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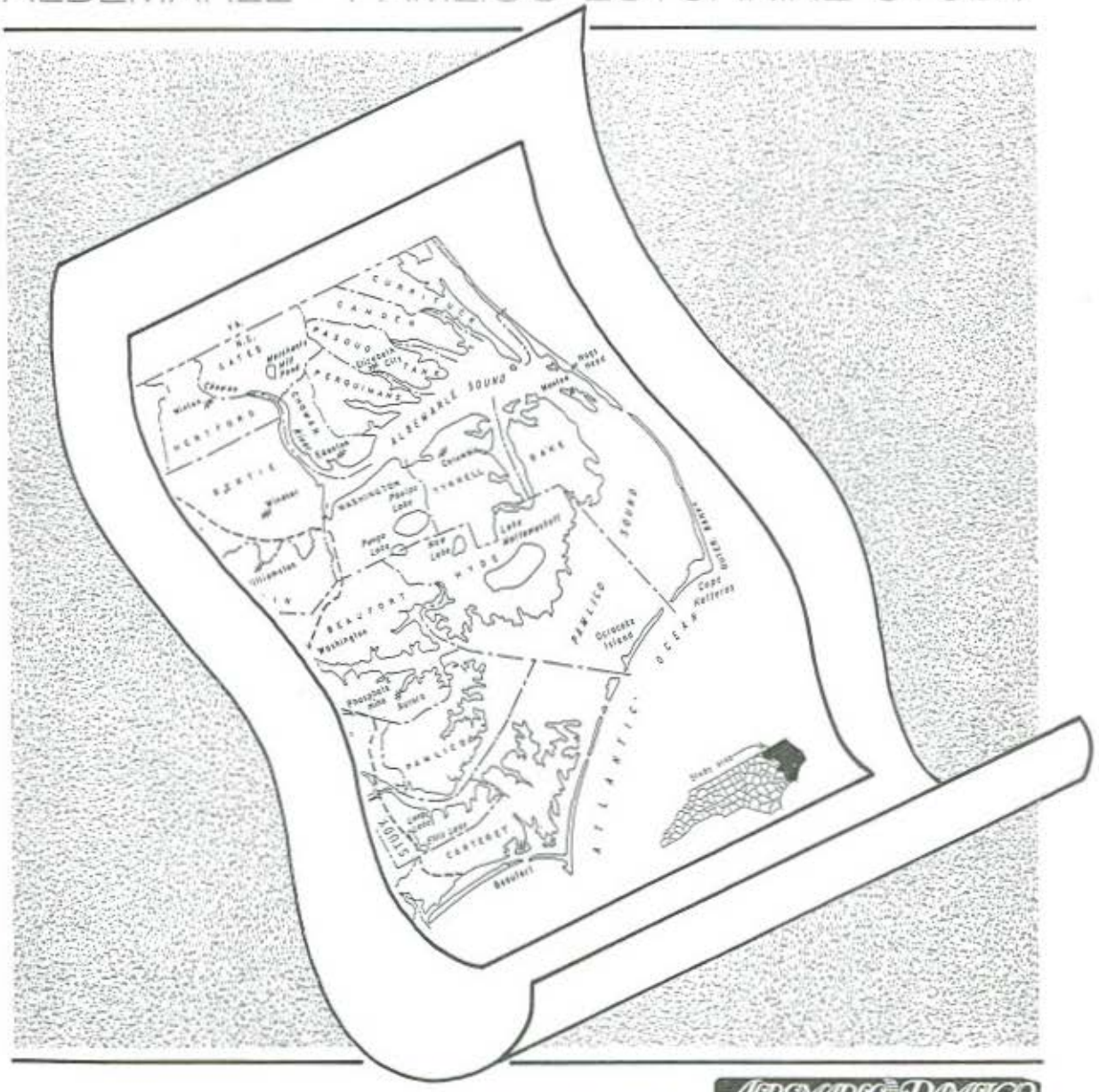
Reduction of Estuarine Nutrient Loading: Nitrogen And Phosphorus Removal In Coastal Swamp Streams

ALBEMARLE - PAMLICO ESTUARINE STUDY



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REDUCTION OF ESTUARINE NUTRIENT LOADING: NITROGEN AND PHOSPHORUS REMOVAL IN COASTAL SWAMP STREAMS

by

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ABSTRACT

Population growth and economic development cause increasing nutrient releases to streams and estuaries from agriculture, urbanization, and industrialization. Swamps and bottomlands along Coastal Plain streams are capable of removing much of this increased nutrient load. The wetlands along streams, generally termed riparian wetlands, normally have wide, flat floodplains which provide very large areas of soil surface well adapted for processing plant nutrients. This study aimed to increase understanding of the efficiency with which riparian wetlands strip out nitrogen and phosphorus from municipal wastewater effluents.

The initial phase of the study was devoted to selection of sites which were representative of the many forested wetlands impacted by municipal wastewaters in eastern North Carolina. Two swamp-stream sites were selected for intensive study, Bridgers Creek which receives wastewater from the town of Rich Square, and Deep Creek which similarly serves Scotland Neck. Samples of water were collected at about ten stations above, at, and below wastewater outfalls every three weeks for nearly two years. The extensive study utilized sites near Clarkton, Pink Hill, LaGrange, Walstonburg, Enfield, Macclesfield, and Lewiston-Woodville. They were sampled only quarterly for one year to determine variability among bottomland systems. Field measurements were made of water temperature, conductivity, dissolved oxygen, and pH. At the two intensive sites, stream discharges were also estimated. Grab samples of water were collected and returned to the laboratory for measurements of chloride and nutrient concentrations, including nitrate, ammonium, total N, phosphate, and total P. The chloride concentrations were used to make corrections for in-stream dilution, permitting calculation of net downstream changes in nutrient concentrations.

The receiving streams usually had waters much lower in conductivity and nutrients than the wastewater. The effluent generally increased these parameters just below the outfall, but concentrations decreased again downstream more rapidly than was expected based on dilution alone, demonstrating net nutrient removal. Median net removal efficiencies for ammonium, total N, phosphate, and total P within about 4 km below the Rich Square and Scotland Neck outfalls ranged from about 50% to 100% of the amounts in the effluent. About 80% of the nitrate was removed in the Deep Creek swamp below Scotland Neck. Rich Square effluent had very low concentrations of nitrate. Nitrate changes relative to the amount in the wastewater there ranged from very high to very low, with no significant median change below the outfall over the period of

study. The sites in the extensive study also showed a pattern of net nutrient removals in the downstream swamp-stream systems, although the data base was small. Ammonium removal was generally poor and inconsistent at the extensive sites, especially where effluent concentrations were relatively low.

The efficiencies of nutrient removal at the intensive sites were generally similar to removals which have been measured in other N.C. Coastal Plain swamp streams. Furthermore, there was general agreement with results from other Southeastern states that riparian wetlands effectively trap sediments and nutrients from agricultural and municipal sources, delaying and reducing their transport to the coast.

General Recommendations

Maintaining good water quality in North Carolina estuaries is an important goal because of their economic, recreational, and aesthetic values. The forested bottomlands and swamps along Coastal Plain streams are multipurpose natural areas. Because of demonstrated capabilities of riparian forested wetlands to reduce nutrient loadings to the estuaries, it is critical that both the areal extent and the functional properties of the riparian wetlands be maintained. These wetlands must be protected from channelization and conversion to farmland, processes which destroy them, from adverse changes to vegetative structure and soil properties, and from hydraulic or nutrient overloading. The methods from this study provide relatively inexpensive methods for assessing wetland nutrient-removal abilities so that year-to-year changes in removal efficiency of many streams can be determined.

Additional research is needed regarding the relationships between nutrient loading and wetland functioning. One such study is the determination of the amount of change and potential damage to wetlands by municipal wastewater loads, for example changes to soil fauna, microbial populations, and plant associations close below the outfall. Knowledge of the rate of accumulation of phosphorus and other elements in the soils and biota below the outfall is also needed. We need to know the impacts of land use in the watershed, for example, the effect of suspended sediments from soil erosion on the efficiency of phosphorus removal from wastewater. Finally, incorporation of the results into models of nutrient flux from the watershed to the estuaries will help predict maximum permissible wastewater discharges without damaging swamp functioning. Studies such as these will ultimately aid in making management decisions regarding the importance of wetlands to water quality.

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SUMMARY AND CONCLUSIONS

Population growth and economic development cause increasing nutrient releases to streams and estuaries from agriculture, urbanization, and industrialization. More nutrients enter headwater streams in North Carolina than reach the estuaries, partly because of removal by swamps and bottomlands which border Coastal Plain streams. These wetlands are thus interposed between the watershed nutrient sources and the estuarine sinks. These wetlands along streams, termed riparian wetlands, normally have wide, flat floodplains which provide large areas of soil surface for processing nutrient loads. Nutrients not removed from the streams before reaching the estuary contribute to nuisance algal blooms, hypoxic bottom waters, decreased fish and shellfish harvests, and other problems. The goal of this study was to increase understanding of the efficiency with which Coastal Plain riparian wetlands strip out nitrogen and phosphorus from municipal wastewater effluents.

The initial phase of this study was devoted to selection of sites representative of the forested wetlands receiving municipal wastewaters in eastern North Carolina. A preliminary list of 35 municipalities was provided by the N.C. Division of Environmental Management. This list was shortened and sites were ranked based on information gathered on field trips to the wastewater treatment plants and associated streams and wetlands. A one-day workshop with forested-wetland authorities of the Southeast provided perspectives useful in making final selection of study sites. The differences among the selected sites in the type of wastewater treatment, in the size and water quality of the receiving stream, and in the nature of the wetland system along the stream were representative of the variability in these factors in eastern North Carolina.

Two swamp-stream sites were selected for intensive study, Bridgers Creek which receives wastewater from the town of Rich Square, and Deep Creek which similarly serves Scotland Neck. Samples of water were collected at about ten stations above, at, and below wastewater outfalls every three weeks for two years. A more extensive study utilized seven additional sites near the towns of Clarkton, Pink Hill, LaGrange, Walstonburg, Enfield, Macclesfield, and Lewiston-Woodville. They were sampled only quarterly for one year to determine variability among bottomland systems. On the field trips, measurements were made of water temperature, conductivity, dissolved oxygen, and pH. At the two intensive sites, stream discharges were also estimated. Grab samples of water were collected and returned to the laboratory for measurements of chloride, nitrate, ammonium, total N, phosphate, and total P

concentrations. The chloride concentrations were used to correct for in-stream dilution, permitting calculation of net downstream changes in nutrient concentrations.

The waters of the receiving streams usually had low concentrations of chloride and nutrients. The effluent generally increased these parameters just below the outfall, but concentrations decreased again downstream more rapidly than expected from dilution alone. Such decreases which exceed the rate of simple dilution represent net nutrient removal. Median net removal efficiencies for ammonium, total N, phosphate, and total P within about 4 km of the Rich Square and Scotland Neck outfalls ranged from about 50% to 100% of the amounts in the effluent. About 80% of the nitrate was removed in the Deep Creek wetland below Scotland Neck. Rich Square effluent had very low concentrations of nitrate; nitrate changes relative to the amount in the wastewater ranged from very high to very low, with the median showing no significant change below the outfall. The data base was smaller, but the sites in the extensive study also showed a pattern of net nutrient removals in the swamp-stream systems below the outfalls. Ammonium removal was generally poor and inconsistent at the extensive sites, especially where effluent concentrations were relatively low.

The efficiencies of nutrient removal at the intensive sites were generally similar to removals which have been measured in other N.C. Coastal Plain swamp streams. Furthermore, these results generally agreed with results from other Southeastern states that riparian wetlands effectively trap sediments and nutrients from agricultural and municipal sources, delaying and reducing their transport tot the coast.

RECOMMENDATIONS

General Recommendations

Good water quality in North Carolina estuaries is important because of their economic, recreational, and aesthetic values. The forested bottomlands and swamps along Coastal Plain streams are dynamic multipurpose natural areas. Because of demonstrated capabilities of riparian forested wetlands to reduce nutrient loadings to the estuaries, it is critical that both the areal extent and the functional properties of the riparian wetlands be maintained. They must be protected particularly from channelization and conversion to farmlands, a process which effectively destroys them. Consideration must also be given to protection from adverse changes to vegetative structure and soil properties, for example through unwise forestry practices, which will decrease nutrient removal capabilities. Finally, the riparian forested

wetlands must be protected from damage caused by nutrient overloading. They appear to function well in removing modest amounts of nutrients, for example below properly-functioning wastewater treatment plants. However, heavier loads may exceed their removal capacity, allowing nutrients to continue downstream, and imposition of such excessive loads may adversely change the wetland itself. The methods and data from this study may help development of relatively inexpensive methods for assessing wetland nutrient-removal abilities so that year-to-year changes in removal efficiency of many streams can be determined.

Research Recommendations:

Additional research is needed regarding the relationships between nutrient loading and wetland functioning. One study which should be undertaken is measurement of the amount of change and potential damage to wetlands by municipal wastewater loads. It is likely that the additional nutrients, and in many cases the constant minimum stream flows, delivered by the effluent will affect plant species composition. Physical and chemical changes attributable to the effluent probably also markedly affect the soil fauna, microbial populations, and perhaps vegetative structure, especially close below the outfall. A study of the rate of accumulation of phosphorus and other elements in the soils and biota below the outfall would be of particular value. How long does it take under given waste loads for the soil to become so rich in these elements that further removal ceases? Studies are also recommended having to do with land use in the watershed. For example, does increased concentration of suspended sediments from soil erosion increase or decrease the efficiency of removal of phosphorus and other elements from wastewater? How does logging of bottomland timber affect trapping of nutrients from agricultural and municipal sources? Finally, incorporation of the results into models of nutrient flux from the watershed to the estuaries will help predict maximum permissible wastewater discharges which do not damage swamp functioning, thereby protecting estuarine water quality while urbanization of the Coastal Plain is increasing. Studies such as these will ultimately aid in making management decisions regarding the importance of wetlands to water quality.

INTRODUCTION

EUTROPHICATION OF ESTUARIES

North Carolina's varied and extensive estuaries are naturally nutrient-rich. They assimilate, recycle, and partially remove heavy loads of nutrients which enter from farms and towns in the watershed and from some industrial outfalls. High primary productivity of estuarine phytoplankton, benthic macrophytes, and salt marshes requires readily available nutrients; it is the basis of important North Carolina commercial seafood harvests. Excessive nutrient concentrations, however, may cause dense algal blooms, anoxic bottom waters, and fish kills, damaging both commercial and recreational interests (Ryther and Dunstan 1971; Kuenzler *et al.* 1982; Copeland *et al.* 1983; 1984).

Excessive algal growth resulting from high nutrient concentrations in tidal rivers and oligohaline estuaries is a serious environmental problem. Problems have occurred in the low salinity regions of the Chowan and Neuse Rivers (Stanley and Hobbie 1977; Kuenzler *et al.* 1982; Stanley 1983; Paerl 1987). When temperature and light conditions are satisfactory for rapid algal growth, nutrients become the major controlling factor. Estuarine nutrient levels, especially in the upper, oligohaline region, are strongly affected by loads received from the water-shed (Kuenzler *et al.* 1979). Nitrogen and phosphorus removal by soils and biota between the watershed sources and the estuary help to decrease these loading rates (Kuenzler 1989, 1990).

In the Pamlico and the Chowan River estuaries, either nitrogen (N) or phosphorus (P) may be limiting from time to time (Kuenzler *et al.* 1979, 1982; Sauer and Kuenzler 1981). Prior studies have recommended that loadings of both nutrients be reduced to improve water quality (Kuenzler *et al.* 1979, 1982; Paerl 1987). We need more information on sources, cycling, and ultimate fate of nutrients in our sounds and estuaries. Numerous scientific studies over the past 20 years in several of our estuaries have been summarized in Copeland *et al.* (1983; 1984) and Copeland *et al.* (1989), but the data base is still inadequate for many management purposes.

NUTRIENT PROCESSING BY FORESTED WETLAND SYSTEMS

The streams and rivers originating in and crossing the Coastal Plain province are largely bordered by floodplain swamps and bottomlands generally termed riparian wetland forests. Studies of the functioning of North Carolina swamp stream and river bottomland systems (Kuenzler *et al.* 1977,

1980; Brinson *et al.* 1981, 1983, 1984) have emphasized nutrient processing by litter and soils during flooding events rather than nutrient removals by these wetland systems on an annual basis. One study, however, showed losses of N and P downstream of waste-water outfalls in two Coastal Plain swamp streams (Kuenzler 1987). Nutrient concentrations usually decreased downstream much faster than did the conservative element chloride, demonstrating net nutrient removal from the water, not simply dilution. During flooding events, rapid change in nutrient concentration downstream resulted primarily from dilution, but when the streams were low the nutrients decreased much faster than chloride. At both sites, nutrient concentrations declined significantly within a few hundred meters of the outfall, and were essentially undetectable 4 km downstream. Use of this method of determining net nutrient removal permitted interpretation of results where data on hydrology and total nutrient loading rates were lacking.

The published literature shows that Southeastern forested wetlands can remove major percentages of suspended sediments from cropland runoff and N and P from both point- and non-point sources of pollution (Kitchens *et al.* 1975; Boyt *et al.* 1977; Ewel and Bayley 1978; Tietjen and Carter 1981; Kemp and Day 1984; Lowrance *et al.* 1984; Peterjohn and Correll 1984; Yarbro *et al.* 1984; Chescheir *et al.* 1987; Kuenzler 1987, 1988). Kuenzler and Craig (1986) used a mass-balance model of wetland nutrient removals to estimate downstream impacts of nutrient loading from different land uses in the Chowan River. Much of the nutrient yield from agricultural and municipal sources in the watershed is apparently removed by forested riparian wetlands before reaching the estuary. Improved understanding of rates and controls of nutrient removal by wetland systems along Coastal Plain streams will aid in determining their importance in maintaining estuarine water quality.

