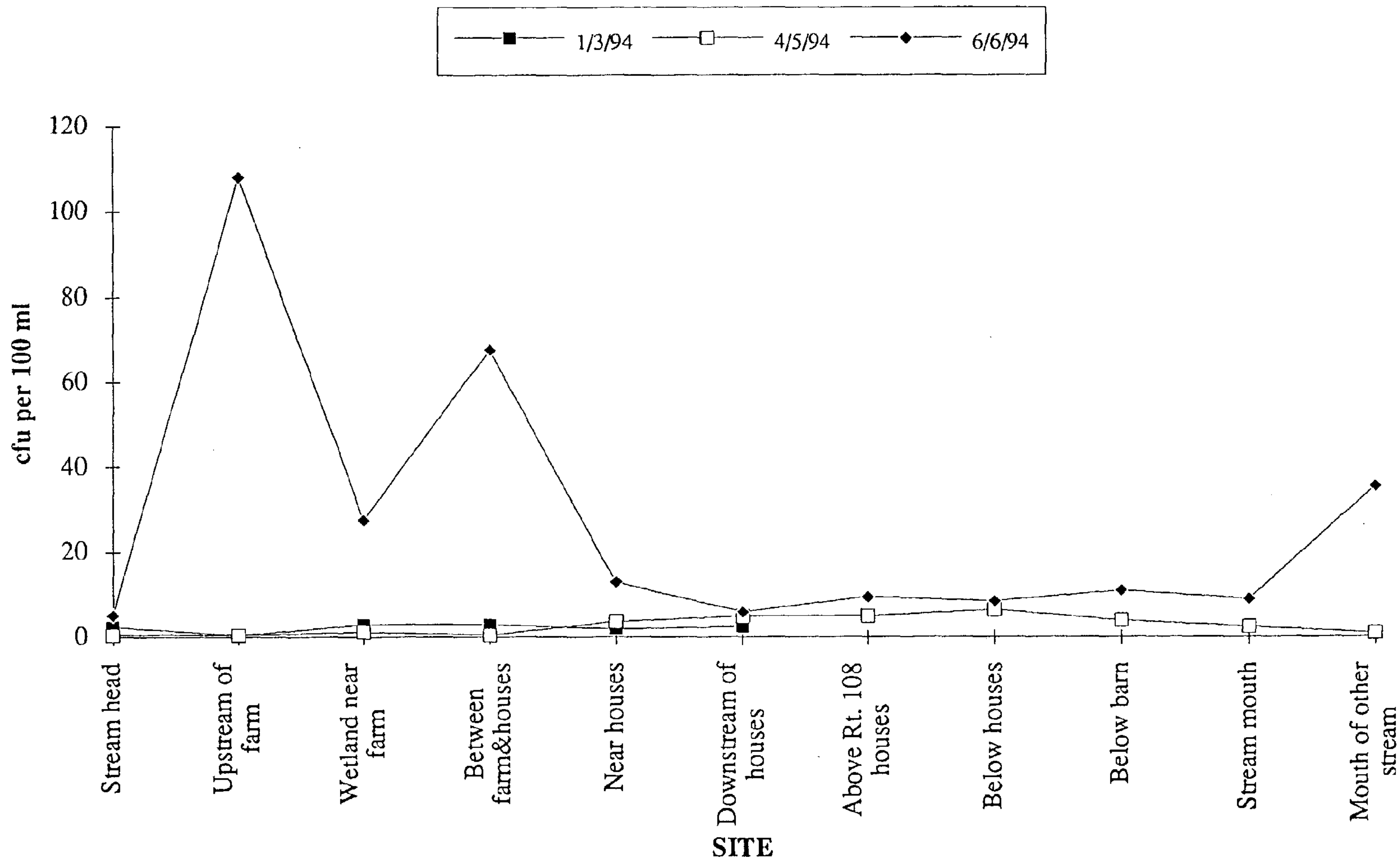


**Figure 3-8. Enterococci concentrations in Gerrish Brook (north branch): 1/94-6/94.**



# TABLES AND FIGURES

## OBJECTIVE 4

**Table 4-1. Indicator concentrations and geometric means (per 100 ml) in Beards Creek: 7/93-6/94.**

## Fecal coliforms

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/8/93 | | 83 | 595 | | | | | | | | 50 | 37750 |
| 7/13/93 | 24 | 23 | 525 | 225 | 11 | 49 | 2480 | 1770 | 0 | | 35 | 6000 |
| 7/15/93 | | 70 | 2315 | | | | | | 17 | | 258 | 10500 |
| 8/11/93 | 26 | 23 | 135 | 126 | 6 | 43 | 720 | 235 | 30 | | 150 | 200 |
| 8/17/93 | 25 | 14 | 360 | 1360 | 1800 | 24 | 670 | 680 | 1245 | | | 630 |
| 8/24/93 | 20 | 14 | | | 550 | | 290 | | | | | |
| 11/16/93 | 73 | 76 | 95 | 23 | 4 | 5 | 10 | 415 | 58 | 1 | 1 | 3 |
| 7-Dec | 300 | 250 | 185 | 143 | 280 | 63 | 25 | 16 | 300 | 240 | 54 | 83 |
| 2/1/94 | | | | | | | | 155 | 88 | | | |
| 2/15/94 | | | | | | | | | 93 | | | |
| 2/22/94 | | 150 | | | | | | 308 | 355 | | | |
| 3/1/94 | | | | | | | | 110 | 100 | | | |
| 3/8/94 | | 368 | | | | | | 230 | 240 | | | |
| 3/15/94 | | | | | | | | 50 | | | | |
| 3/23/94 | 13 | 25 | 63 | 40 | 115 | 6 | 2 | 190 | 140 | 15 | 56 | 30 |
| 5/9/94 | 365 | 221 | 438 | 295 | 240 | 123 | 10 | 235 | 275 | 25 | 405 | 113 |
| 6/14/94 | | | 100 | 400 | | 300 | 185 | 2700 | 6600 | | | 1000 |
| 6/20/94 | 200 | 5 | 145 | 100 | 15 | 590 | 240 | 1400 | 100 | 16 | 50 | 7100 |
| GEO AVE | 57 | 51 | 251 | 157 | 67 | 50 | 97 | 281 | 171 | 16 | 54 | 562 |
| STD DEV | 4 | 4 | 3 | 3 | 9 | 5 | 10 | 4 | 5 | 8 | 6 | 18 |