NUTRIENT DECREASES IN WETLANDS BELOW OUTFALLS

Three major processes decrease nutrient concentrations below wastewater outfalls. First, there is dilution of the wastewater with stream- or ground-water. This reduces solute and particle concentrations, although the quantity carried by the stream, and thus the downstream load, actually increases. Furthermore, the soil and wetland biota take up some nutrients by processes such as abiotic sorption or fixation (*e.g.*, phosphate), microbial immobilization, and plant uptake. Finally, there is mass efflux of some elements from the wetland to the atmosphere; methanogenesis and denitrification, for example, remove carbon and nitrogen, respectively. The first process is neither removal from the water nor retention in the system, the second is removal and retention, the third is removal from the water but not retention. The term "removal"

will be used here for net removal of nutrients from stream water, including retention and mass efflux, after correction for dilution.

Denitrification is an important pathway by which inorganic N is removed from wet soils and stream waters (*e.g.*, Engler and Patrick 1974; Gambrell *et al.* 1975 a, b; Gilliam and Jacobs 1983; Duff *et al.* 1984), but biological uptake by decomposing litter may also be important (Qualls 1984). Phosphorus in wetland stream or flood waters is often removed quite effectively (Nichols 1983) by sedimentation, biological uptake, and soil fixation (Kuenzler *et al.* 1980; Richardson 1985). The data summarized in Nichols (1983) for several Northern wetlands shows decreasing efficiency of removal with loading rate and with duration of loading.

Management of nutrient inputs to the Albemarle-Pamlico System would be improved by information on rates of nutrient removal by swamps and on factors controlling removal processes. The objective of this study was to provide additional knowledge and understanding of nutrient removal rates below point sources by bottomland forest systems bordering our Coastal Plain streams. Knowledge of nutrient loading rates from the watershed, as affected by swamp removal, is necessary to forecast the rate of eutrophication in the Albemarle-Pamlico system. Understanding of the ability of riparian systems to remove nutrients will aid management decisions regarding the need for more intensive municipal waste treatment, for extension of Best Management Practices to more farms, and for protection of streams with functioning riparian zones from channelization or other destruction.

THE STUDY AREAS

Several riparian swamp and bottomland sites on the North Carolina Coastal Plain were selected by methods given below. This region is characterized by low elevations, gentle slopes, sandy-to-clayey soils, abundant rainfall, sluggish streams, high water tables, and abundant wetlands. Many municipalities have been permitted to discharge their wastewaters into streams bordered by forested bottomlands or swamps. There were differences among sites, but all were selected because their streams had substantial areas of forested wetlands.

The "extensive" study included seven sites, all but one of which (Clarkton) was in the Albemarle-Pamlico region (Fig. 1; Table 1). Four or five stations at each site were sampled quarterly for one year. At a typical site, one station was upstream of the wastewater outfall, another was at the outfall, and two or three were along the stream below the outfall. Watershed areas above the outfalls on these streams varied from

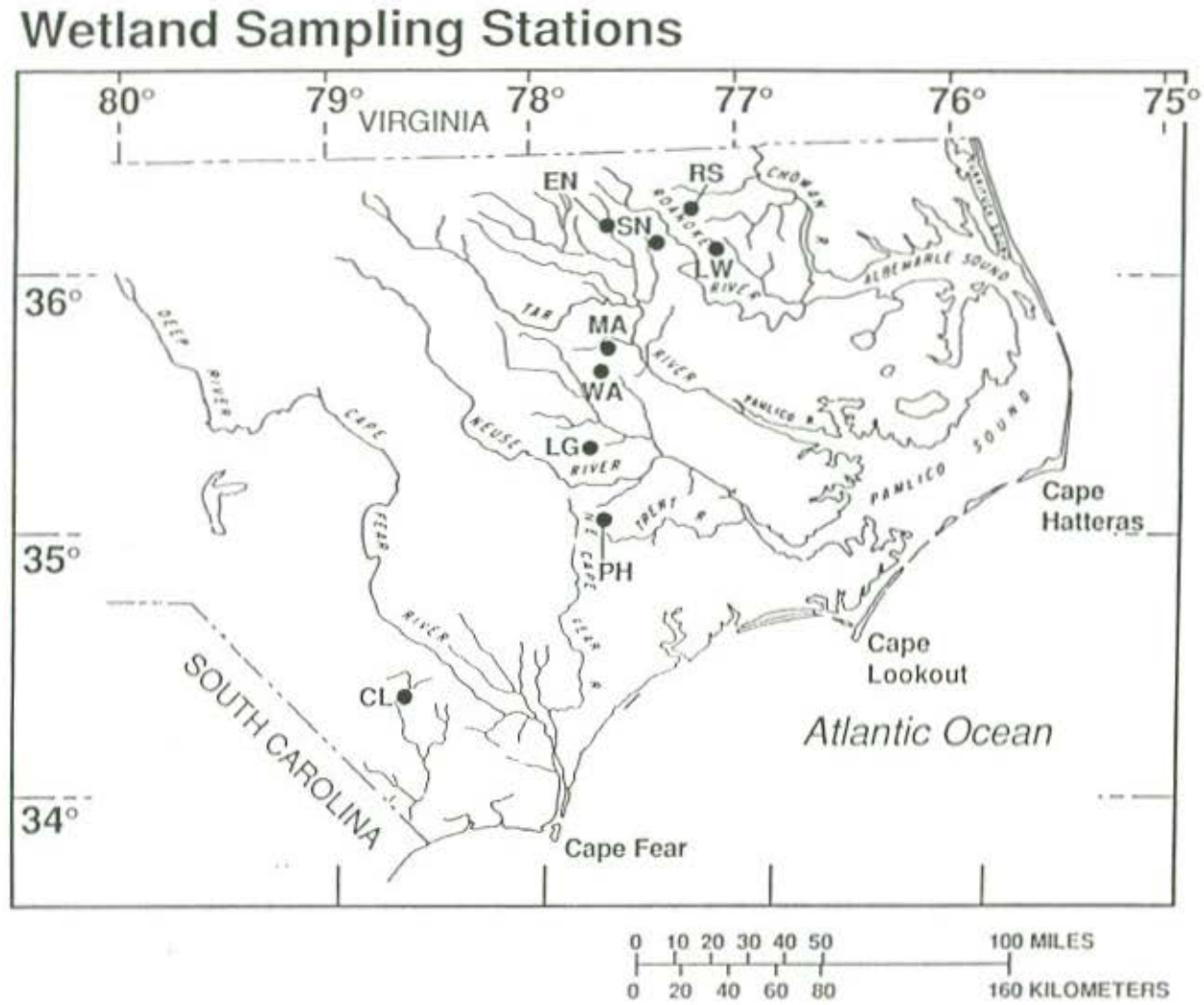

Figure 1. Map of eastern North Carolina showing major streams and locations of study sites. (adapted from Giese 1979)

Table 1. Locations and descriptions of municipalities and receiving streams included in the study. Watershed areas are measured to the confluence with the major receiving water.

Municipality	County	N. Lat.	W. Long.	Receiving Stream	Watershed Area (km^2)	River Basin
			Extensive Study Sites			
Clarkton	Bladen	34°29'	78°39'	Big Foot Creek	12	Waccamaw
LaGrange	Lenoir	35°19'	77°47'	Mosely Creek	7	Neuse
Pink Hill	Lenoir	35°03'	77°44'	Cherry Hill Br.	5.2	Neuse
Walstonburg	Green	35°36'	77°40'	Thompson Swamp	18	Neuse
Macclesfield	Edgecombe	35°45'	77°40'	Bynum Mill trib.	3.9	Tar-Pamlico
Lewiston-Woodville	Bertie	36°08'	77°09'	Cashie River	61	Roanoke
Enfield	Halifax	36°11'	77°39'	Burnt Coat Swamp	94	Tar-Pamlico
			Intensive Study Sites			
Rich Square	Northhampton	36°15'	77°18'	Bridgers Creek	9	Roanoke
Scotland Neck	Halifax	36°07'	77°26'	Deep Creek	108	Tar-Pamlico

about 4 km^2 at Macclesfield to about 94 km^2 at Enfield (Table 1). Waste-waters received secondary or tertiary treatment; wastewater design flows ranged from 0.100 to 0.675 million gallons per day (mgd = 0.0438 m^3s^{-1})(Table 2).

More intensive study was conducted at two other sites (Fig. 1; Table 1, 2), each having about 10 stations which were sampled monthly for about 20 months. Wastewater from Rich Square received secondary treatment in a stabilizing lagoon (oxidation pond). The effluent entered a small, unnamed tributary and then flowed to Bridgers Creek (Fig. 2) on which downstream sampling stations were established. Bridgers Creek had a watershed area of 9.2 km^2 above its confluence with the unnamed tributary. An oxidation ditch treatment plant provided secondary treatment of Scotland Neck wastewater and discharged to the channelized Canal Creek (Fig. 2). Its waters joined those of Deep Creek (108 km^2 watershed) in a wide floodplain swamp. Treatment plant design flows at these sites were 0.300 and 0.675 mgd (Table 2). Further details of these sites and stations are given in Appendix A and B.

Table 2. Descriptions of municipal wastewater treatment plants included in the study. (Source N.C. Division of Environmental Management data).

Municipality	Design Flow (mgd)	Treatment Type
		Extensive Study Sites
Clarkton	0.240	Secondary: large lagoon with aeration in one cell followed by settling in second cell.
LaGrange	0.600	Tertiary: oxidation ditch and sand filters with post-aeration.
Pink Hill	0.136	Secondary: contact stabilization and settling pond.
Walstonburg	0.138	Secondary: extended aeration with clarifiers and post-aeration.
Macclesfield	0.175	Tertiary: oxidation ditch and sand filters.
Lewiston-Woodville	0.100	Secondary: aeration basin with secondary clarifier.
Enfield	0.500	Secondary: biological treatment using trickling filters.
		Intensive Study Sites
Rich Square	0.300	Secondary: biological treatment with stabilizing lagoon (approx. 1 month retention time).
Scotland Neck	0.675	Secondary: oxidation ditch.

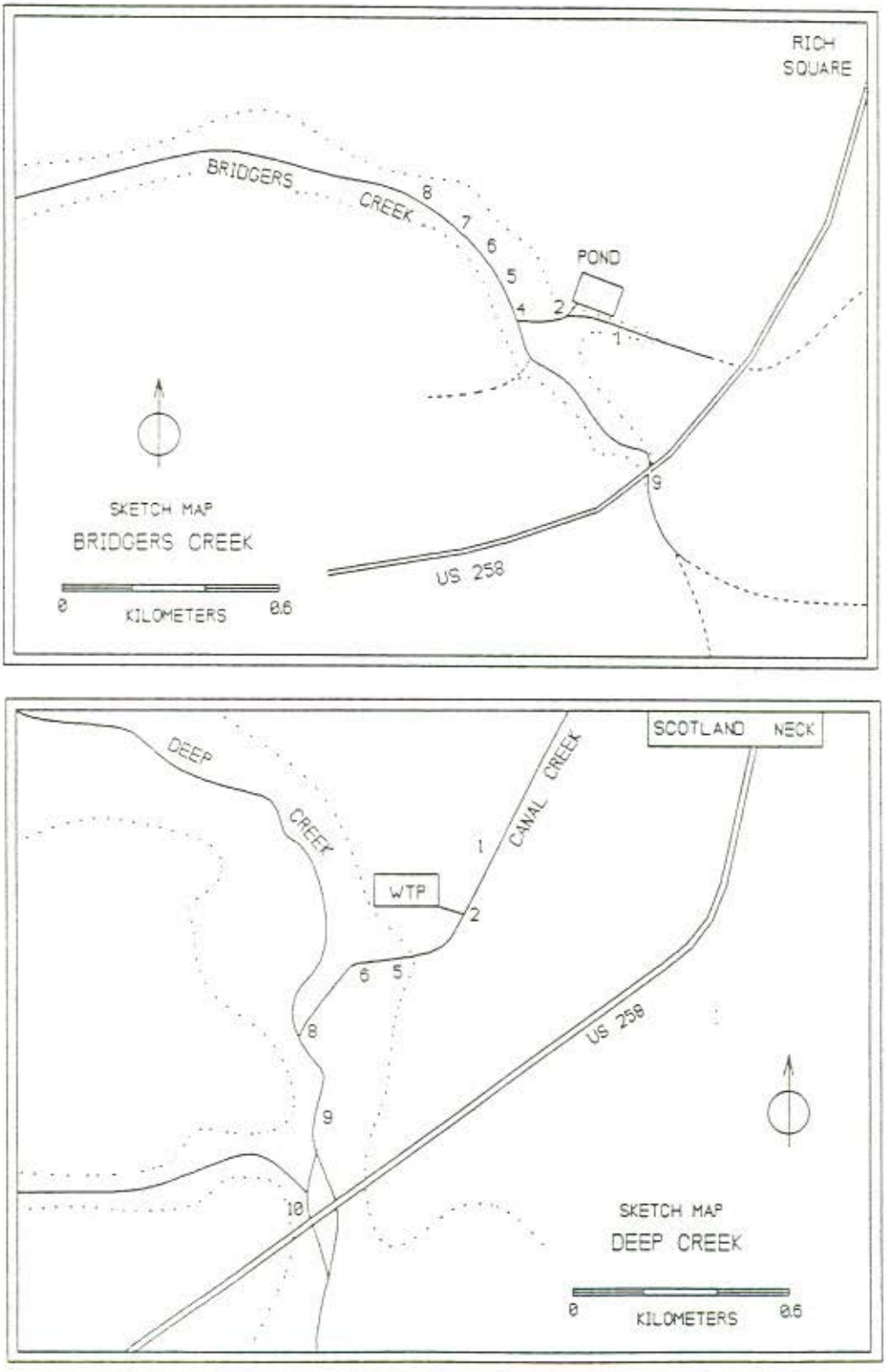

Figure 2. Sketch maps of the Rich Square-Bridgers Creek and Scotland Neck-Deep Creek study sites showing locations of sampling stations (BC10, DC7, and DC7.5 are off the map to the left). Dashed line indicates boundary of wetland. Approximately to scale.

METHODS

SITE SELECTION

Care was given to site selection to improve interpretability of research results. A satisfactory study site should be: (1) representative of most swamp and bottomland streams and forests of the area; (2) an extensive, normally-functioning forested floodplain system; (3) undisturbed in the recent past and the duration of the study; (4) accessible, with permission of the landowner; (5) close enough to other sites so that more than one may be sampled on one day; and (6) significantly enriched with municipal wastewater nutrients. Bottomland forests along small-to-medium streams were considered most appropriate because they are abundant and frequently used for wastewater disposal, they usually have large floodplain areas relative to stream discharge, and they are measurably affected by, but also can affect, nutrient concentrations below outfalls.

The U.S. Geological Survey (USGS) gauging stations and municipal outfalls were plotted on topographic maps. There were 40 gauging stations in the Coastal Plain (Barker, *et al.* 1986), 28 of them in the Albemarle-Pamlico drainage basin. There were 48 municipalities which discharged >0.1 million gallons per day (MGD) on the Division of Environmental Management (DEM) list of permitted dischargers, but, unfortunately, no USGS gauging stations were on their receiving streams. Based on data provided by DEM concerning each stream and wastewater treatment plant (WTP), 35 outfalls appeared inappropriate because of excessive dilution by a large river, very low dilution, tidal influence, recent conversion to land application of sewage, proximity to the Piedmont, discharge to a channelized stream, or heavy industrial waste loading.

The 13 remaining sites were visited for further evaluation. Data were gathered from the plant operators about wastewater loads and treatment. At each potential site, notes were made of accessibility, stream characteristics, width of floodplain, and dominant tree species. Five more sites were assigned lower priority at this stage because of poor access, excessive dilution, or severe downstream flooding by beaver dams.

The remaining eight prospective sites received another field evaluation. A long stretch of each stream was walked to observe soil, plant species composition, size and location of tributaries, and general nature of the floodplain. Preliminary sampling stations were established above the outfalls, at the outfalls, and at points of about 40, 100, 300, and 1,000 m

below the outfall. Field measurements (pH, conductivity, and temperature) were made and water samples taken for laboratory analysis of nutrients. In May 1988, we held a workshop with Southeastern wetlands ecologists and water quality experts to examine data from these sites. With their help, we selected two sites (near the towns of Rich Square and Scotland Neck) for intensive study (the "intensive" sites) and seven additional sites for less frequent visits (the "extensive sites"). Site descriptions are in Appendices A and B.

WATERSHED AREAS AND STREAM LENGTHS

The watershed areas of streams and tributaries at our study sites were measured using USGS topographic maps (7.5 minute series; scale = 1:24,000). The watershed area above the effluent discharge and of downstream tributaries were outlined in pencil and measured using a Lasico planimeter calibrated against the map scale. Watershed areas were difficult to determine accurately where drainage divides near towns and pocosins were uncertain. Stream lengths between sampling stations were measured either in the field with a Hip-Chain (Topometric Products Ltd.) or along the indicated main channel as shown on USGS maps.

FIELD TRIP PREPARATIONS

Sampling trips were made about every three weeks. Sample bottles were prelabeled to show station number, sampling date, and type of nutrient analysis. The middle seat of the field van was removed and replaced with a custom-made work bench on which a pH meter, vacuum pump, 3-way filter manifold, and lamp were installed, permitting pH measurements and sample filtration while in the field and during the return trip.

Prior to each field trip, meters were calibrated and standard spike solutions were prepared. The field meters used for measuring temperature, dissolved oxygen, conductivity, pH, and stream discharge were: (1) Yellow Springs Instrument (YSI) Co. Model 54A oxygen meter, (2) YSI Model 33 Salinity-conductivity-temperature (S-C-T) meter, (3) Corning pH/C 107 meter, and (4) Marsh-McBirney 201D flow meter. The dissolved oxygen meter was calibrated against Winkler titrations of two samples taken from a container of tap water equilibrated with air. The conductivity function of the S-C-T meter was calibrated against a standard KCl solution; the temperature element was checked against an ASTM thermometer. The pH meter was checked for proper functioning. The flow velocity meter was checked against its calibration function.

A standard spike solution containing 10 mg/L each of ammonium-N, nitrate-N, and phosphate-P in deionized water was

prepared in a plastic 100 ml volumetric flask. This standard was used to deliver a 0.5 mg/L spike to the B2 bottles upon returning to the laboratory and to make a 0.5 mg/L spike in distilled water in the field.

SAMPLING AND SAMPLE HANDLING

Field procedures consisted of measuring dissolved oxygen, conductivity, and water and air temperature, and collecting water samples at each station. The data and field observations were recorded in a field notebook. Dissolved oxygen was measured by swinging the probe gently in the main channel flow, avoiding contact with the bottom. Conductivity measurements were taken at the same time and place. Conductivity of the wastewater was measured directly in the effluent flow as readings varied greatly only a short distance downstream. Water temperature (°C) was measured with the conductivity probe thermistor. Stream velocities and water depths were measured at Bridgers Creek and Deep Creek.

Grab samples of surface water were taken at each station in the main channel flow for three types of nutrient analysis: (1) Labile (ammonium, nitrate + nitrite, and phosphate), (2) Total Filtered (filtered Kjeldahl N = FKN; Filtered total P = TFP), and (3) Total (total P = TP; total Kjeldahl N = TKN). During sampling, disturbance of bottom sediments was avoided to prevent contamination of the sample. Bottles were rinsed with sample water before filling. At two stations at each site, two larger water samples collected in a plastic pitcher were split into replicates for analysis of precision (bottles A1 and A2) and accuracy (bottles B1 and B2). Bottle B2 received a spike containing 0.5 mg/L each of nitrate-N, ammonium-N, and phosphate-P from the standard spike solution.

Water velocity measurements were made at stations DC10 and BC9. At station DC10, measurements were made from the east side of the southernmost of the two bridges that span the stream. The tape-down distance from bridge railing to the stream channel bottom and to the water surface were measured at twelve equidistant points along the railing. Velocity was measured by lowering the Marsh-McBirney probe on a long pipe into the water facing upstream. Velocity measurements were made similarly at station BC9; because the cross-section was rectangular, flat-bottomed, and much smaller than at DC10, only one velocity and water depth measurement was made on each date.

Water samples were stored on ice in the van until pH measurements and filtering were done; bottles were returned to the ice after pH measurements and filtering were completed. The pH meter was calibrated against pH 4.0 and 7.0 standard buffers and readings were made as soon as possible, usually

within two hours of collection. After 19 March 1989, pH readings were taken only on every other trip. The specialized filtration manifold in the van permitted filtrates to be collected directly in the subsample bottles. The filter funnel and Whatman GF/F glass microfibre filter were rinsed with deionized water. A small portion of sample filtrate was used for rinsing the subsample bottles. Then 50 ml of filtrate was dispensed into the Labile and Total Filtered bottles. About 100 ml of filtered water was used for assessment of spike recovery (bottles B2). The distilled water field spike consisted of 5.00 ml of standard spike solution made up to 100-ml with deionized water and stored on ice.

Immediately upon returning to the laboratory, the bottles labeled Total and Total Filtered were preserved by acidification with 3 to 5 drops, depending on the sample volume, of sulfuric acid to reach a pH of about 2. The spiked samples were prepared by adding 5.00 ml of standard spike solution to 95 ml of sample water from the B2 bottles (Labile, Total, and Total Filtered) in 100-ml graduated cylinders. All sample bottles and the distilled water field spike were held in a 4°C refrigerator until chemical analyses were completed.

LABORATORY PROCEDURES

Chemical analyses were done on an Orion autoanalyzer following EPA-approved procedures (U.S. Environmental Protection Agency 1983a) provided by Orion Scientific Instrument Co. for their automatic analyzer (Table 3).

Ammonium and phosphate analyses were done within 24 hours. Dissolved fractions of total N and total P were distinguished from the particulate fractions based on filtration through acid-washed Whatman GF/C filters (*ca.* 0.5 m porosity). All data were entered onto a Lotus 1-2-3 spreadsheet for data compilation, analysis, and plotting.

Quality assurance procedures were established in accordance with U.S. Environmental Protection Agency (1979). Standard curves were run for each analysis with every batch of samples. Analytical sensitivity, or lowest detectable concentration (LDC), was calculated to be twice the standard deviation of seven or more blank samples (Wilson 1961) (Table 3). Accuracy was determined from percentage recovery of spiked samples (Table 3).

The Labile samples were refrigerated and analyzed within 24 hours of sample collection. Before analysis of Labile samples, a peak sheet was prepared with a quality control section with replicate samples, the distilled water field spike, and a complete standard curve. The samples on the peak

Table 3. Automated analytical methods for chloride and nutrient concentrations (see text.)

Nutrient Form	Procedure	EPA No.	Sensitivity (mg/L)	Recovery (%) (mean ± S.D.)
Nitrate + nitrite	Cadmium reduction	353.2	0.001	94 ± 17
Ammonium	Phenate	350.1	0.003	96 ± 10
Total Kjeldahl N	Block digestion; phenate	351.2	0.020	97 ± 23
Phosphate	Ascorbic acid	365.1	0.001	98 ± 12
Total P	Block digestion; ascorbic acid	365.4	0.005	94 ± 16
Chloride	Ferricyanide	325.2	0.020	

sheet were arranged in order of increasing concentration to avoid sample swamping. Also, from 3-5 check standards were included in the analysis. Samples and stock standards were removed from the refrigerator and warmed to room temperature. While the reagents were being prepared, the autoanalyzer was prepared for low concentration analyses. After the autoanalyzer was warm (>30 min.), the reagent lines were connected, and the samples were loaded onto the automatic sampler in 4-ml conical polystyrene sample cups. After completing analysis of a set of samples, the autoanalyzer was cleaned, the reagent lines were removed, and excess reagent returned to the refrigerator. The autoanalyzer was run with distilled water for at least 10 minutes to clean it before being shut down.

The Total and Total Filtered samples were digested prior to their analysis using a Tecam DG 1 Block Digester and PTC 2 Programmable Temperature Controller. Standards were prepared for simultaneous digestion. After warming the samples to room temperature, they were dispensed into the digestion tubes along with 5 ml of digestion solution and 4-8 boiling chips. The tubes were vortex mixed and placed on the digestion block. After digestion and cooling, the samples received 25 ml of water and were vortexed, capped, and returned to the refrigerator. The digested samples were analyzed within 2 days of digestion according to procedures outlined above.

DATA ANALYSIS

Data handling, descriptive statistics, and construction of graphs were done using Lotus 1-2-3 on an IBM PC computer. Data on concentrations of chloride and nutrients are reported as elemental mass per liter, *e.g.*, mg Cl/L, mg N/L or mg P/L. Experience with natural and polluted surface waters of the region has indicated that nitrate dominates in the nitrate + nitrite analysis and orthophosphate dominates in the filterable reactive phosphorus analysis. These fractions have therefore been designated nitrate and phosphate. Where an analysis indicated a concentration below the lowest detectable concentration of that method, a value of half the LDC was assigned.

Changes in nutrient concentrations in stream water may occur by dilution or by transformations and transfers between the water and the stream sediments, its organisms, or the atmosphere. Rates of removal of nutrients from the effluent were distinguished from simple dilution by comparing nutrient changes downstream of the outfall to changes in chloride concentration, a conservative property. Decreases in chloride concentration of the effluent were attributed to dilution by water from tributaries or base flow with the same concentration

as the upstream, unimpacted water at the "control" station. Net nutrient removal, after correction for dilution, included physical, chemical, and biological retention as well as losses of nitrogen to the atmosphere. Nutrient removal was calculated following the methods of Kuenzler (1987). The amount of nutrient removed from the water was estimated by comparing the measured nutrient concentration in effluent to the calculated concentration (corrected for dilution) at each downstream station. The fraction remaining, (FR_i), of effluent chloride concentration at a downstream Station i was:

$$FR_i = ([Cl_i]-[Cl_u]) / ([Cl_e]-[Cl_u]) \quad (1)$$

where $[Cl_i]$, $[Cl_u]$, and $[Cl_e]$ are the chloride concentrations of Station i, the upstream station, and the effluent, respectively.

Net changes in wastewater nutrients below the outfall were calculated using the chloride concentration changes. Assuming that each effluent nutrient was diluted to the same extent as the chloride, a predicted nutrient concentration, $[N_i]_{pred}$, at downstream Station i was calculated:

$$[N_i]_{pred} = (FR_i*[N_e]_{meas}) + ((1-FR_i)*[N_u]_{meas}) \quad (2)$$

where $[N_e]_{meas}$ and $[N_u]_{meas}$ were the measured nutrient concentrations of the effluent and at the upstream station, respectively. The difference between the measured and the calculated nutrient concentrations, $D[N_i]$, represents the net amount removed from, or added to, the water by the wetland-stream system:

$$D[N_i] = [N_i]_{meas} - [N_i]_{pred} \quad (3)$$

The nutrient change at each downstream station i was divided by FR_i to estimate the concentration if dilution had not occurred, and this was divided by the measured effluent concentration to obtain a percentage of the sewage nutrient change, SNC(%):

$$SNC(\%) = (100)*(D[N_i]/FR_i)/[N_e]_{meas} \quad (4)$$

Calculations were modified where a partially diluted wastewater flow joined another tributary. For example, nutrient removals below Station BC4 (Fig. 3) used the BC4 chloride concentration as $[Cl_e]$ to calculate FR_i (Eq. 1) and the BC4 nutrient concentration as $[N_e]$ to calculate SNC(%) instead of the effluent chloride and nutrient concentrations. Furthermore, the chloride and nutrient concentrations of this new tributary (as measured at BC9) were used as $[Cl_u]$ and $[N_u]$, respectively, to calculate $[N_i]_{pred}$ (Eq. 2) and SNC(%) (Eq.4) instead of the concentrations above the outfall at BC1.

Nutrient changes at these downstream stations are, then, the percentage changes of all nutrients in the stream in excess of the concentrations in the tributary dilution water. For stations below the confluence of Canal Creek and Deep Creek (Station DC6), the chloride and nutrient concentrations of Stations DC7 and DC7.5 were weighted on the basis of watershed areas, about 39 and 31 km^2, respectively, for use in Equations 1 and 2.

Calculations of sewage nutrient change (SNC) were not done at stations where (1) FR_i was between 0.05 and -0.05 because small errors in analyses, especially where concentrations are low, make large differences. Furthermore, division by numbers near zero in the calculation of SNC result in very large, sometimes anomalous results. Nor were calculations of SNC performed when concentration of the nutrient was below the analytical sensitivity (LDC) of the method at the effluent station or the station just below the confluence with a new tributary (*e.g.*, Stations BC4 or DC6). Results are presented as medians 95% C.I. (McGill *et al.* 1978). Nutrient changes at downstream stations were not considered significantly different from zero if the median value did not exceed the 95% confidence interval.

RESULTS

EXTENSIVE STUDY SITES

Comparison of Effluent to Upstream Water Quality.

Chloride concentrations were higher in wastewater effluent (averaging 20.4 to 49.6 mg Cl/L) than in the receiving stream above the outfall (averaging 10.3 to 19.1 mg/L)(Table 4). Although each station was sampled only four times during the year, there was no overlap between chloride concentrations of effluents and those of receiving streams. The effluent contained two-to-five times higher levels of chloride than did the stream water at all stations except Big Foot Creek and Thompson Swamp. Nitrate concentrations in the stream waters were generally low (<0.75 mg N/L), except for Cherry Tree Branch (2.75 mg/L). The effluents showed widely varying mean nitrate concentrations, from 0.27 mg/L in the Clarkton effluent entering the tributary to Big Foot Creek to 19.5 mg/L being discharged to the low-nitrate Cashie River. This large variability makes it difficult to generalize about nitrate impacts on receiving waters. Mean ammonium concentrations in each of the receiving waters also varied about one order of magnitude, from 0.05 to 0.44 mg N/L (Table 4); individual samples varied from undetectable values to about 1.5 mg/L (Appendix C). The treatment plants were variably effective in removing ammonium, releasing mean concentrations of 2-7 mg N/L at Clarkton, Pink Hill, and Enfield whereas the mean concentrations were undetectable in LaGrange and Walstonburg effluents. Finally, mean phosphate concentrations ranged from 0.02 to 0.10 mg P/L in the receiving streams, but were much higher (0.41-1.54 mg/L) in the effluents (Table 4). Phosphate measurements on each sampling date showed effluent concentrations averaging about 15 times higher than those of the receiving stream.

Downstream Changes in Conductivity, Chloride, and Nutrients.

Results from the LaGrange site illustrate the general patterns of changes in conductivity and chloride concentrations at the extensive sites. Wastewater effluent usually had much higher solute concentrations, including chloride, than the upstream, control stations. Dilution of the effluent by Mosely Creek water from above, and to a lesser extent from tributaries below, the outfall is clearly evident in the chloride concentrations (Fig. 3). The patterns of change in conductivity (not shown) and chloride were generally very similar, showing the importance of chloride as a major anion and the relatively conservative nature of both parameters.

Table 4. Comparison of chloride, nitrogen, and phosphate concentrations at upstream and wastewater effluent stations of the extensive study. Most stations were sampled four times.

Station	Station Code	Chloride Mean	Chloride S.D.	Nitrate Mean	Nitrate S.D.	Ammonium Mean	Ammonium S.D.	Phosphate Mean	Phosphate S.D.
Big Foot Creek	CL3	19.1	2.2	0.40	0.04	0.11	0.07	0.02	0.01
Clarkton effluent	CL1	27.9	4.9	0.27	0.06	2.31	0.32	0.41	0.18
Mosely Creek	LG1	12.8	1.3	0.32	0.50	0.44	0.62	0.08	0.10
LaGrange effluent	LG2	27.8	4.9	11.91	1.70	0.004	0.003	1.54	0.40
Cherry Tree Branch	PH1	11.3	0.5	2.75	0.09	0.06	0.03	0.03	0.01
Pink Hill effluent	PH2	31.4	5.8	1.64	0.86	6.79	3.48	0.96	0.25
Thompson Swamp	WA1	12.9	1.0	0.71	0.47	0.05	0.07	0.07	0.04
Walstonburg effluent	WA2	20.4	1.9	8.20	3.93	0.003	0.001	0.84	0.75
Bynum Mill tributary	MA1	14.0	3.2	0.72	0.40	0.21	0.17	0.10	0.05
Macclesfield effluent	MA2	36.7	4.8	9.68	3.55	0.15	0.25	1.22	0.59
Cashie River	LW1	10.3	1.0	0.10	0.17	0.09	0.11	0.08	0.06
Lewiston-Woodville effl.	LW2	49.6	14.9	19.50	11.44	0.20	0.20	1.28	0.91
Burnt Coat Swamp	EN1	10.6	1.4	0.30	0.20	0.08	0.11	0.05	0.03
Enfield effluent	EN2	31.6	6.2	2.10	0.92	5.62	2.88	0.73	0.41

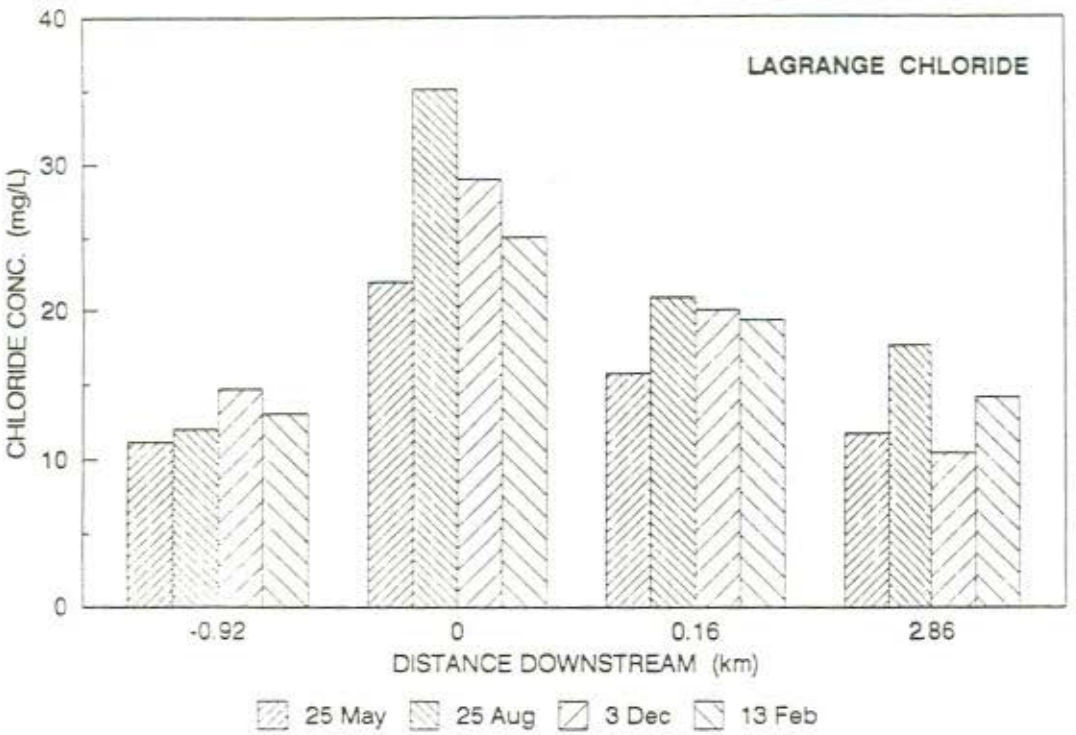

Figure 3. Chloride concentrations in Mosely Creek above and below the LaGrange outfall.