## Enterococci

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/8/93 | | 3 | 450 | | | | | | | | 28 | 5760 |
| 7/13/93 | 18 | 228 | 280 | 690 | 5 | 23 | 600 | 190 | 0 | 15 | 8 | 26000 |
| 7/15/93 | | 27 | 1230 | | | | | | 0 | | 239 | 44000 |
| 8/11/93 | 2 | 6 | 125 | 445 | 155 | 38 | 230 | 210 | 0 | | 74 | |
| 8/17/93 | 20 | 1 | 40 | 0 | 15 | 12 | 40 | 515 | 0 | | 142 | 220 |
| 8/24/93 | 6 | 0 | | | 6 | | 95 | | | | | |
| 11/16/93 | 6 | 2 | 50 | 30 | 10 | 18 | 5 | 255 | 68 | 3 | 0 | 5 |
| 7-Dec | 400 | 400 | 418 | 500 | 1150 | 114 | 22 | 26 | 68 | 78 | 400 | 500 |
| 2/1/94 | | | | | | | | 335 | 81 | | | |
| 2/15/94 | | | | | | | | | 23 | | | |
| 2/22/94 | | 35 | | | | | | 25 | 38 | | | |
| 3/1/94 | | | | | | | | 28 | 31 | | | |
| 3/8/94 | | 195 | | | | | | 164 | 87 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/15/94 | | | | | | | | 28 | | | | |
| 3/23/94 | 86 | 98 | 30 | 23 | 60 | 16 | 5 | 43 | 53 | 43 | 35 | 6 |
| 5/9/94 | 300 | 210 | 211 | 301 | 813 | 121 | 17 | 189 | 40 | 13 | 228 | 98 |
| 6/14/94 | 255 | 5 | 130 | 600 | 300 | 110 | 85 | 300 | 288 | 26 | 40 | 235 |
| 6/20/94 | 18 | 73 | 173 | 410 | 25 | 180 | 72 | 220 | 0 | 120 | 10 | 855 |
| GEO AVE | 32 | 19 | 164 | 229 | 56 | 46 | 44 | 115 | 36 | 24 | 61 | 462 |
| STD DEV | 6 | 11 | 3 | 4 | 7 | 3 | 5 | 3 | 6 | 4 | 4 | 22 |

## *Clostridium perfringens*

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/13/93 | 9 | 6 | 81 | 6 | 1 | 0 | 16 | 59 | 8 | 1 | 5 | |
| 7/15/93 | | 4 | 68 | | | | | | 3 | | 49 | 43 |
| 8/11/93 | 1 | 2 | 9 | 13 | 6 | 6 | 6 | 8 | 8 | | 51 | 150 |
| 8/17/93 | 6 | 2 | 22 | 56 | 6 | 9 | 11 | 26 | 6 | | 6 | 495 |
| 8/24/93 | 3 | 1 | | | 11 | | 8 | | | | | |
| 11/16/93 | 12 | 35 | 1 | 9 | 10 | 4 | 6 | 83 | 47 | 5 | 5 | 60 |
| 7-Dec | 61 | 68 | 22 | 41 | 36 | 22 | 5 | 20 | 13 | 17 | 48 | 39 |
| 2/1/94 | | | | | | | | 7 | 8 | | | |
| 2/15/94 | | | | | | | | | 7 | | | |
| 2/22/94 | | 40 | | | | | | 26 | 31 | | | |
| 3/1/94 | | | | | | | | 11 | 16 | | | |
| 3/8/94 | | 180 | | | | | | 114 | 74 | | | |
| 3/15/94 | | | | | | | | 24 | | | | |
| 3/23/94 | 39 | 93 | 34 | 21 | 44 | 11 | 5 | 19 | 19 | 13 | 29 | 25 |
| 5/9/94 | 75 | 70 | 39 | | | | 3 | 15 | 6 | 5 | 71 | 29 |
| 6/14/94 | | | | | | | | | | | | |
| 6/20/94 | 4 | 16 | 19 | 10 | 9 | 36 | 5 | 23 | 16 | 8 | | |
| GEO AVE | 10 | 15 | 20 | 17 | 9 | 11 | 6 | 24 | 12 | 6 | 21 | 66 |
| STD DEV | 4 | 6 | 4 | 2 | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 3 |

**Table 4-2. Annual and seasonal geometric means (per 100 ml) for bacterial indicators in Beards Creek: 7/93-6/94.**

**Fecal coliforms**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GEO AVE | 57 | 51 | 251 | 157 | 67 | 50 | 97 | 281 | 171 | 16 | 54 | 562 |
| STD DEV | 4 | 4 | 3 | 3 | 9 | 5 | 10 | 4 | 5 | 8 | 6 | 18 |
| Summer | 24 | 29 | 512 | 338 | 90 | 37 | 767 | 656 | 85 | | 91 | 3128 |
| Autumn | 148 | 138 | 133 | 57 | 31 | 17 | 16 | 81 | 132 | 13 | 7 | 16 |
| Winter | | 235 | | | | | | 143 | 147 | | | |
| Spring | 97 | 30 | 141 | 147 | 75 | 108 | 31 | 641 | 399 | 18 | 104 | 393 |