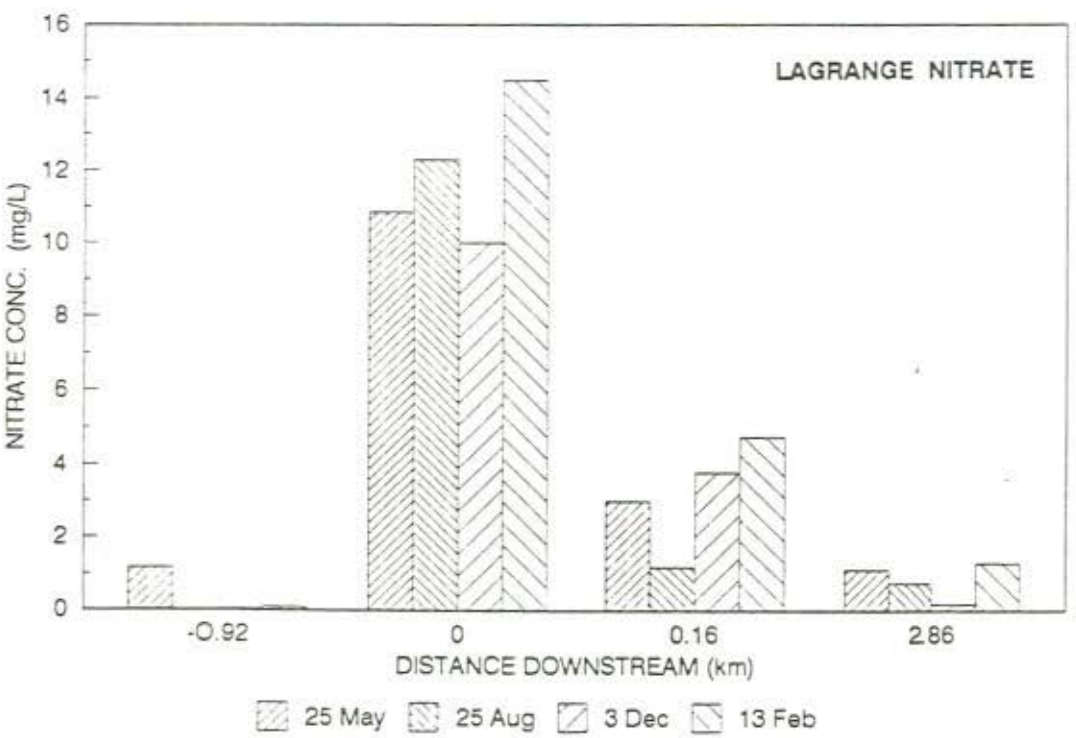

Figure 4. Nitrate concentrations in Mosely Creek above and below the LaGrange outfall.

The patterns of nitrate and phosphate change at Mosely Creek (Fig. 4, 5) resembled those of chloride (Fig. 3). Nutrient concentrations generally were low in water from upstream and tributary stations, were markedly incremented by effluents, but then declined rapidly below the outfall. The much greater relative decrease in nitrate than in chloride concentration below the outfall (Fig. 4, 3) cannot be explained by dilution, but is attributable to net nitrate removal. Ammonium concentrations were lower in the LaGrange effluent (Fig. 6) than in Mosely Creek and were low relative to stream water. The concentrations below the outfall increased partly because of dilution with richer stream water, but ammonification of sewage organic N and dissimilatory reduction of some of the abundant nitrate probably contributed significantly to net ammonium increases.

INTENSIVE STUDY SITES

Hydrology and Dissolved Oxygen

Although measurements of water depth and stream discharge at Bridgers Creek and Deep Creek were not made on most sampling trips, there were clear seasonal changes at each site. Stream discharges were least during the warm period (about July to October) and sometimes ceased, for example in June-October 1989 at Bridgers Creek (Fig. 7). At Deep Creek, even the effluent occasionally seeped and evaporated away entirely between DC6 and DC9 in summer and fall. The shallow waters at these times were very difficult to sample without entraining soil particles. Dissolved oxygen data are missing on some dates because of meter malfunction or lack of water (Appendix Table E, F). There was, however, a pattern of low dissolved oxygen concentrations in the warm seasons as illustrated at Bridgers Creek (Fig. 8).

Effluent and Tributary Chloride Concentrations.

At both intensively studied sites, large amounts of chloride and nutrients were added by wastewater to the wetland streams. The median chloride concentration in Rich Square effluent (BC2) over a 20-month period was 29.2 mg/L. This was about twice the median for the initial dilution water (BC1) but more than 3 times greater than in the main stream of Bridgers Creek at Station BC9 (8.3 mg/L; Table 5). The chloride concentrations decreased downstream from BC4 to BC10 in proportion to the excess of dilution over evaporation, although the large confidence intervals indicate considerable temporal variability at each station (Table 5). The large variablity is clearly evident when the temporal changes are plotted (Fig. 9). Furthermore, cloride was often less concentrated in the effluent (BC2) than at BC1, suggesting pollution of this ditch

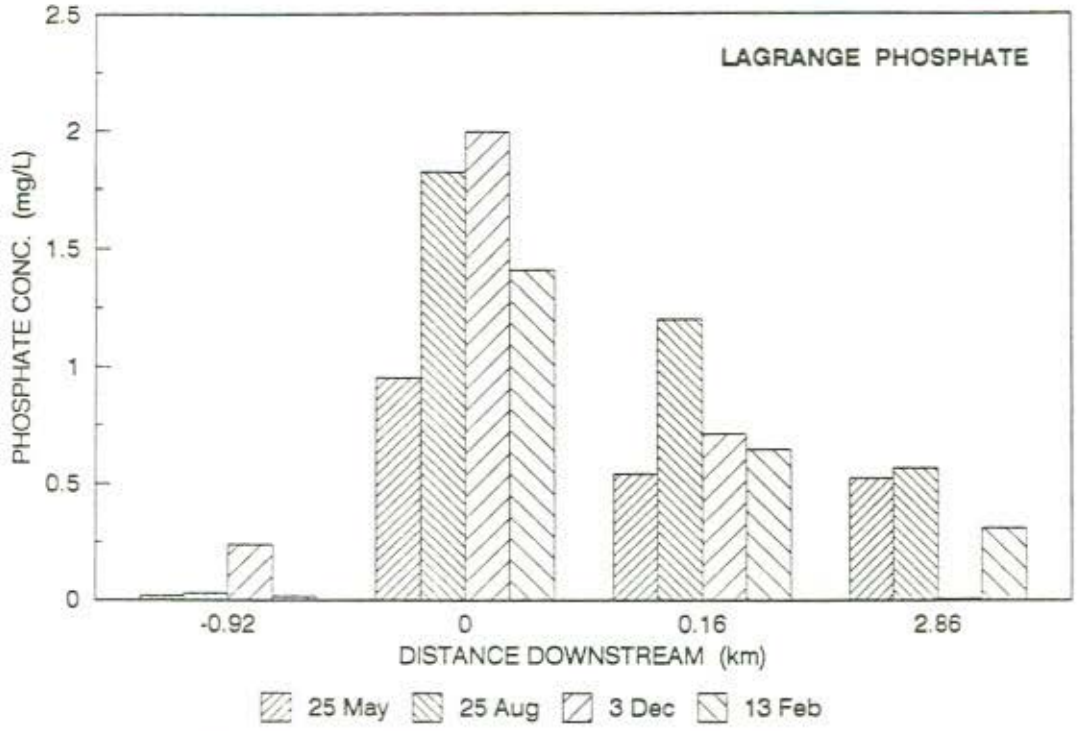

Figure 5. Phosphate concentrations in Mosely Creek above and below the LaGrange outfall.

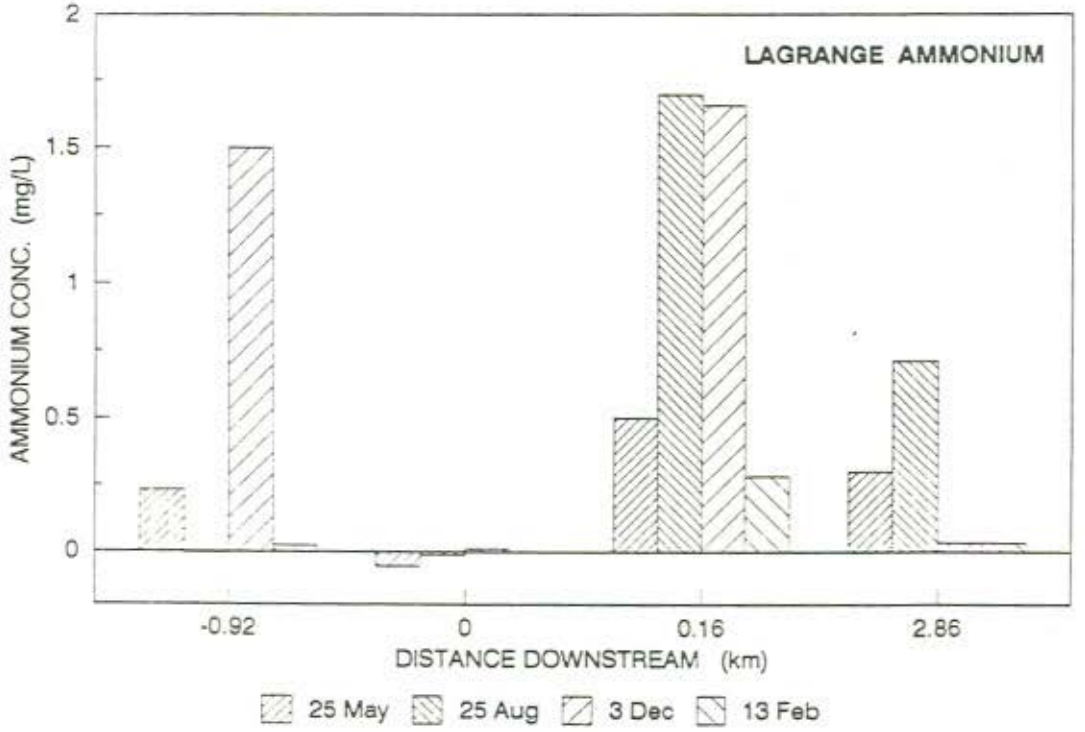

Figure 6. Ammonium concentrations in Mosely Creek above and below the LaGrange outfall.

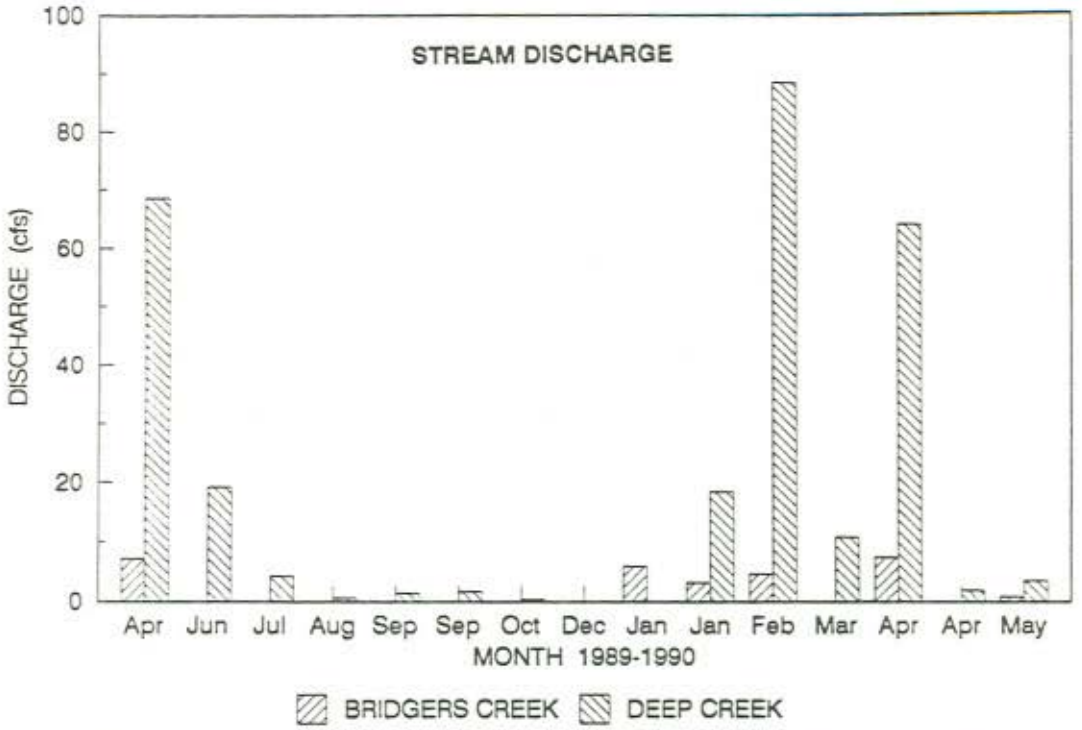

Figure 7. Stream discharges at Bridgers Creek Station BC5 and Deep Creek Station DC9.

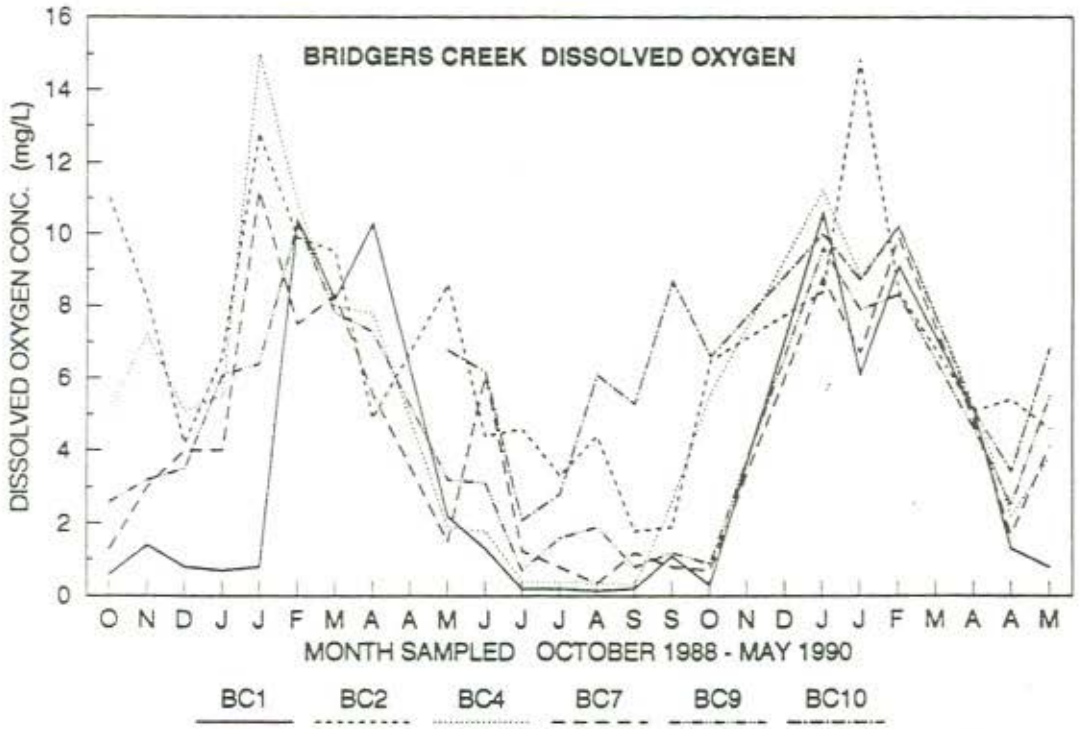

Figure 8. Seasonal and spatial variation in dissolved oxygen in Bridgers Creek. The stations are described in the text.

Table 5. Chloride and nutrient concentrations (median ± 95% C.I.) at the main Bridgers Creek and tributary stations (Oct 88 - May 90). Distances are measured from the wastewater outfalls.

Station	Distance (km)	n	Chloride (mg/L)	Nitrate (mg/L)	Ammonium (mg/L)	Total N (mg/L)	Phosphate (mg/L)	Total P (mg/L)
				Tributary Stations				
BC1	-0.084	24-26	13.9 ± 8.0	0.054 ± 0.021	0.87 ± 0.71	2.65 ± 1.30	0.237 ± 0.567	0.53 ± 0.79
BC9	-0.630	25-26	8.3 ± 1.6	0.077 ± 0.036	0.08 ± 0.04	1.47 ± 0.53	0.081 ± 0.017	0.24 ± 0.10
				Effluent and Downstream Stations				
BC2	0.000	23-26	29.2 ± 3.1	0.050 ± 0.034	3.21 ± 1.07	11.54 ± 2.27	0.677 ± 0.184	1.96 ± 0.33
BC4	0.098	25-26	23.5 ± 5.3	0.057 ± 0.057	2.84 ± 1.38	6.74 ± 1.94	0.573 ± 0.264	1.15 ± 0.44
BC5	0.200	25-26	16.9 ± 6.1	0.063 ± 0.023	1.93 ± 1.39	3.46 ± 2.20	0.557 ± 0.243	1.24 ± 0.52
BC6	0.291	25-26	18.5 ± 6.8	0.063 ± 0.029	2.02 ± 1.42	3.05 ± 1.98	0.381 ± 0.239	1.11 ± 0.50
BC7	0.405	25-26	17.9 ± 6.0	0.051 ± 0.031	1.46 ± 1.35	3.34 ± 1.77	0.421 ± 0.210	0.89 ± 0.44
BC8	0.562	24-25	16.5 ± 6.0	0.088 ± 0.035	1.78 ± 1.12	2.30 ± 2.11	0.341 ± 0.213	0.62 ± 0.36
BC10	3.750	17-18	11.6 ± 1.9	0.475 ± 0.084	0.049 ± 0.074	1.70 ± 0.42	0.137 ± 0.022	0.22 ± 0.12

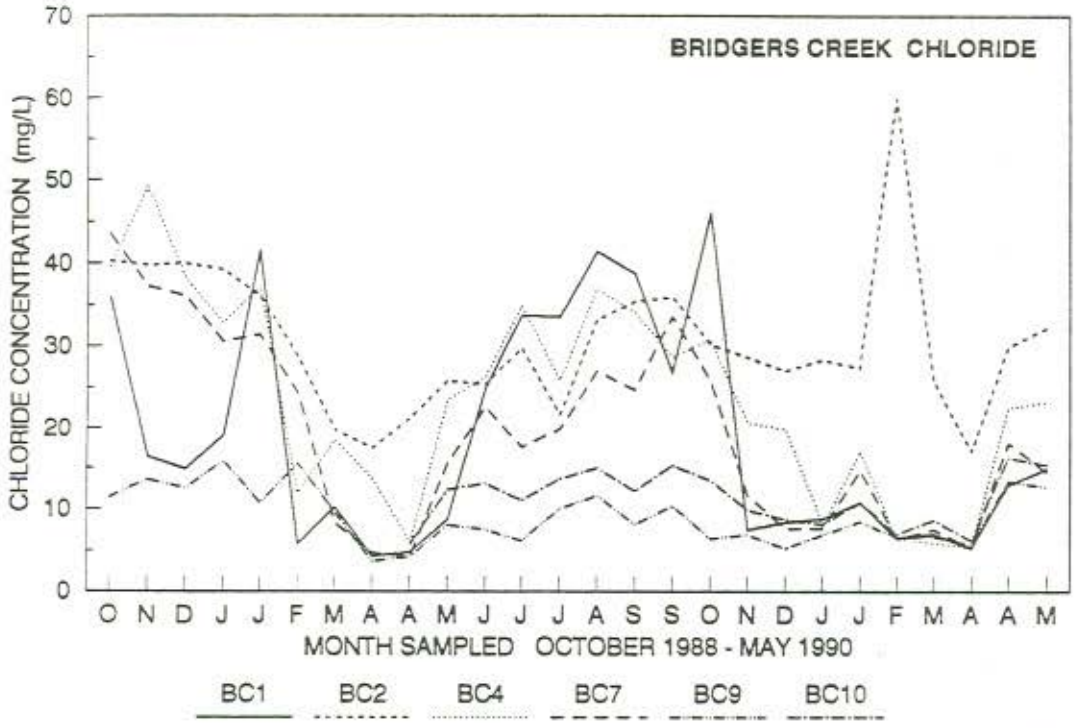

Figure 9. Seasonal and spatial variation in chloride concentration in Bridgers Creek. The stations are described in the text.

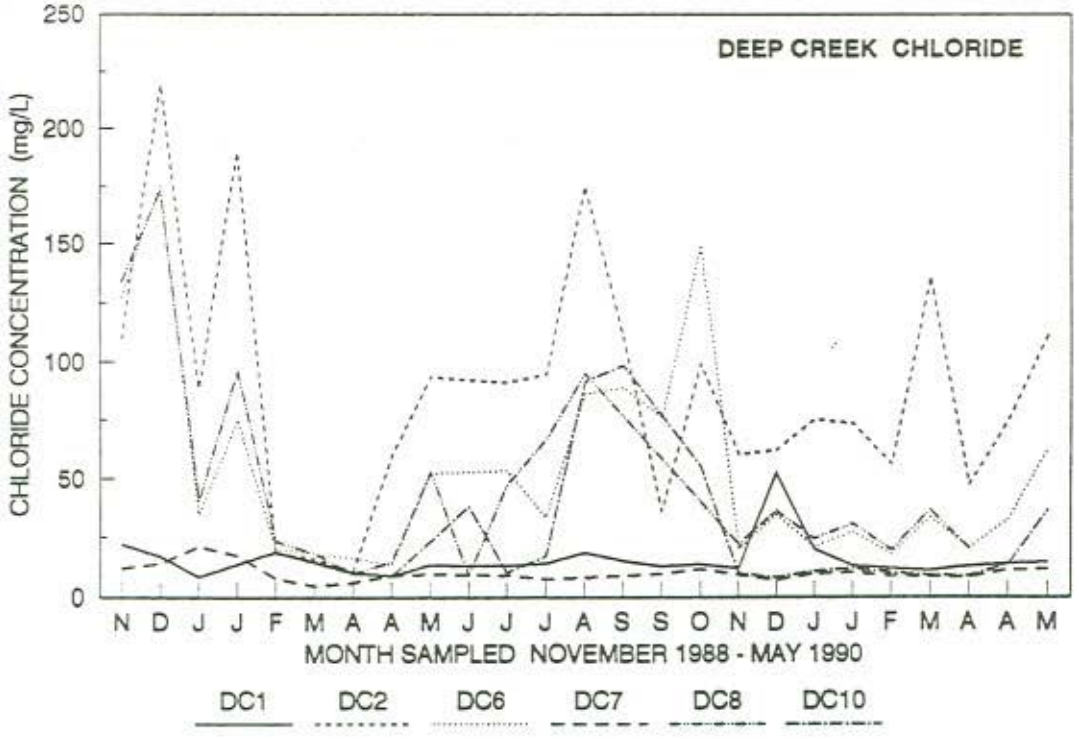

Figure 10. Seasonal and spatial variation in chloride concentration in Deep Creek. The stations are described in the text.

above the outfall. Station DC2 usually had chloride levels in the range of about 20-40 mg/L. The chloride concentrations at all stations generally declined during the cool, wetter seasons, except in the effluent during the last third of the study (Fig. 9). Except in late winter, Bridgers Creek upstream at Station BC9 tended to be lower in chloride than BC4, providing a basis for assessing the amount of dilution of the waste stream below BC4. There was, however, little apparent dilution between BC5 and BC8, but substantial decrease in chloride concentration between BC8 and BC10.

The effluent of the Scotland Neck treatment plant (BC2) during the nineteen month sampling period was even richer in chloride (median 89 mg/L; Table 6) than that of Rich Square. It was about 6.5 times as concentrated as the dilution water of Canal Creek (Station DC1). The two major upstream branches of Deep Creek (Stations DC7 and DC7.5) had low and relatively constant chloride concentrations near 10 mg/L, (Table 6). There was a general pattern of decreasing median chloride concentrations downstream of the outfall, down to about 11 mg/L at DC10. The 95% C.I. at each station, however shows large temporal variability (Table 6) depending on the vagaries of stream mixing in the channel and on the floodplain and on variations in precipitation and evapotranspiration. The temporal pattern of chloride at Deep Creek was variable but somewhat less erratic than at Bridgers Creek (Fig. 10). The effluent (DC2) usually contained more chloride than any other station. The diluting waters of Canal Creek (DC1) and at Station 7 upstream on Deep Creek usually had the lowest chloride concentrations. The concentrations at DC6 where Canal Creek fans out onto Deep Creek floodplain usually showed evidence of some dilution, but exceeded the effluent concentrations on two dates in September and October 1989 (Fig. 10).

Seasonal and Spatial Distributions of Nutrients in Bridgers Creek

The nitrate and phosphate concentrations in Rich Square effluent were relatively low (Table 5), presumably because of efficient removal in the lagoon. The median annual concentration of phosphate was <1 mg P/L and that of nitrate was <0.1 mg N/L. The relatively high median ammonium and phosphate concentrations at Station BC1 suggested that this ditched branch had already received pollution from Rich Square above the lagoon outfall. During dry weather, BC1 may also have been impacted by wastewater which backed up into the branch. The median nitrate concentration of the Rich Square lagoon effluent at Station BC2 (0.050 mg/L) was not significantly different from that of tributary stations BC1 and BC9, and concentrations did not change significantly downstream

Table 6. Chloride and nutrient concentrations (median ± 95% C.I.) at the main Deep Creek and tributary stations (Nov 88 - May 90). Distances are measured from the wastewater outfalls.

Station	Distance (km)	n	CHLORIDE (mg/L)	NITRATE (mg/L)	AMMONIUM (mg/L)	TOTAL N (mg/L)	PHOSPHATE (mg/L)	TOTAL P (mg/L)
				Tributary Stations				
DC1	-0.075	24-25	13.6 ± 0.7	1.44 ± 0.45	0.084 ± 0.104	2.40 ± 0.30	0.094 ± 0.036	0.12 ± 0.06
DC7	-5.800	23-24	9.4 ± 1.1	0.16 ± 0.07	0.15 ± 0.11	1.56 ± 0.42	0.068 ± 0.043	0.23 ± 0.10
DC7.5	-5.380	17-18	10.1 ± 1.2	0.44 ± 0.14	0.23 ± 0.10	1.66 ± 0.17	0.14 ± 0.08	0.44 ± 0.16
				Effluent and Downstream Stations				
DC2	0.000	24-25	89.0 ± 15.7	6.71 ± 2.13	0.13 ± 0.29	11.43 ± 1.99	1.69 ± 0.42	2.86 ± 0.72
DC4	0	12-14	48.8 ± 27.5	5.30 ± 2.26	0.24 ± 0.50	7.13 ± 3.05	0.70 ± 0.45	1.24 ± 0.77
DC5	0.220	24-25	46.1 ± 18.2	5.57 ± 1.46	0.19 ± 0.13	7.35 ± 1.72	0.80 ± 0.31	1.29 ± 0.57
DC6	0.308	24-25	34.1 ± 17.8	5.14 ± 1.35	0.26 ± 0.15	7.46 ± 1.26	0.66 ± 0.37	1.20 ± 0.44
DC8	0.500	19-20	33.7 ± 13.9	3.60 ± 1.43	0.43 ± 0.43	5.83 ± 2.00	0.67 ± 0.22	1.31 ± 0.44
DC9	0.700	19-20	20.1 ± 16.9	0.698 ± 1.22	0.16 ± 0.11	3.01 ± 1.79	0.35 ± 0.30	0.66 ± 0.55
DC10	1.260	15-16	11.3 ± 11.0	0.38 ± 0.97	0.08 ± 0.04	1.64 ± 1.26	0.16 ± 0.21	0.49 ± 0.32

except for a large increase 3.75 km below the outfall at Station BC10 (Table 5). The source of this nitrate input above BC10 is unknown. There was far more ammonium (median = 3.21 mg/L) than nitrate in the effluent. Ammonium constituted about 28% of the median total N; organic N presumably was important in the lagoon. Median concentrations showed a decrease in ammonium to BC8, then a dramatic decrease at BC10, the station where nitrate increased 5 fold. Median concentrations of ammonium, phosphate, total N, and total P at Station BC10 resembled those in the tributary dilution water at Station BC9 (Table 5).

The seasonal patterns of nutrient concentration at Bridgers Creek (Fig. 11-15) showed much of the variability seen in the chloride values (Fig. 9), although there seemed to be more internal consistency in the data. For example, chloride and all nutrients forms showed a large peak in late January 1989. Nitrate levels at Stations BC1, BC2 and BC4 were relatively erratic during most of the study period (Fig. 11). With a few exceptions, nitrate and ammonium in the effluent (Station BC2) were not higher than all other stations. Except at the most downstream station (BC10), nitrate concentrations were generally lower during the warm, drier period (May-September) than during the rest of the year.

Not only was ammonium generally much more concentrated than nitrate in the Bridgers Creek system, its temporal distribution was different. Ammonium showed relatively high concentrations down through Station BC7 during late summer and early fall (Fig. 12). The total-N distribution (Fig. 13) reflected that of ammonium, including the sharp peak at BC1 in late January 1989 and the broad peak in late summer-early fall 1990. The relatively high ammonium concentration at Station BC7 in late September 1989 was not an outlier. Total N exceeded 40 mg N/L also at BC5 on September 4 and 24 and on October 15, 1989, and at BC6 on September 24 (not shown). Total-P concentrations were 73.9 and 9.7 mg P/L at Stations BC5 and BC6, respectively, on September 4 and between 18.8 and 11.8 mg/L at BC6 and BC7 on September 24. During this period the stream channel was heavily overgrown with mud plantain (*Heteranthera reniformis*) and other macrophytes; the water was nearly stagnant, very turbid, and low in dissolved oxygen (Fig. 8). Stations BC9 and BC10, above and far below the outfall, respectively, tended to have least total N.

The temporal distributions of phosphate at Bridgers Creek resembled those of ammonium, with highest concentrations often occurring at BC1, especially in late January and through late summer and early fall (Fig. 14). Relatively low phosphate concentrations were found at most stations during the cold season. Stations BC9 and BC10 usually had lowest phosphate

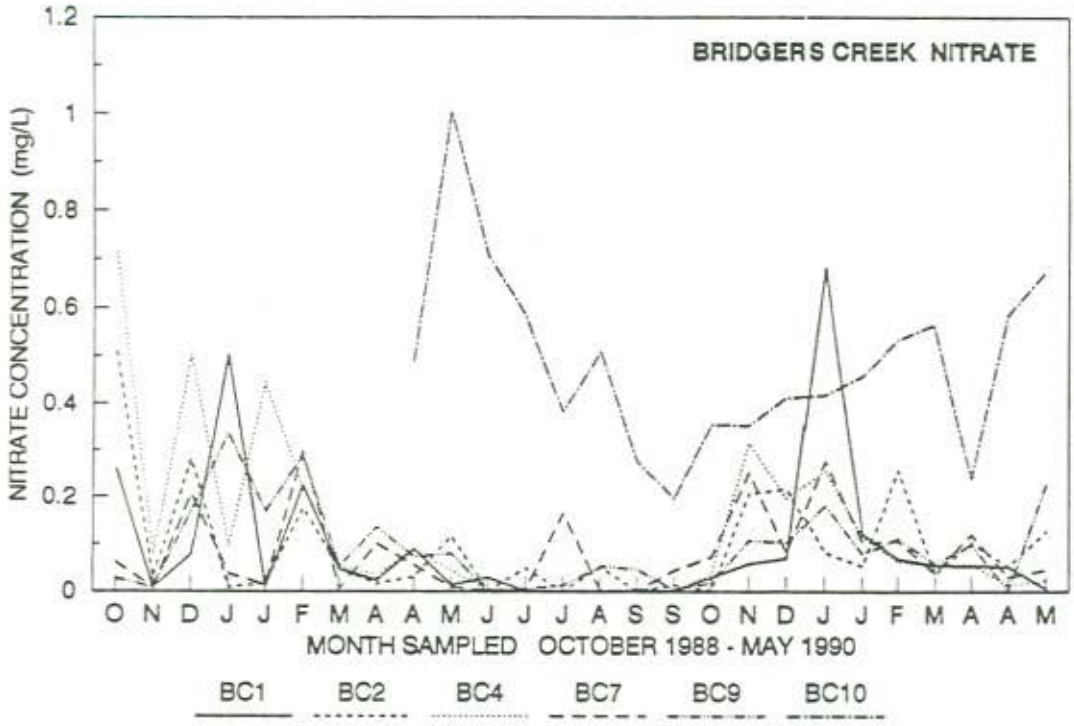

Figure 11. Seasonal and spatial variation in nitrate concentration in Bridgers Creek. The stations are described in the text.

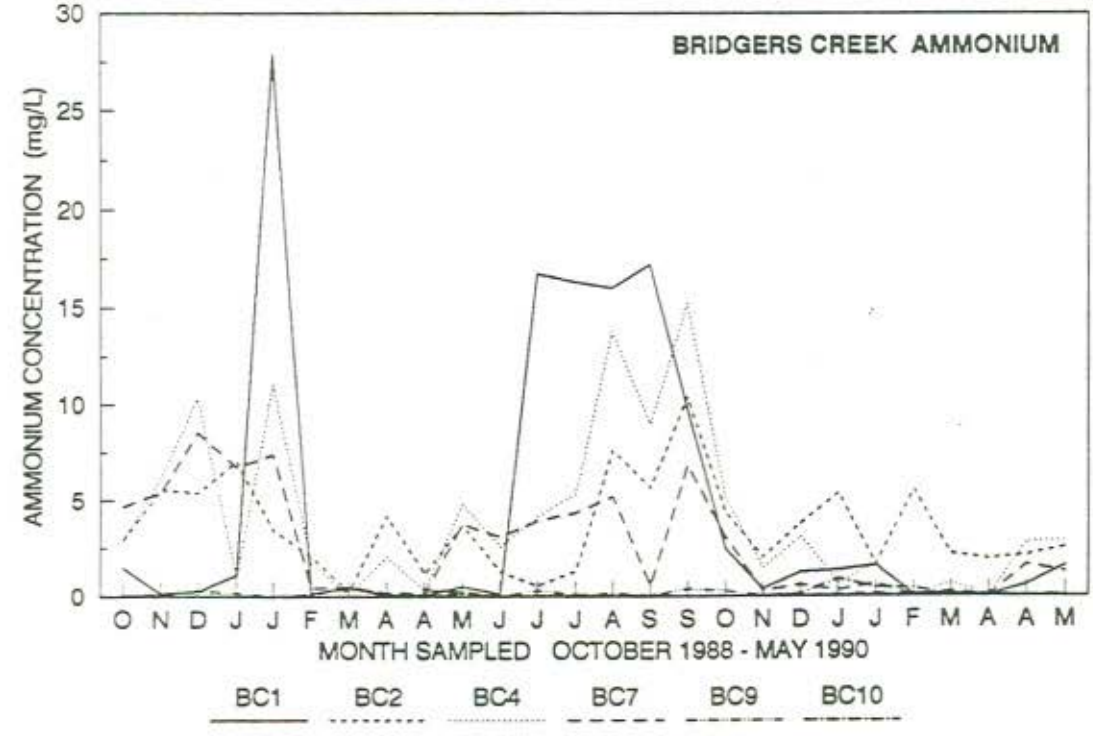

Figure 12. Seasonal and spatial variation in ammonium concentration in Bridgers Creek. The stations are described in the text.