**Enterococci**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GEO AVE | 32 | 19 | 164 | 229 | 56 | 46 | 44 | 115 | 36 | 24 | 61 | 462 |
| STD DEV | 6 | 11 | 3 | 4 | 7 | 3 | 5 | 3 | 6 | 4 | 4 | 22 |
| Summer | 8 | 5 | 239 | 554 | 16 | 22 | 151 | 274 | 0 | 15 | 56 | 6170 |
| Autumn | 49 | 24 | 145 | 122 | 107 | 45 | 10 | 81 | 68 | 14 | 400 | 50 |
| Winter | | 83 | | | | | | 64 | 45 | | | |
| Spring | 104 | 52 | 109 | 202 | 138 | 79 | 27 | 152 | 85 | 36 | 42 | 105 |

***Clostridium perfringens***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GEO AVE | 10 | 15 | 20 | 17 | 9 | 11 | 6 | 24 | 12 | 6 | 21 | 66 |
| STD DEV | 4 | 6 | 4 | 2 | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 3 |
| Summer | 3 | 2 | 32 | 16 | 4 | 7 | 10 | 23 | 6 | 1 | 17 | 147 |
| Autumn | 26 | 48 | 5 | 19 | 18 | 9 | 5 | 41 | 25 | 9 | 15 | 48 |
| Winter | | 85 | | | | | | 22 | 18 | | | |
| Spring | 22 | 47 | 29 | 15 | 20 | 20 | 4 | 19 | 12 | 8 | 45 | 27 |

## TABLE 4-3. NH4, NO3 AND PO4 CONCENTRATIONS AT THE BEARDS CREEK STATIONS

### NH4

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9A | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/30/93 | | 0.58 | 4.61 | 4.27 | 14.09 | 3.96 | 21.05 | 9.86 | 59.26 | | 21.88 | 7.24 | 8.57 |
| 7/13/93 | 0.89 | 4.70 | 5.62 | 15.25 | 10.57 | 42.54 | 22.23 | 5.09 | 0.36 | | 18.63 | 17.04 | |
| 8/17/93 | 4.21 | 2.38 | 2.53 | 51.86 | 7.94 | 11.22 | 13.31 | 3.82 | 6.89 | 9.76 | | 5.33 | 5.32 |
| 11/16/93 | 2.70 | 0.59 | 1.30 | 2.89 | 5.78 | 6.22 | 7.66 | 3.32 | 4.55 | | 0.95 | 1.87 | 1.95 |
| 12/7/93 | 1.73 | 1.21 | 1.99 | 1.11 | 2.61 | 2.78 | 1.81 | 3.21 | 3.70 | | 2.98 | 3.68 | 0.97 |
| 3/15/94 | | | | | | | | 1.01 | | | | | |
| 3/23/94 | 4.97 | 3.78 | 2.36 | 3.02 | 1.85 | 3.43 | 0.91 | 6.74 | 7.32 | | 5.26 | 3.88 | 0.96 |
| 5/9/94 | 3.93 | 2.32 | 1.42 | 2.73 | 4.73 | 2.60 | 1.84 | 2.12 | 16.62 | | 7.61 | 2.55 | 1.70 |
| 6/14/94 | 9.86 | 2.05 | 10.10 | 4.84 | 11.79 | 5.38 | 2.83 | 9.61 | 10.12 | | 4.83 | 7.31 | 9.14 |
| 6/20/94 | 2.83 | 10.00 | 8.99 | 4.55 | 6.41 | 11.14 | 5.96 | 6.94 | 10.92 | | 3.04 | 20.76 | 8.73 |
| **MEAN NH4** | **3.89** | **3.07** | **4.32** | **10.06** | **7.31** | **9.92** | **8.62** | **5.17** | **13.31** | **9.76** | **8.15** | **7.74** | **4.67** |

### NO3

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9A | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/30/93 | | 0.70 | 13.16 | 20.89 | 79.72 | 25.86 | 56.12 | 46.93 | 32.80 | | 5.49 | 1.07 | 24.36 |
| 7/13/93 | 0.21 | 0.33 | 13.10 | 22.40 | 56.93 | 10.03 | 49.04 | 63.04 | 61.52 | | 0.99 | 3.89 | |
| 8/17/93 | 2.98 | 0.55 | 2.33 | 4.42 | 79.83 | 7.07 | 29.54 | 47.75 | 57.42 | 50.18 | | 18.31 | 14.60 |
| 11/16/93 | 6.01 | 10.30 | 10.52 | 14.56 | 32.22 | 23.37 | 24.97 | 32.49 | 30.96 | | 0.53 | 0.45 | 10.62 |
| 12/7/93 | 27.08 | 32.04 | 24.48 | 28.51 | 58.15 | 15.67 | 20.58 | 12.38 | 29.36 | | 25.11 | 30.23 | 28.72 |
| 3/15/94 | | | | | | | | 4.93 | | | | | |
| 3/23/94 | 20.63 | 21.25 | 37.41 | 16.95 | 47.67 | 14.38 | 13.28 | 22.79 | 26.73 | | 10.13 | 20.15 | 19.81 |
| 5/9/94 | 10.87 | 9.75 | 9.95 | 10.59 | 26.33 | 2.75 | 7.12 | 9.71 | 7.68 | | 0.19 | 9.26 | 18.29 |
| 6/14/94 | 6.69 | 0.10 | 6.84 | 11.67 | 24.82 | 3.02 | 15.53 | 43.17 | 30.63 | | 1.17 | 2.55 | 19.08 |
| 6/20/94 | 0.57 | 0.26 | 11.87 | 20.45 | 15.36 | 4.77 | 8.40 | 52.56 | 42.39 | | 2.66 | 2.68 | 31.83 |
| **MEAN NO3** | **9.38** | **8.36** | **14.41** | **16.72** | **46.78** | **11.88** | **24.96** | **33.57** | **35.50** | **50.18** | **5.78** | **9.84** | **20.91** |

### PO4

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9A | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/30/93 | | 0.16 | 0.52 | 0.34 | 0.34 | 0.18 | 0.53 | 0.35 | 0.10 | | 0.18 | 0.32 | 0.70 |
| 7/13/93 | 1.02 | 0.25 | 0.52 | 0.46 | 0.26 | 0.53 | 0.45 | 0.71 | 1.32 | | 0.93 | 0.51 | |
| 8/17/93 | 1.74 | 0.02 | 0.04 | 0.75 | 0.06 | 0.34 | 0.28 | 0.34 | 0.18 | 0.37 | | 0.14 | 0.68 |
| 11/16/93 | 0.49 | 0.38 | 0.17 | 0.27 | 0.40 | 0.33 | 0.28 | 1.85 | 0.25 | | 0.12 | 0.17 | 0.42 |
| 12/7/93 | 0.55 | 0.49 | 0.59 | 0.64 | 1.07 | 0.52 | 0.29 | 0.23 | 0.31 | | 0.33 | 0.49 | 0.39 |
| 3/15/94 | | | | | | | | 0.39 | | | | | |
| 3/23/94 | 0.52 | 0.65 | 0.48 | 0.36 | 0.65 | 0.25 | 0.20 | 0.48 | 0.48 | | 0.44 | 0.46 | 0.40 |
| 5/9/94 | 0.44 | 0.46 | 0.39 | 0.51 | 0.84 | 0.31 | 0.20 | 0.37 | 0.21 | | 0.18 | 0.52 | 0.38 |
| 6/14/94 | 0.15 | 0.26 | 0.31 | 0.18 | 0.50 | 0.30 | 0.20 | 0.48 | 0.28 | | 0.22 | 0.20 | 0.50 |
| 6/20/94 | 0.28 | 1.33 | 0.62 | 0.34 | 0.14 | 0.36 | 0.30 | 0.45 | 0.30 | | 0.41 | 0.67 | 0.58 |
| **MEAN PO4** | **0.65** | **0.44** | **0.40** | **0.43** | **0.47** | **0.35** | **0.30** | **0.57** | **0.38** | **0.37** | **0.35** | **0.39** | **0.50** |

Figure 4-1. Geometric mean bacterial indicator concentrations in Beards Creek: 7/93-6/94.

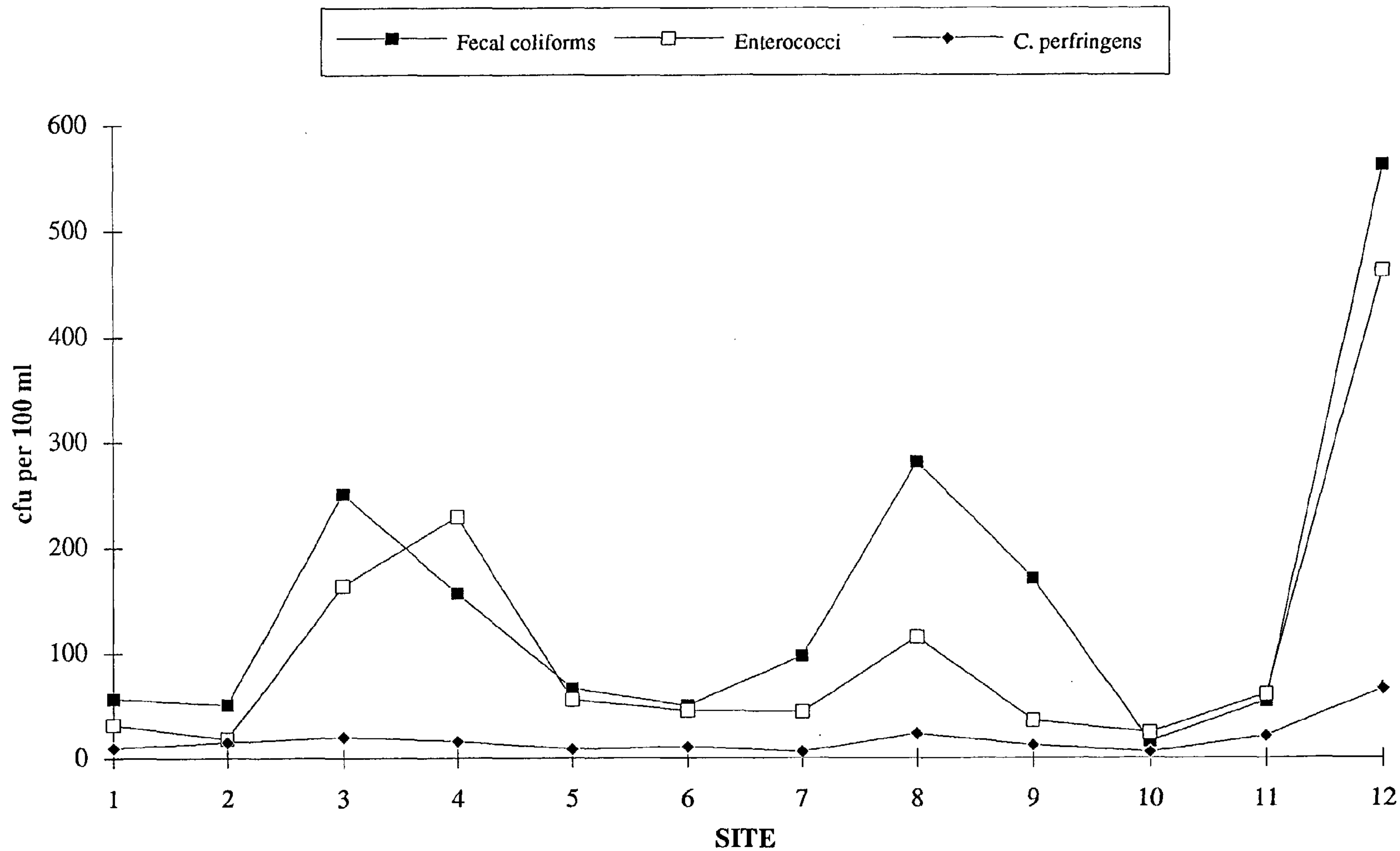


Figure 4-2. Seasonal fecal coliform concentrations in Beards Creek: 7/93-6/94.