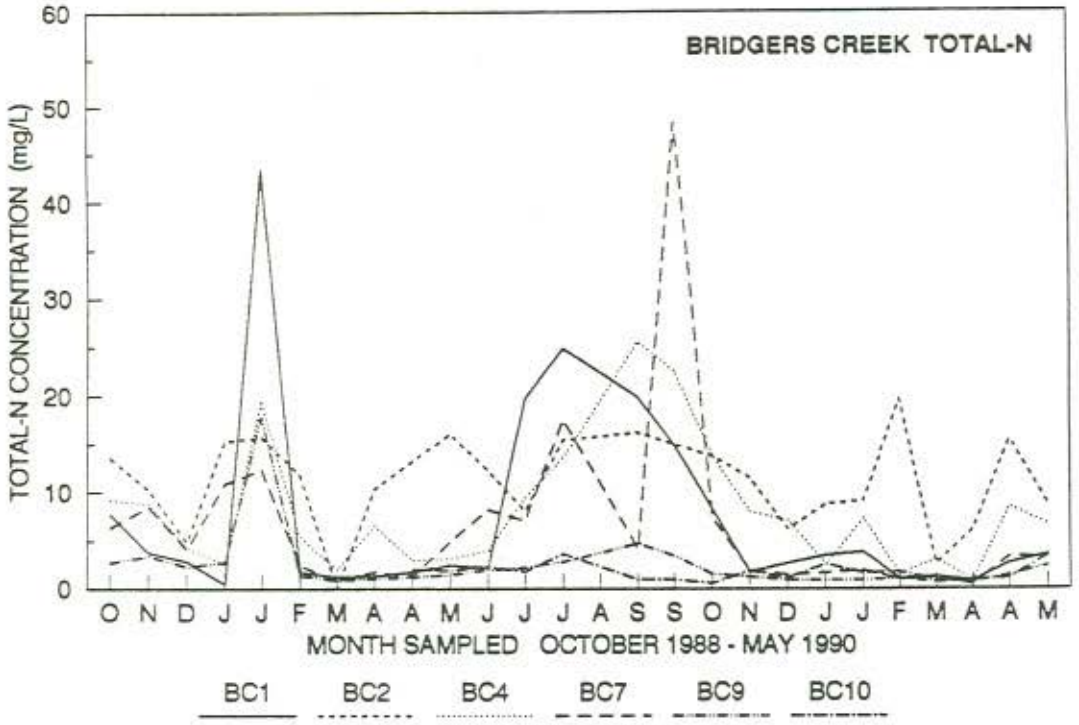

Figure 13. Seasonal and spatial variation in total-N concentration in Bridgers Creek. The stations are described in the text.

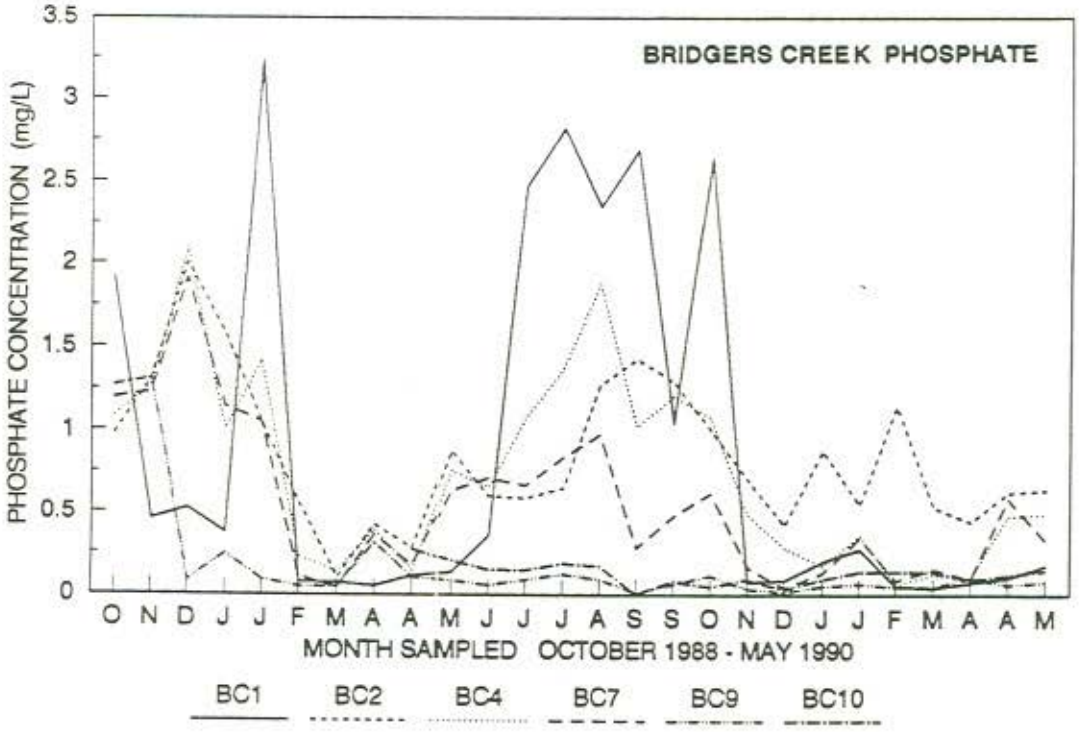

Figure 14. Seasonal and spatial variation in phosphate concentration in Bridgers Creek. The stations are described in the text.

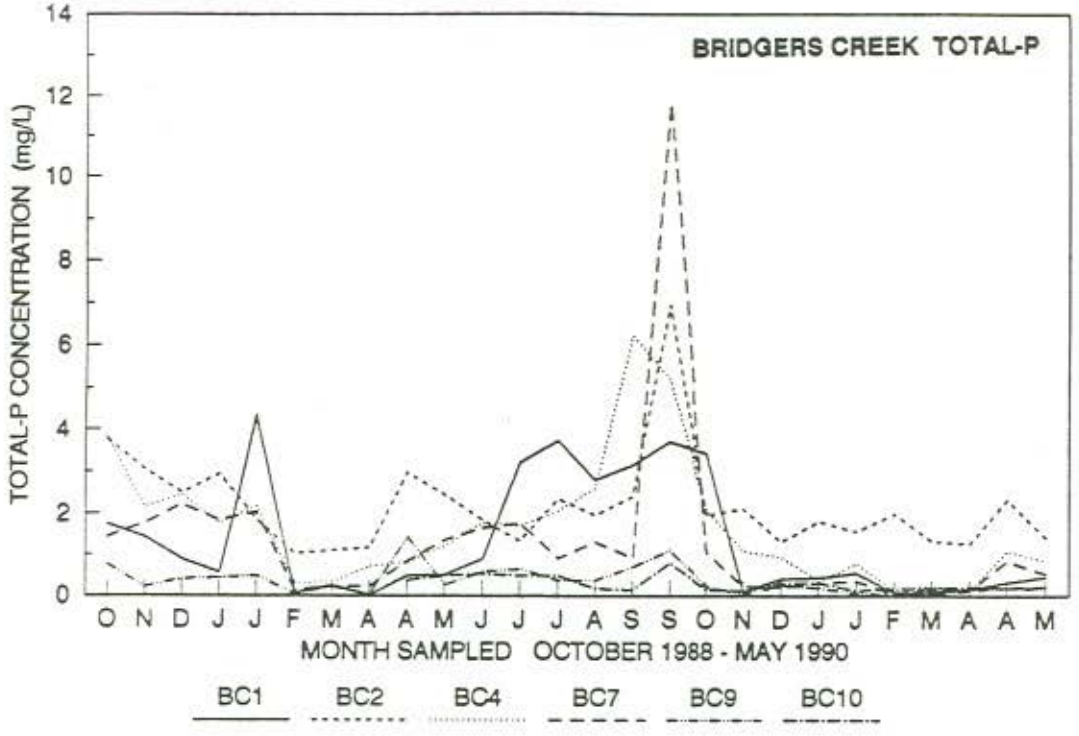

Figure 15. Seasonal and spatial variation in total-P concentration in Bridgers Creek. The stations are described in the text.

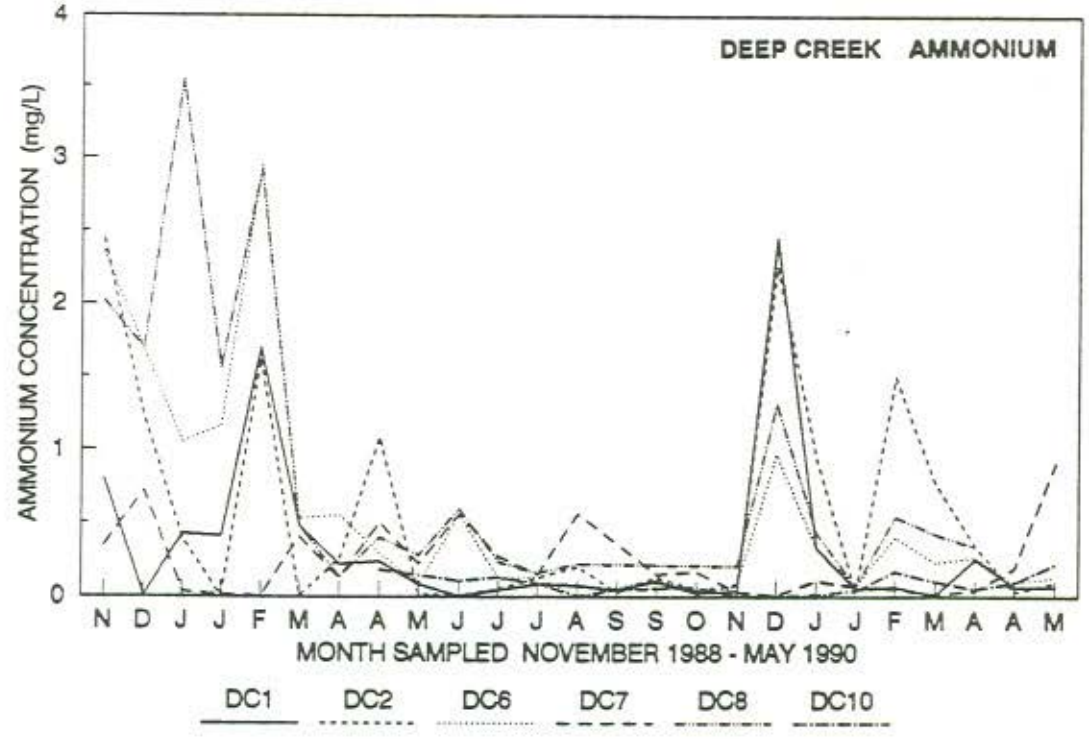

Figure 16. Seasonal and spatial variation in ammonium concentration in Deep Creek. The stations are described in the text.

concentrations. Finally, the total-P distribution roughly reflected the changes in phosphate except for the high peak at Station BC7 on September 24, 1989 (Fig. 15). During the stagnant period mentioned above, total P exceeded 10 mg P/L at BC5 on September 4 and at BC6 and BC7 on September 24 (not shown).

Seasonal and Spatial Distributions of Nutrients in Deep Creek

Mean nutrient concentrations in Scotland Neck effluent (Station DC2) (Table 6), especially nitrate and phosphate, were considerably higher than in Rich Square effluent (Table 5). The relative proportions of effluent nitrate and ammonium were the reverse of those from Bridgers Creek, with nitrate dominating (medians of 6.71 *vs.* 0.13 mg N/L) (Table 6). Median effluent nitrate was about 60% of effluent total N. Median phosphate concentration in the effluent (1.69 mg P/L) was 10- to 25-fold higher than that of tributaries at Stations DC1, DC7, and DC7.5. Nitrate and phosphate concentrations tended to decrease as wastewater nutrients were diluted and removed below the outfall (Table 6). None of the nutrient forms appeared to be significantly different from concentrations at tributary stations DC7 and DC7.5 by the time the stream reached DC10. The net removals of these nutrients will be examined below.

Temporal patterns of nutrients in the Deep Creek system were more consistent than those at Bridgers Creek. Except for ammonium (Fig. 16), the highest nutrient concentrations on each sampling date were usually found at the effluent station DC2 (Fig. 17-20). The tributary stations DC1 and DC7 usually had nutrient concentrations among the lowest of any stations. However, the other tributary station, DC7.5, had a significantly higher median nitrate concentration than Station 7 (Table 6). All nutrient forms showed unusually low concentrations in the effluent and at the downstream stations during the winter-spring period of 1989. A less-distinct minimum was seen in late winter 1990. Except for a decrease of about 1.5 mg/L in median nitrate (Table 6), Station DC8 showed little or no decrease in nitrogen and phosphorus concentrations compared to DC6, suggesting little dilution or uptake over this distance (Fig. 17-20); more rapid decreases occurred below DC8 (Table 6). The final station, DC10, showed its highest seasonal concentrations of nitrate, total N, phosphate, and total P in early fall 1989 and in May 1990 (Fig. 17-20).

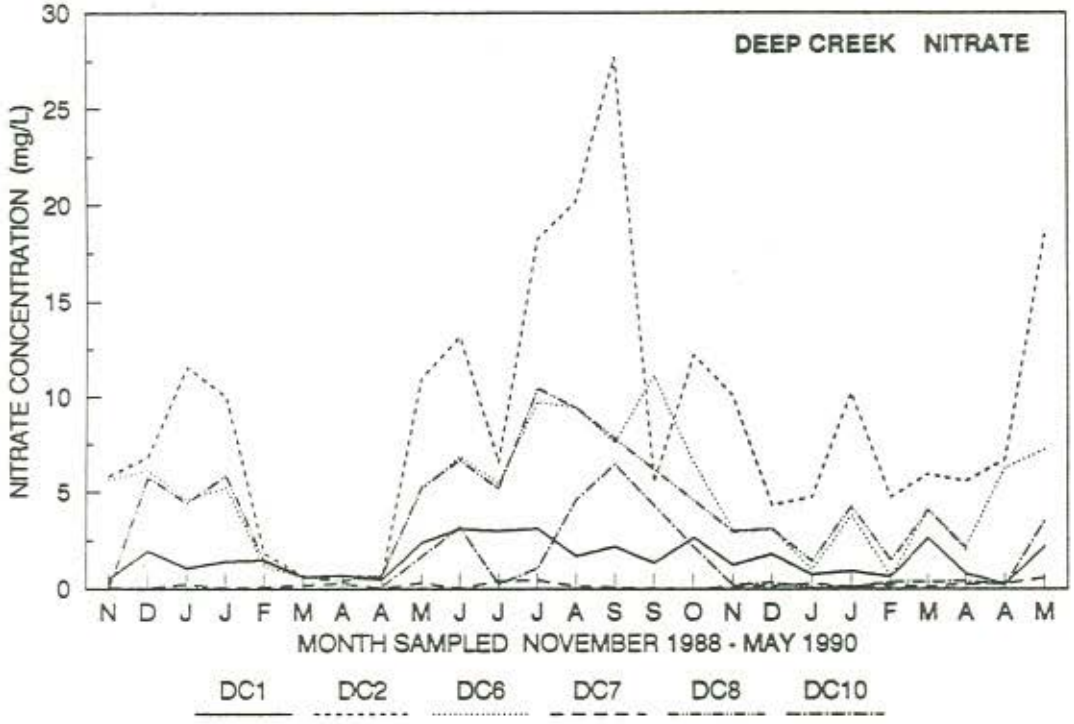

Figure 17. Seasonal and spatial variation in nitrate concentration in Deep Creek. The stations are described in the text.

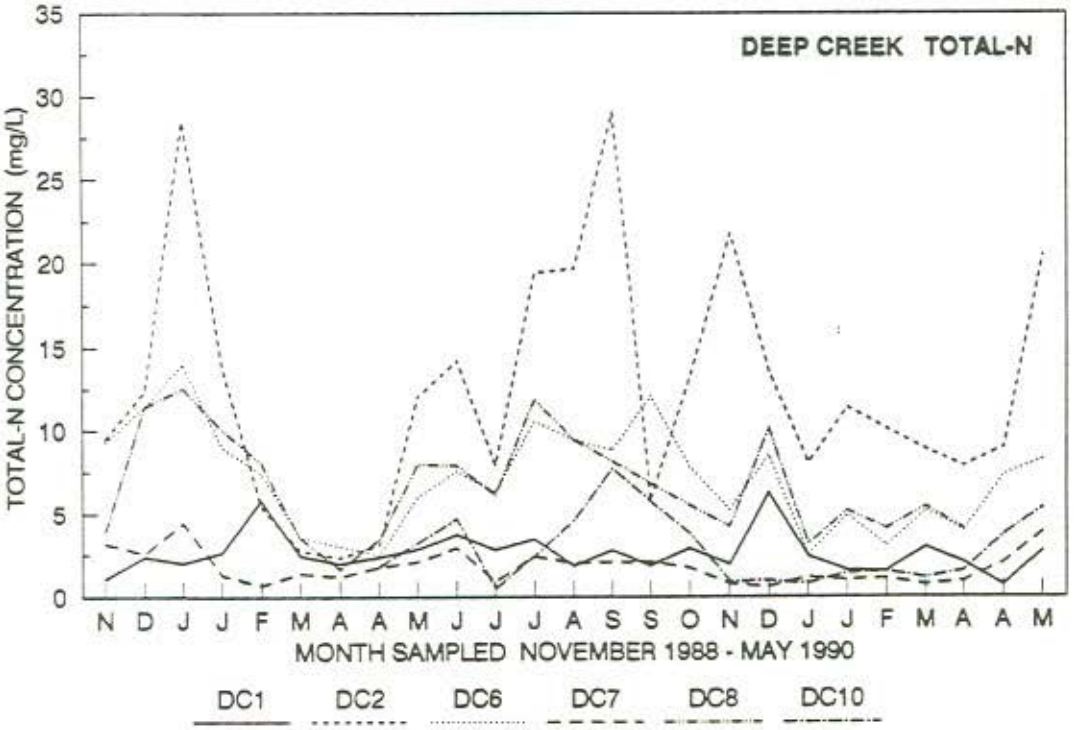

Figure 18. Seasonal and spatial variation in total-N concentration in Deep Creek. The stations are described in the text.