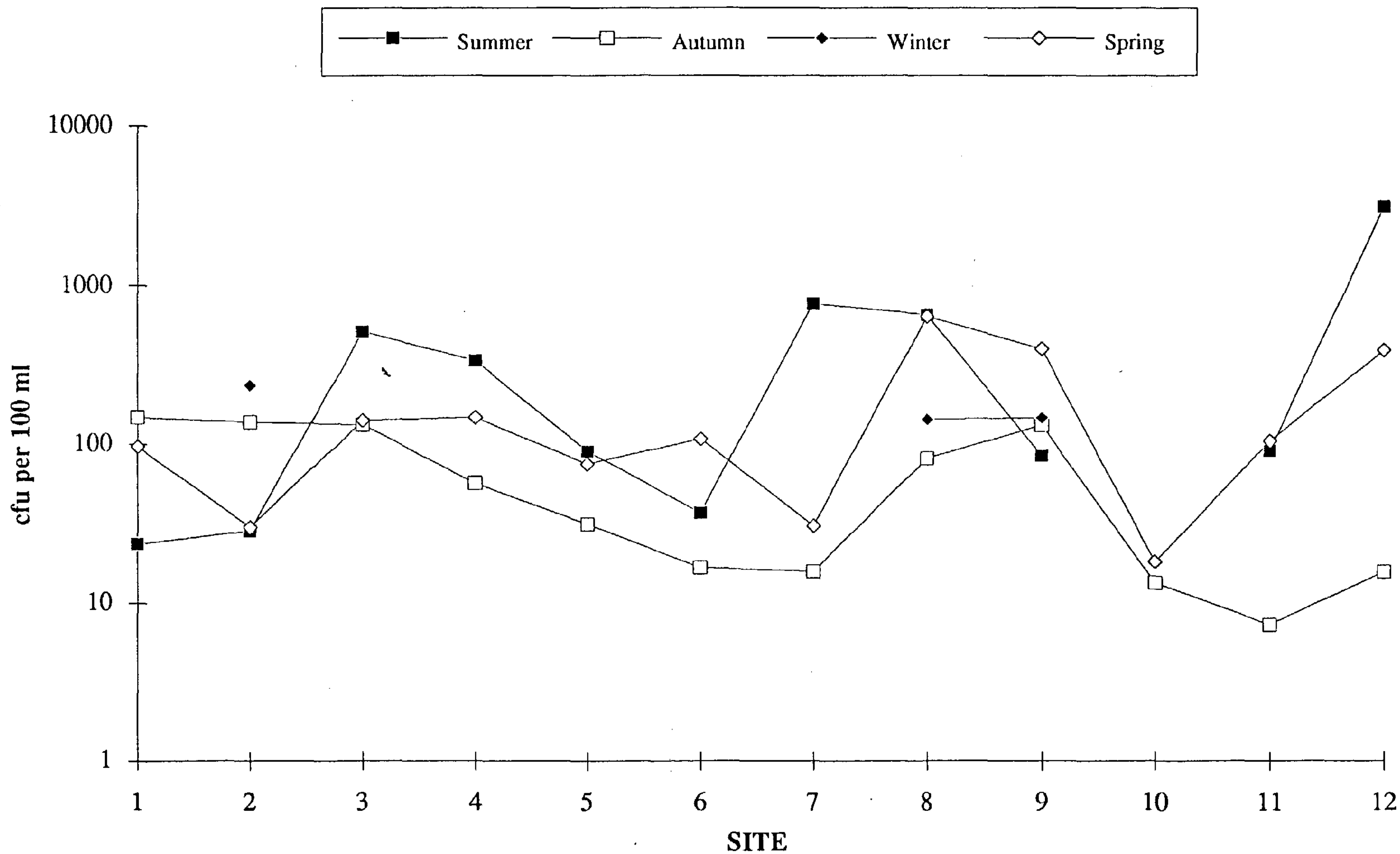


**Figure 4-3. Seasonal enterococci concentrations in Beards Creek: 7/93-6/94.**

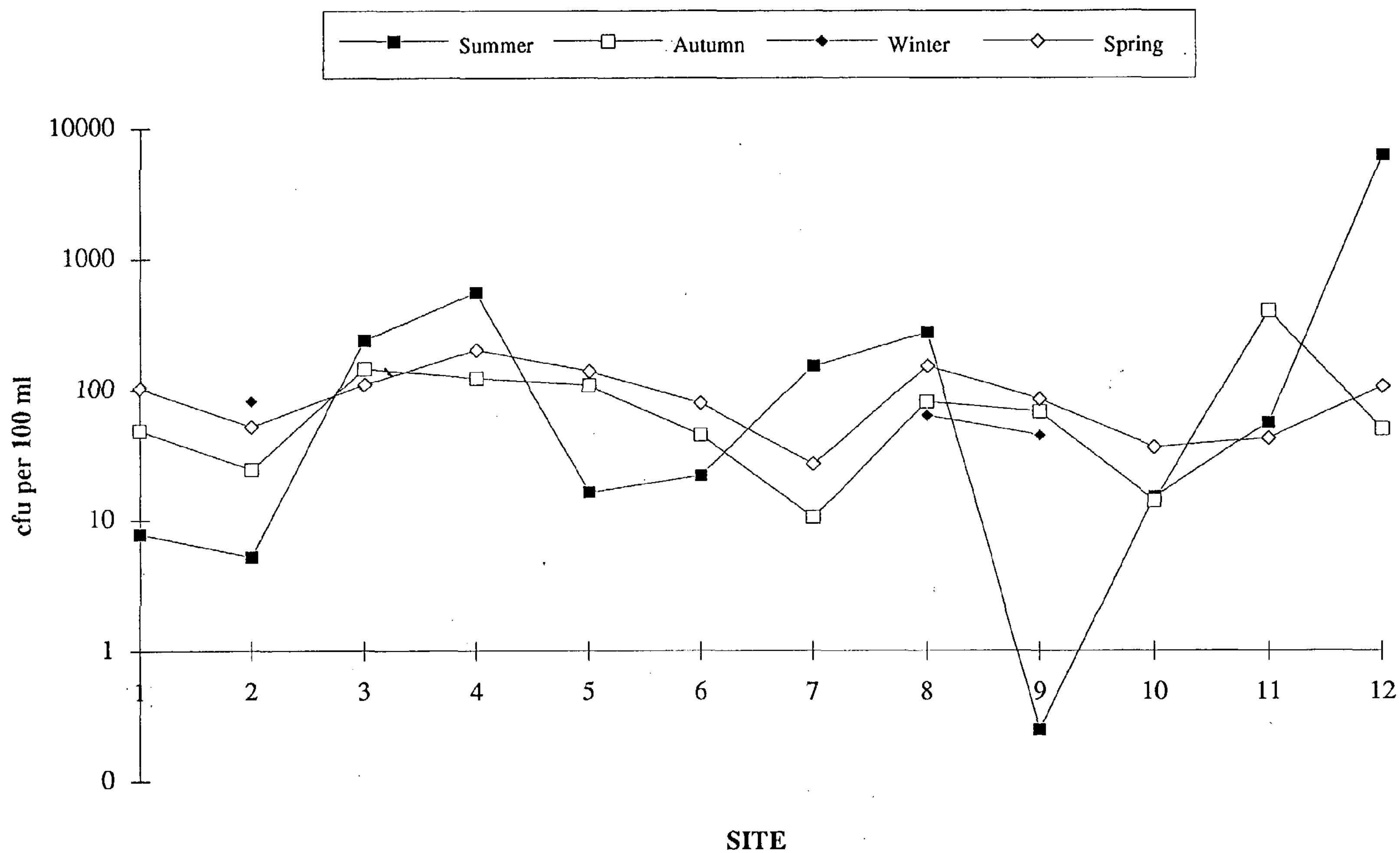


Figure 4-4. Seasonal C. perfringens concentrations in Beards Creek: 7/93-6/94.

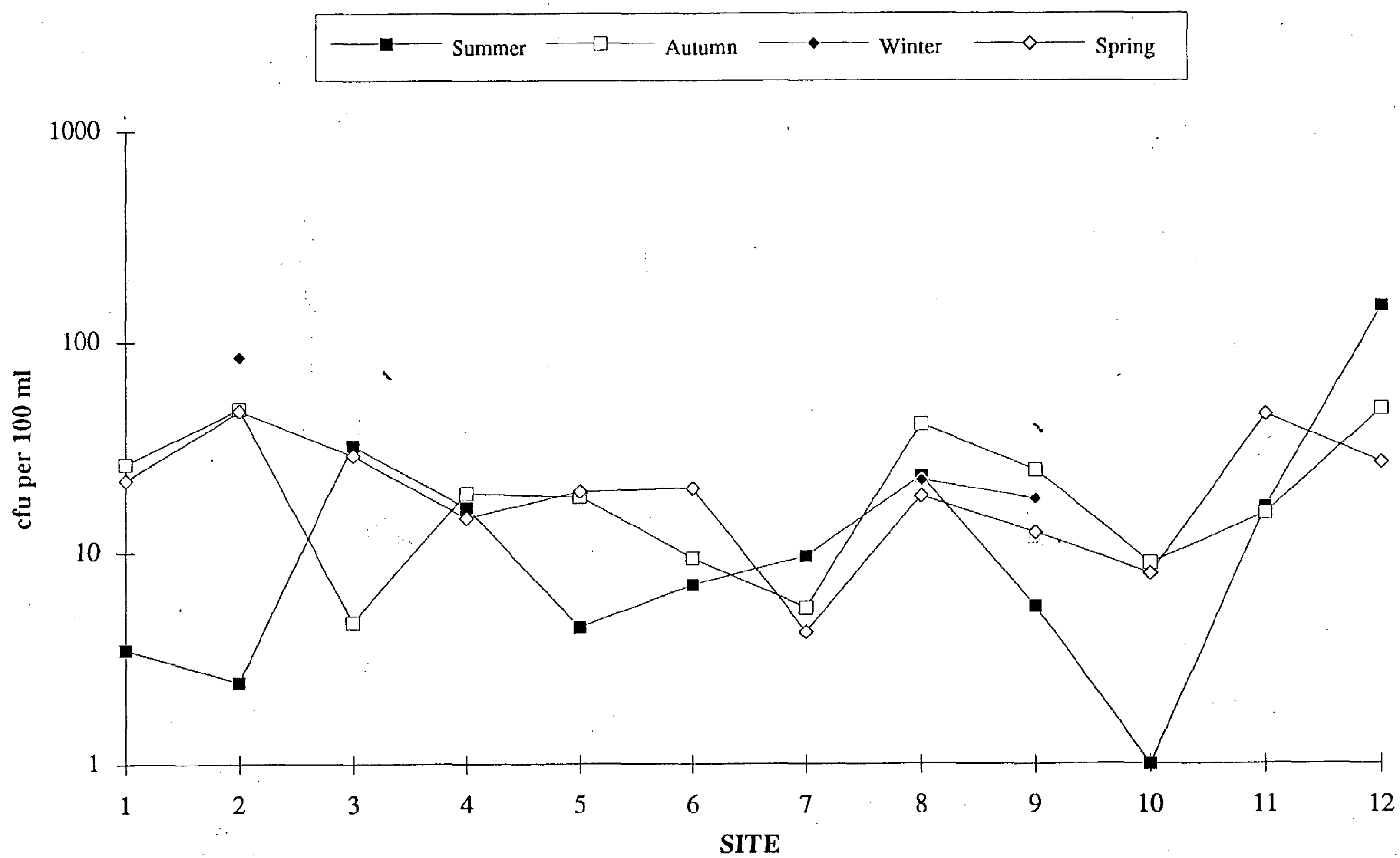


FIGURE 4-5. MEAN NH4 CONCENTRATION AT THE BEARDS CREEK STATIONS 6/93-6/94

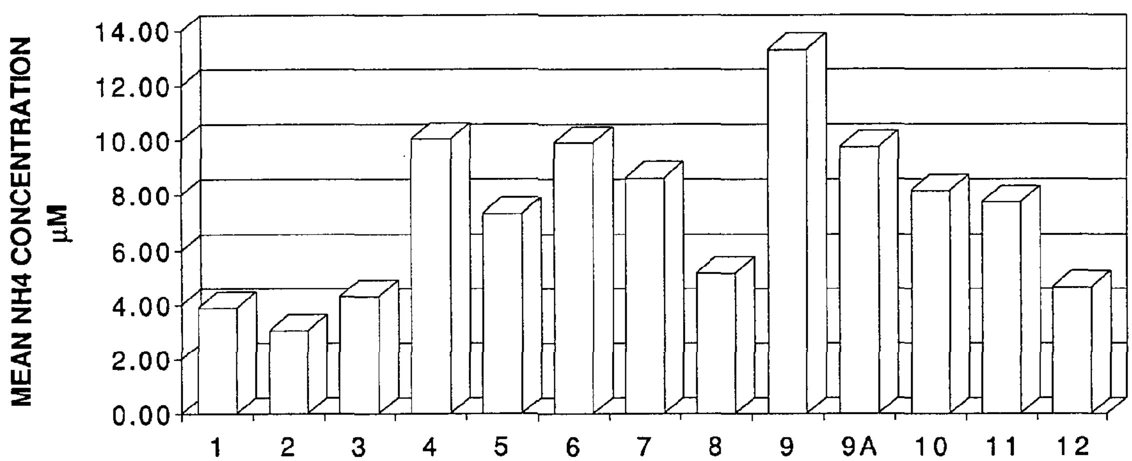


FIGURE 4-6. MEAN NO3 CONCENTRATIONS AT THE BEARDS CREEK STATIONS 6/93-6/94

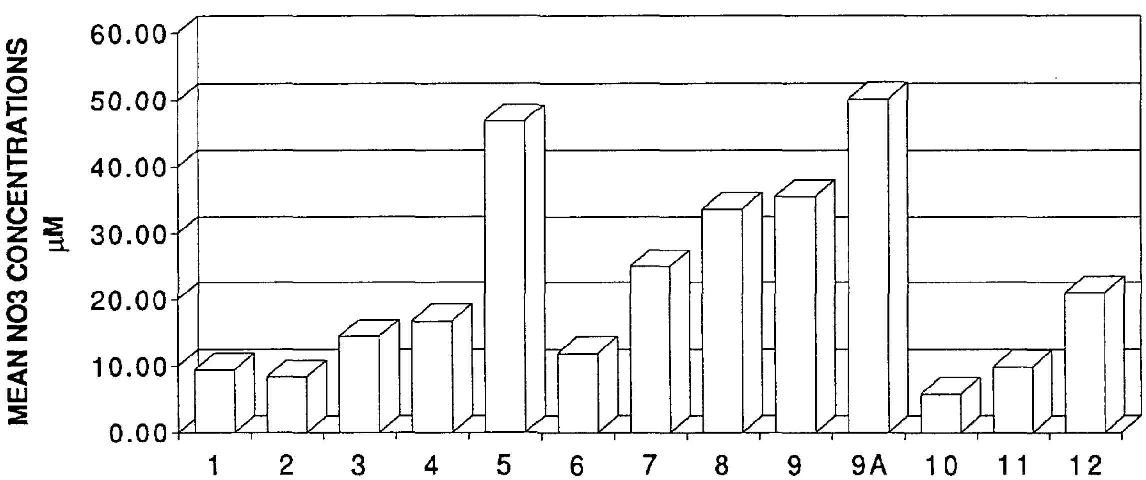