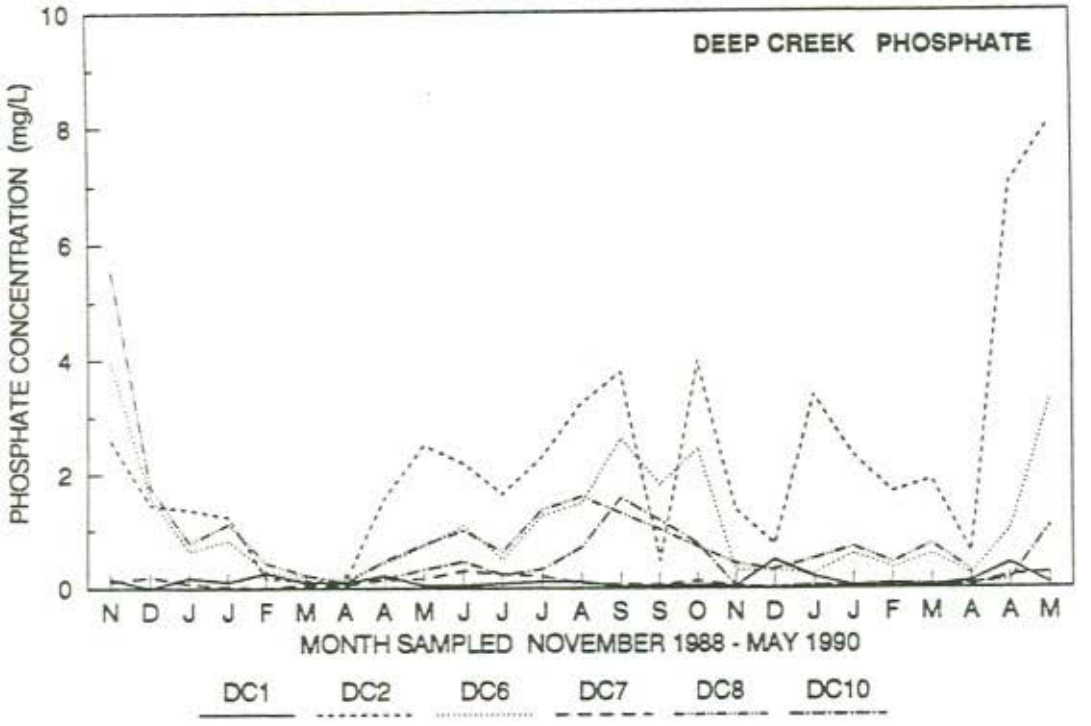

Figure 19. Seasonal and spatial variation in phosphate concentration in Deep Creek. The stations are described in the text.

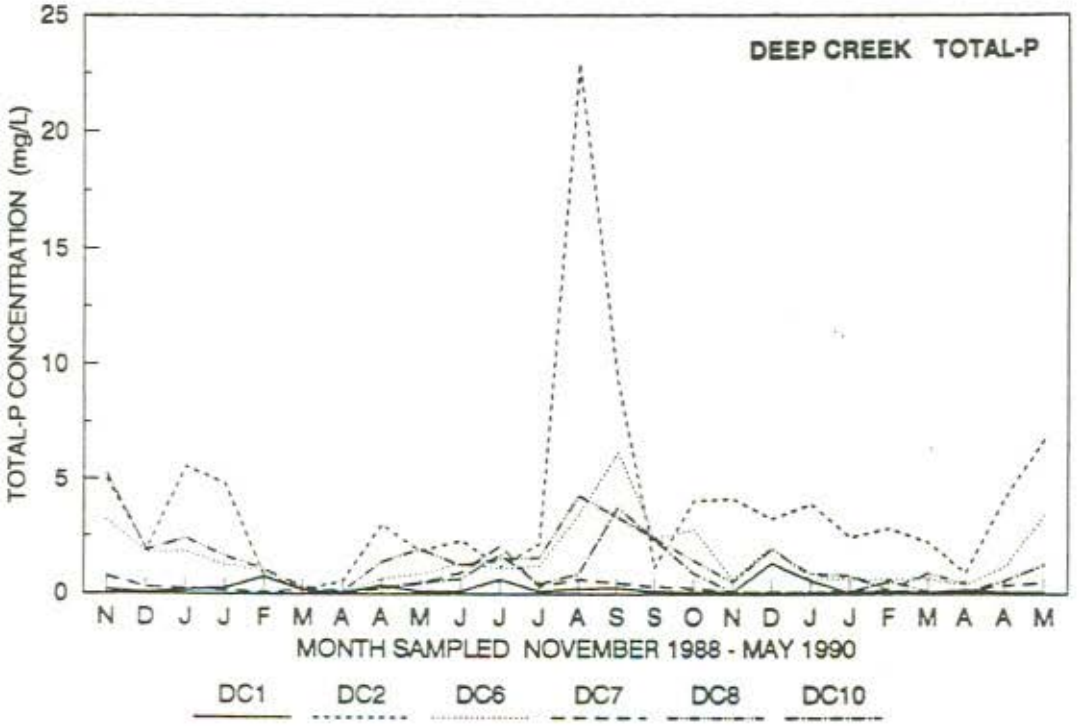

Figure 20. Seasonal and spatial variation in total-P concentration in Deep Creek. The stations are described in the text.

DISCUSSION

CHLORIDE FOR ASSESSING INSTREAM DILUTION

The approach used here for estimating efficiencies of sewage nutrient removal in wetlands was developed by Kuenzler (1987) and used in another study in a North Carolina Piedmont bottomland stream system (Kuenzler *et al.* 1990). The approach assumes that chloride behaves conservatively in the stream and wetland, an assumption supported by its chemical, physical, and biological properties. The assumption was also verified, to a first approximation, by a comparison of a Piedmont stream discharge as measured at a USGS gauging station to its discharge calculated from the rates of upstream sewage discharge and chloride concentrations and the chloride concentrations at that gauging station (Kuenzler, *et al.* 1990).

Use of an in-stream tracer, such as chloride, to estimate dilution is essential where wastewater flow is not constant or is not mixed uniformly across a stream or floodplain. Nutrient removal is interpreted, then, in terms of representative parcels of water sampled from within an imperfectly mixed system. Each parcel of water below an outfall has a different history. The fixed sampling stations along a major channel provide a basis for evaluating the dilution-corrected changes in nutrient concentration of that parcel. Because chloride was used to estimate downstream nutrient dilution in this study, its accurate measurement was important. An error in chloride measurement affects the accuracy of the removal estimate for all nutrient forms at that station on that date. Chloride concentrations were measured in duplicate samples from the effluent and one or two upstream tributary stations. The chloride concentrations were also compared to conductivities at each station to reduce the possibility of erroneous values. In the few cases where the chloride concentration was inconsistent with conductivity, sewage nutrient changes were not calculated.

Wastewater usually contained much higher concentrations of chloride than did local streams. If sewage chloride behaves conservatively, its concentration downstream probably decreases mainly by dilution with water from other tributaries. It is not feasible to find and measure all cryptic sources of base flow and minor tributaries which might have chloride, and nutrient concentrations, different from the major tributaries. Chloride concentrations in N.C. Coastal Plain precipitation have been found to be only about 1 mg/L (Kuenzler *et al.* 1977; Gambell and Fisher 1966), so heavy local showers may cause dilution. Amounts of chloride, however, may also increase downstream due to evapotranspiration or unknown pollutant

sources. Thus there is always some uncertainty as to the accuracy of the estimation of downstream dilution.

The calculation of the dilution correction (Equation 1) was based on the fraction of effluent chloride remaining (FR_i) downstream. When FRI_i was in the range 0 to 1.0, the effluent chloride, $[Cl_e]$, was assumed to have undergone normal dilution with water of the same concentration as that of the upstream tributary. Values of FRI_i <0 resulted when the $[Cl_i] < [Cl_u]$; these values were assumed to result from downstream dilution by waters without chloride or, for the calculation of $D[N_i]$ (Equation 3), without nutrients. Finally, the calculation of SNC (Equation 4) has FRi in the denominator and is therefore very sensitive to values near zero. Accordingly, nutrient change calculations were not performed where FRi was in the range -0.05 to 0.05.

The net changes in nitrate, ammonium, total-N, phosphate, and total-P below wastewater outfalls, as calculated after correcting for dilution, are presented as percentages of their amounts in the effluent. Negative values indicate net removal of this nutrient form from the water whereas positive values indicate an increase in the water from evapotranspiration or from processes within the stream-wetland system. For example, a decrease in nitrate concentration exceeding that resulting from dilution might be attributable to denitrification. An increase in ammonium might be attributable to degradation of organic nitrogen (ammonification) in the water or soil, perhaps accentuated by evaporation during a dry period. A negative 100% indicates that an amount of nutrient equal to that discharged with the effluent was removed. SNC values less than -100% indicate that even more nutrient was removed below the outfall than was discharged in the wastewater; nutrients from the tributary stream waters also had been removed.

NET NUTRIENT CHANGES BELOW OUTFALLS -- EXTENSIVE SITES

Net nutrient removals below wastewater outfalls occurred at several sites and stations of the extensive study. All forms of nitrogen and phosphorus usually showed net removals at Clarkton Station CL4 (Appendix D). Data from Clarkton Station CL2 were omitted from further consideration for lack of an adequate upstream control station. There was also an unusually high Cl:conductivity ratio at CL3 relative to the ratios at all other stations, suggesting a source of salts different from other tributaries. Nitrate usually showed removals at LaGrange, Pink Hill, Macclesfield, and Enfield. Where nitrate was more concentrated than ammonium in the effluent, total N generally reflected the changes in nitrate; this was true at Walstonburg, Macclesfield, and, to a lesser extent, LaGrange, where total N increased downstream in August and December.

Furthermore, ammonium removal efficiencies could not be calculated at LaGrange in May, August, and February, nor at any Walstonburg station in June, October, and December, because effluent concentrations were below the lowest detectable concentration (LDC).

Strong phosphorus removal was not evident at LaGrange; at both stations on most dates, there appeared to be net increases in phosphate and total P downstream. Poor nutrient removals at LaGrange might be attributed to the deep stream channel, relatively narrow floodplain, and large wastewater discharge. The reason for the apparent difference between nitrate and phosphate removal (Appendix D) is not clear. At Pink Hill, there was no clear pattern among net gains to, or losses from, the water at Stations PH3 just 0.1 km below the outfall; further downstream the pattern shifted to one of general net removal from the water. Note that removal efficiencies often could not be calculated, especially at the Lewiston-Woodville site, because FR_i was between 0.05 and -0.05 (Appendix D), causing uncertainty about the accuracy of the Cl-based dilution factor. An earlier, intensive study of the same Cashie River site (Kuenzler 1987), however, did not have these problems and found net removals of both nitrogen and phosphorus. Although net nutrient removals were often observed, these data from the extensive study clearly show a large amount of variability and uncertainty among sites, stations, and nutrient forms.

Data selected from stations on the streams below the Walstonburg, Macclesfield, and Enfield outfalls illustrate the patterns when nitrate and phosphate removals are relatively high. There were small net increments of nitrate to the stream in June at three sites, as much as 36% at EN4 and 163% in March at MA4, but at other times and stations there was net removal of nitrate, mostly in the range of 10% to 100% (Fig. 21). Phosphate also was generally removed from the sewage effluent. Only in June at Station EN4 was there a significant increment to the water; at other times and stations phosphate removals were usually high (Fig. 22). Similarly, the data at these stations indicate a pattern of net removals of total-N and total-P (Fig. 23, 24). Because nitrate and phosphate dominated wastewater total-N and total-P, respectively, large changes in these inorganic species were reflected in the changes in the total N and P forms. Thus total-N and total-P generally were removed below the outfalls.

Ammonium changes at LaGrange and Macclesfield were often dramatic (Appendix D, Fig. 25), sometimes exceeding 1,000 percent increase or decrease in concentration relative to the amount in the effluent. These large relative changes are attributable to the very low concentrations of ammonium in the effluents of LaGrange and Macclesfield and also to its high

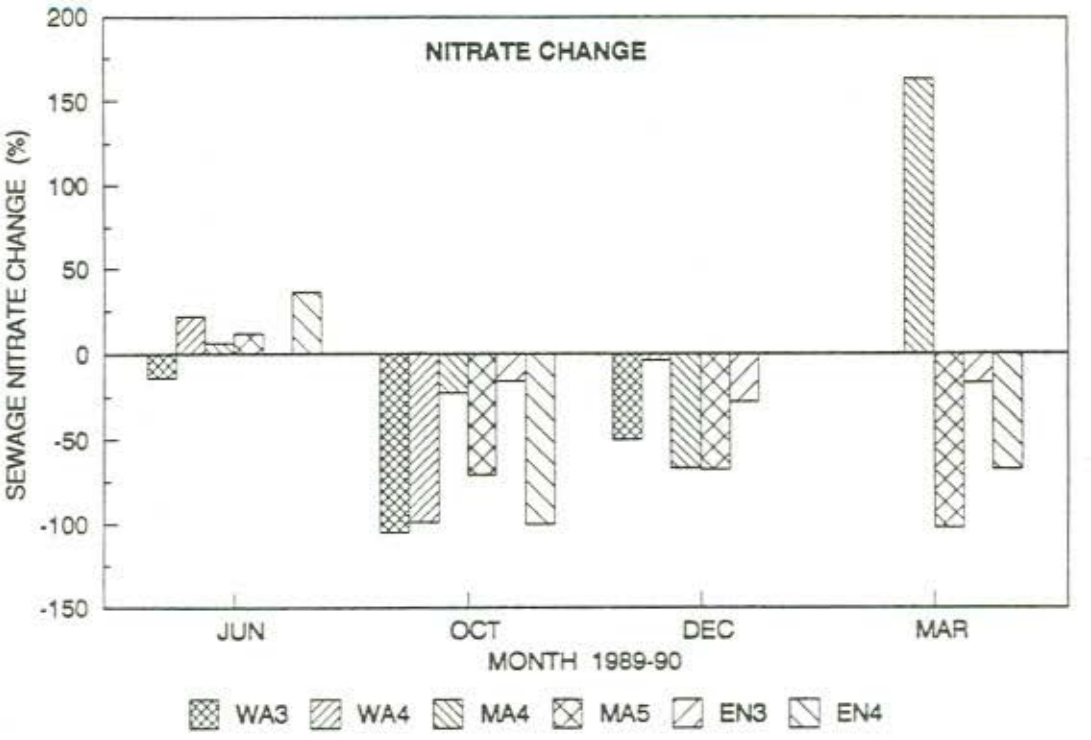

Figure 21. Percentages of sewage nitrate change at stations below Walstonburg (WA), Macclesfield (MA), and Enfield (EN) outfalls.

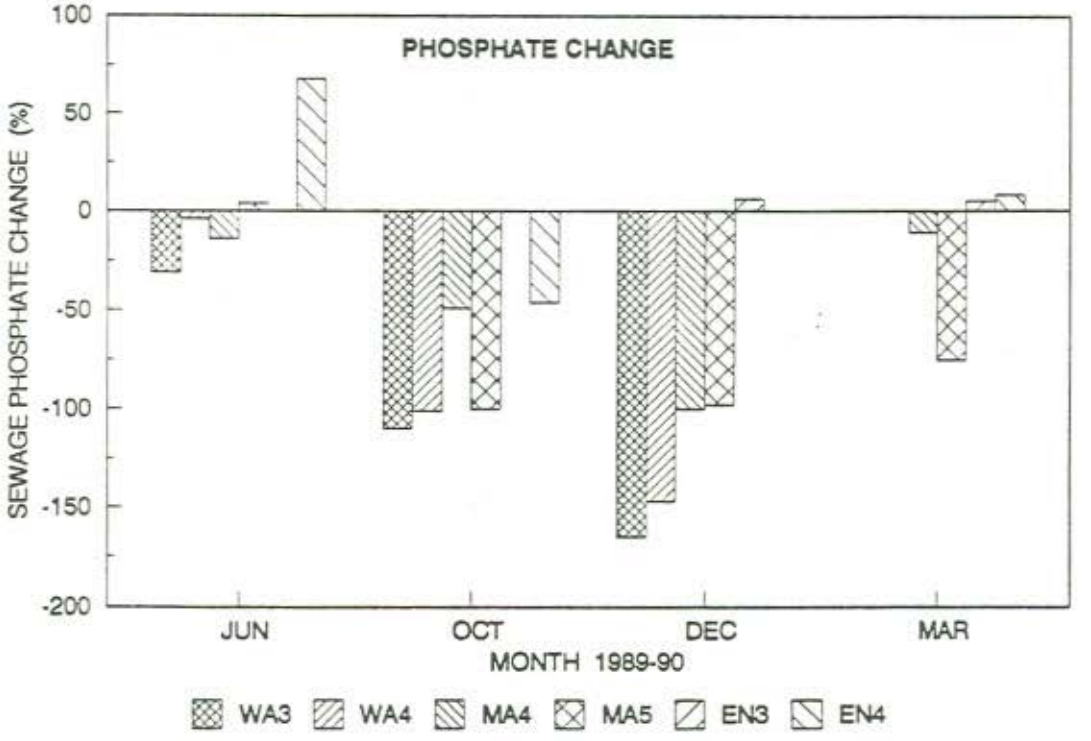

Figure 22. Percentages of sewage phosphate change at stations below Walstonburg (WA), Macclesfield (MA), and Enfield (EN) outfalls.