FIGURE 4-7. MEAN PO4 CONCENTRATIONS AT THE BEARDS CREEK STATIONS 6/93-6/94

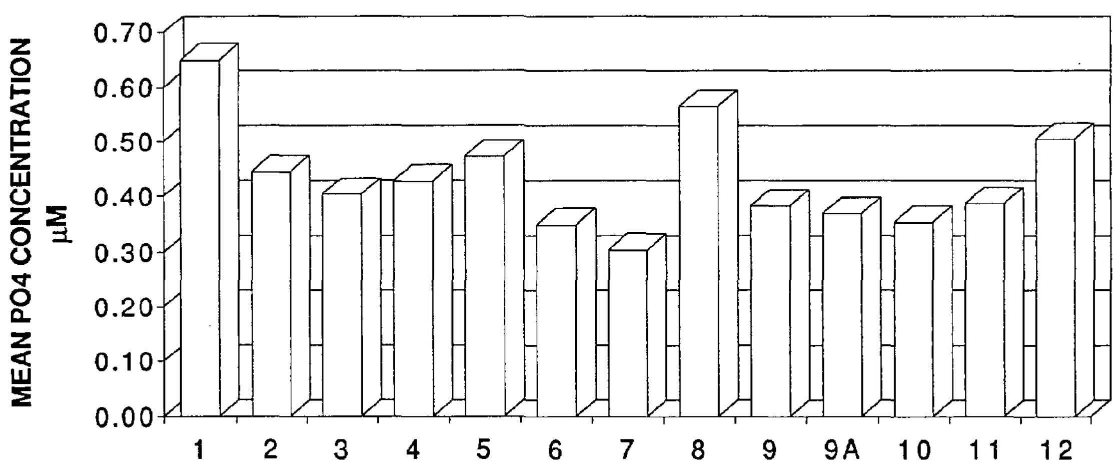


FIGURE 4-8. SEASONAL MEAN NH4 CONCENTRATIONS AT THE BEARDS CREEK STATIONS

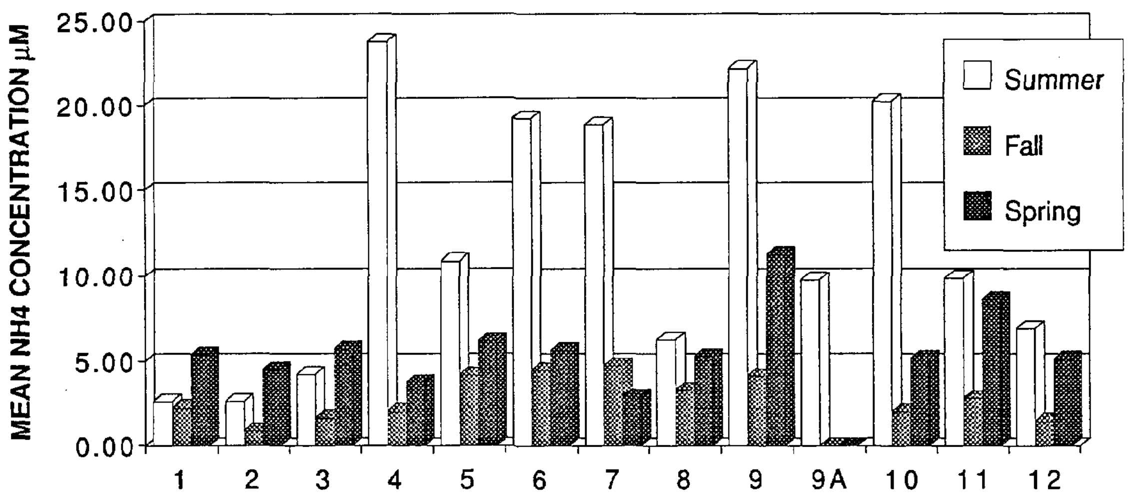
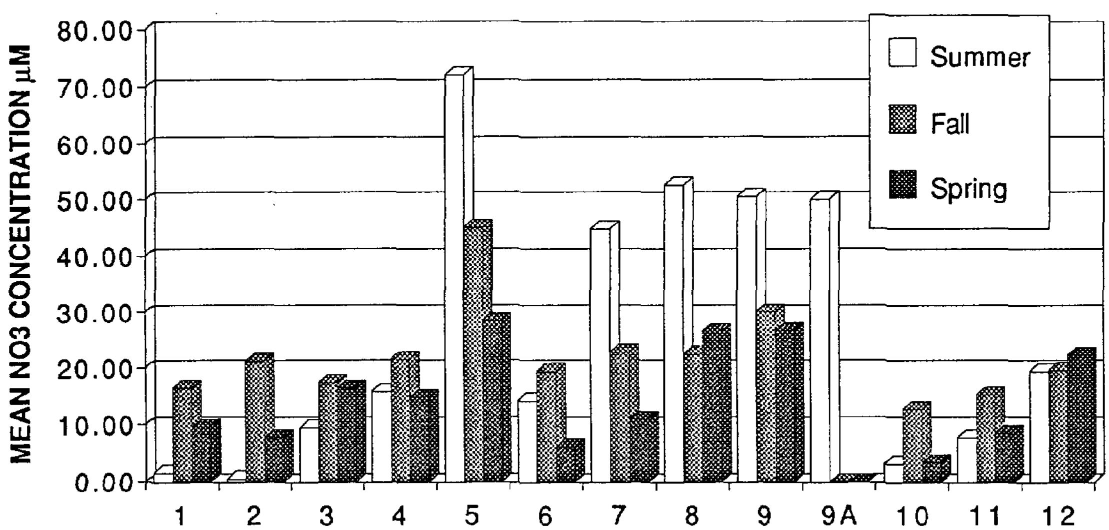


FIGURE 4-9. SEASONAL MEAN NO3 CONCENTRATIONS AT THE BEARDS CREEK STATIONS



## FIGURE 4-10. SEASONAL MEAN PO4 CONCENTRATIONS AT THE BEARDS CREEK STATIONS

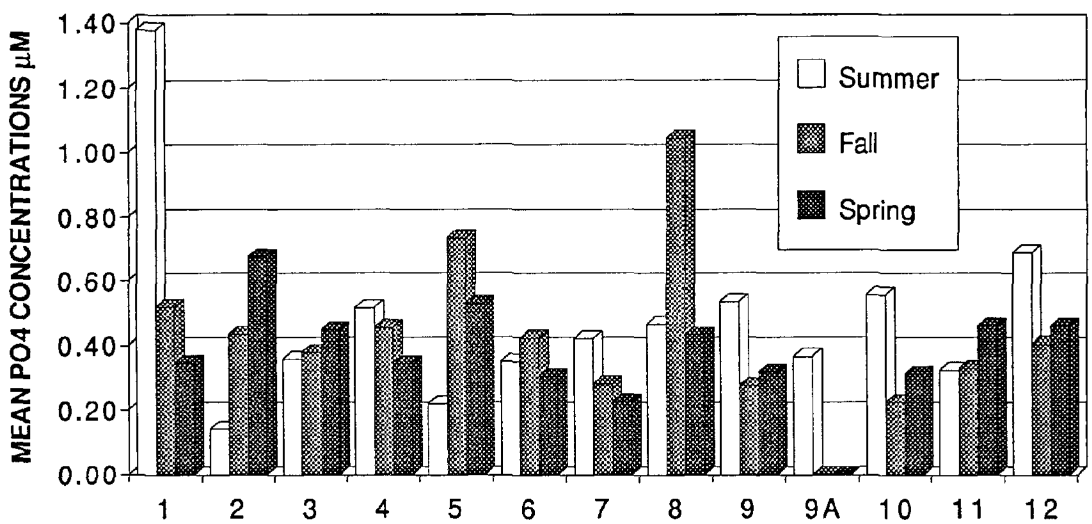


**Figure 4-10. Fecal coliform levels near a sewage pipe at the mouth of Beards Creek: 9/23/93. Salinities were 0, 25, 22.5, and 16.5 ppt from above dam to below pipe.**