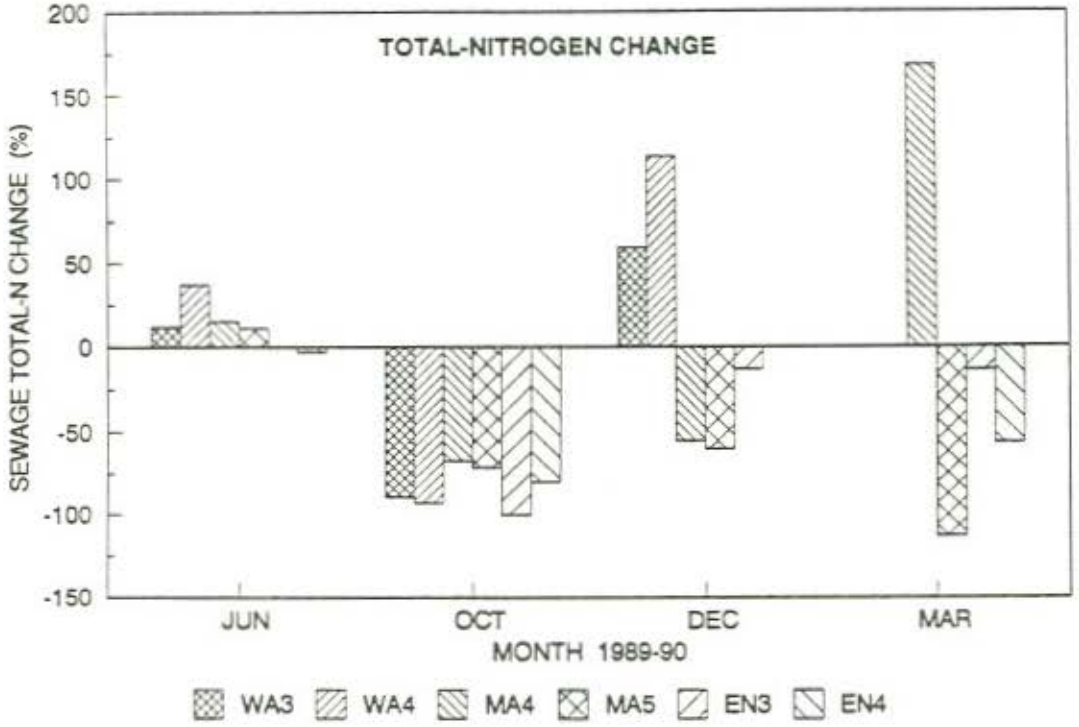

Figure 23. Percentages of sewage total-N change at stations below Walstonburg (WA), Macclesfield (MA), and Enfield (EN) outfalls.

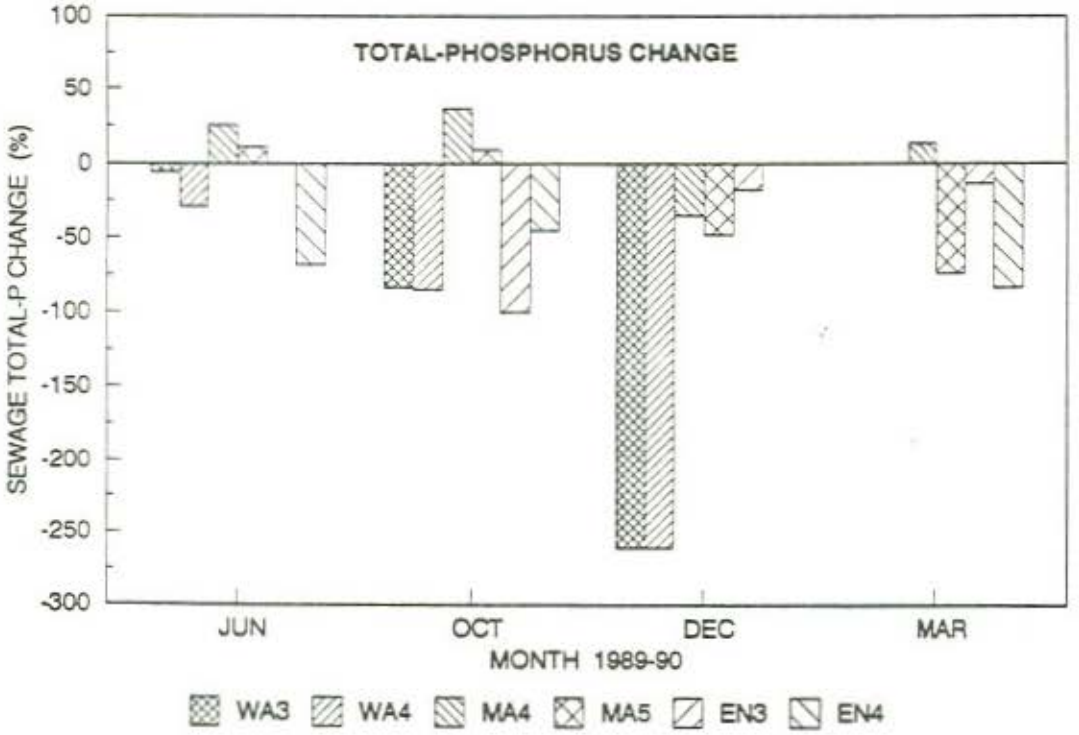

Figure 24. Percentages of sewage total-P change at stations below Walstonburg (WA), Macclesfield (MA), and Enfield (EN) outfalls.

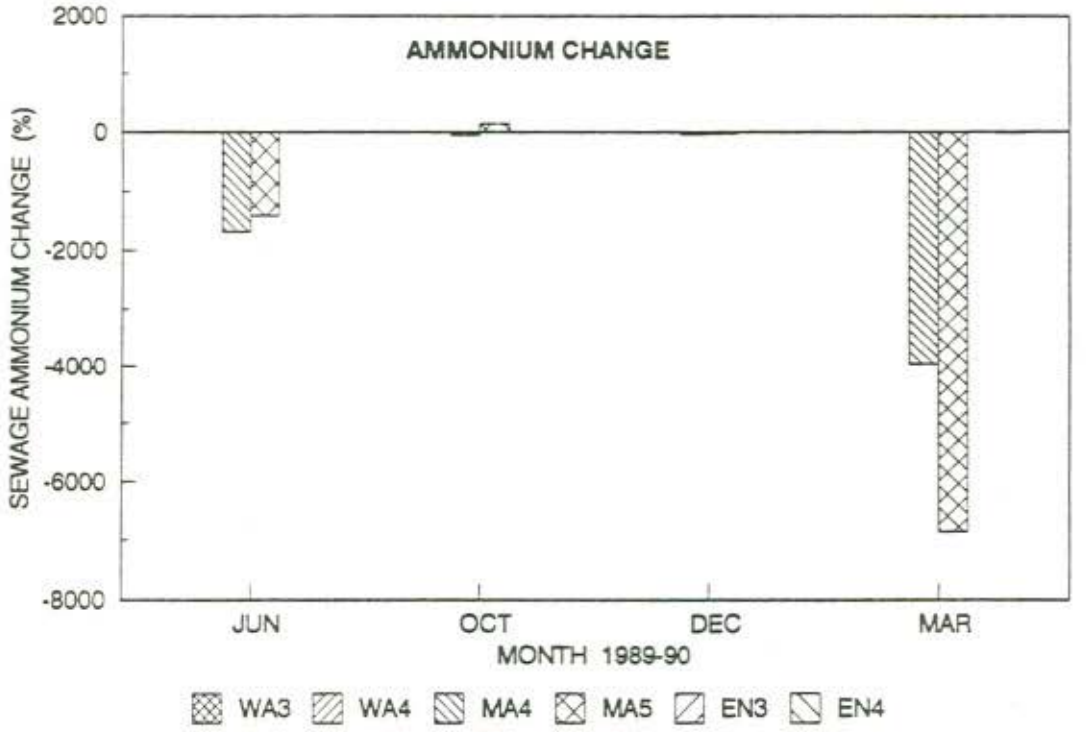

Figure 25. Percentages of sewage ammonium change at stations below Macclesfield (MA) and Enfield (EN) outfalls only.

activity in biological systems. Kuenzler (1987) reported that ammonium concentrations often increased for some distance below wastewater outfalls on swamp streams. Ammonium concentrations were too low in Walstonburg effluent, and usually in LaGrange effluent, to allow calculations of removal (Appendix D). Ammonium processing and transfer rates between water and soils appeared particularly variable.

NET NUTRIENT CHANGES BELOW OUTFALLS -- INTENSIVE SITES

The efficiencies of removal of wastewater nutrients from the two intensively studied streams were evaluated at several downstream stations using median values of SNC calculated as described in Methods.

Removals at Rich Square

Most of the median values at Stations BC4-BC8 had negative signs, suggesting removal of sewage nutrients by this wetland system (Table 7). Except for a slight (12%) removal of total P, however, there was no evidence of significant removal in the short, defined channel above Station BC4 nor down to BC5. Poor net nutrient removal in the upper portions of Bridgers Creek wetland between Stations BC4 and BC7, however, was surprising in view of the soft sediments and the luxuriant herbaceous plant growth. Median values for removal of total N were moderate but significant at Stations BC6-BC8. Because neither nitrate nor ammonium were consistently and significantly removed, total N losses probably came from the soluble and particulate organic-N fractions coming from the algae-rich lagoon. Over the much longer distance to Station BC10, all nutrient forms but nitrate decreased significantly and by large amounts (48-100%)(Table 7). The 21-fold increase in nitrate, if it were significant, would represent a concentration increase of the order of only about 1 mg N/L, emphasizing the fact that small absolute changes may give large relative changes which are not statistically or environmentally significant. The large 95% C.I., however, demonstrates wide variation in amounts of downstream nitrate change.

Removals at Scotland Neck

The median values of sewage nutrient change at Stations DC5 and DC6 during this study were not significant, except for ammonium. Stream flow was restricted to a deep, defined channel above Station DC6, out of contact with normally functioning swamp soils. Ammonium was apparently substantially incremented at Stations DC6 and DC8 relative to the amounts in the effluent. All forms of N and P, however, showed large (44%-122%), significant net losses from the water at the two downstream stations DC9 and DC10 (Table 7) where there had been

Table 7. Percentages of sewage nutrient change (SNC) below wastewater outfalls on Bridgers Creek (BC) and Deep Creek (DC). Values are median percentages ± 95% C.I. Negative values represent net removal of sewage nutrients from the water.

Station	Distance (km)	Nitrate	Ammonium	Total N	Phosphate	Total P
			Rich Square -- Bridgers Creek			
BC4	0.10	26.7 ± 63.9	24.1 ± 39.7	-11.9 ± 26.5	4.2 ± 11.9	-12.5 ± 10.6
BC5	0.20	-34.0 ± 38.4	-6.4 ± 13.9	-6.5 ± 64.2	-5.8 ± 13.8	7.7 ± 20.3
BC6	0.29	-40.1 ± 60.4	-10.1 ± 25.2	-19.8 ± 15.1	-2.3 ± 14.2	6.1 ± 19.0
BC7	0.40	-30.2 ± 69.8	-13.8 ± 26.3	-35.8 ± 22.4	-3.9 ± 16.4	-10.7 ± 22.7
BC8	0.56	5.6 ± 63.5	-14.1 ± 35.8	-31.7 ± 21.8	18.9 ± 28.5	3.9 ± 31.0
BC10	3.75	2,139 ± 2,994	-100.3 ± 8.8	-48.2 ± 33.2	-50.7 ± 16.7	-74.7 ± 16.8
			Scotland Neck -- Deep Creek			
DC5	0.22	2.3 ± 13.7	17.6 ± 34.8	5.9 ± 16.5	3.3 ± 12.2	-3.6 ± 9.4
DC6	0.31	0.6 ± 16.3	56.9 ± 55.7	6.8 ± 16.0	10.7 ± 17.7	-9.4 ± 11.9
DC8	0.50	-4.9 ± 3.8	28.1 ± 27.7	-3.1 ± 9.9	8.2 ± 7.4	10.5 ± 14.7
DC9	0.70	-61.8 ± 22.2	-51.7 ± 42.2	-43.9 ± 19.7	-47.4 ± 31.8	-51.5 ± 36.8
DC10	1.26	-80.9 ± 27.7	-122.5 ± 49.9	-66.1 ± 18.1	-82.8 ± 17.3	-74.5 ± 25.1

sufficient time and soil area to permit nutrient transformations and removals.

RECOMMENDATION FOR MONITORING NUTRIENT REMOVAL EFFECTIVENESS

The relatively low-cost procedures used here in the Extensive Study showed effective removal of point-source nutrients by most swamps and bottomlands. The following guidelines are suggested for cost-effective monitoring of nutrient removal on other swamp streams receiving municipal wastewaters. At least one station must be above the outfall to measure the chloride and nutrient concentrations in the unimpacted (control) stream water. This station should be far enough upstream to be unaffected by effluent during periods of low stream flow, but close enough that it is representative of the water diluting the effluent. The WTP effluent and two or more stream stations below the outfall must also be sampled. Sampling should be done in each season (at least four times per year); more frequent sampling is desirable but increases the field and laboratory costs proportionately. The minimum analyses are chloride, nitrate, ammonium, and filterable reactive phosphorus (phosphate); total-N and total-P data are also useful. Instead of chloride concentrations, conductivity measurements often may prove satisfactory for calculating nutrient dilution. The calculations of sewage nutrient change below the outfalls (see Methods) will show how effectively the wetland is trapping nutrients. This method serves best where dilution is low and, therefore, where nutrient and chloride concentrations are high just below the outfall. If loadings become heavier or the removal efficiency decreases, additional stations may need to be added farther downstream.

Temporal trends in nutrient removal efficiency at downstream stations reflect changes in loading rate, loading duration, or area of functioning wetland. However, these trends will also reflect changes in amount of contact between stream water and the swamp floor caused by natural variation in runoff and flooding. Thus monitoring must take place for several years, including years of higher and lower rainfall and runoff, in order to establish whether the changes in removal efficiencies indicate nutrient overloading within a particular tract of wetland. Data provided to regulatory agencies by the wastewater treatment plants will show whether nitrogen and phosphorus loading has increased during the monitoring period; if so this may account for decreased removal efficiencies in the swamp. If not, the concerned agency must look for evidence of recent changes to the wetland between the outfall and the monitoring stations, especially decreased area for interaction between streamwater and wetland soil. If loadings have not increased and the area of healthy bottomland or swamp forest has not decreased, then decreased removal efficiencies,

especially of phosphorus, may be attributed to saturation of removal capacity by overloading (Nichols 1983; Kadlec 1985)(see also below). It is not practical to provide more detailed procedures here. Management personnel are usually experienced and highly capable at finding site-specific causes of water quality degradation.

WASTEWATER LOADING RELATIVE TO WETLAND DAMAGE

Managers of wetlands receiving wastewaters must determine loading rates which allow effective nutrient stripping without damage to the wetland ecosystem. This study originally aimed to establish criteria for determining such balance points, but could not because of reduced funding. Loadings resulting in death of all trees, such as occurred in the Brown Marsh Swamp sprayfield in 1985-86 (Kuenzler 1987), were clearly excessive. It was not learned whether that tree mortality resulted from physical damage to the tree trunks by the force of water, from the constant wetness of the tree trunks, from excessive hydraulic loading which kept soils saturated, from toxicity of chlorine, ammonium, or other constituent, or from some other cause. Although the direct cause was not determined, the discharge of wastewater by spraying was halted at Brown Marsh Swamp.

Death of wetland vegetation clearly indicates excessive loading rates, but almost no studies have reported tree mortality. In his detailed guidelines for design of natural wetland treatment systems, Knight (1990) stated the goal of "... minimizing impacts of wastewater on the natural flora and fauna of the wetland system". He reported that only relatively minor alterations to biological communities have resulted from discharge of "properly treated effluent", but showed no data and provided no references. Several studies (*e.g.*, Ewel and Odum 1978; Nessel and Bayley 1984 ; Eiband 1991) reported that wastewater nutrients stimulated tree growth. At intermediate loadings, wastewater affects nutrient content and relative growth rates among wetland species (Deghi 1984; Ewel 1984; Straub 1984), resulting in long-term shifts in species composition. From the standpoint of total system functioning, as measured by productivity or nutrient processing, changes in species composition may not be of management concern. In fact, major changes may not be observable for decades. However, since most of the forested wetlands receiving wastewaters in eastern North Carolina are privately owned, changes in plant community structure may translate to a shift to less valuable timber species or to a reduction in habitat quality for game animals. Agencies and organizations concerned with wildlife, including but not restricted to game animals, or concerned with rare and endangered species must consider whether there are damages to these populations even though no changes to the

dominant wetland trees is evident. We must conclude that insufficient understanding of impacts of wastewater on wetland communities exists to predict either the direction or magnitude of changes.

COMPARISONS TO REMOVALS IN OTHER WETLANDS

Municipal wastewaters have been routinely discharged to Southeastern wetlands for many years as a means of disposal (U.S. Environmental Protection Agency 1983). Because of their convenience and their recognized abilities to improve water quality, nearby wetlands are often considered, and promoted, as inexpensive natural wastewater treatment facilities. North Carolina has over 250 discharges to "swamp waters" according to the N.C. Division of Environmental Management (DEM). In addition, municipalities and other dischargers, especially in Florida, have constructed wetlands for water quality improvement as an alternative to more expensive treatment plants. Design and assimilation information for a large number of natural and constructed wetlands has been reviewed by Knight (1990).

Numerous studies of wastewater nutrient removals in Southeastern wetlands have shown significant removals of both nitrogen and phosphorus (reviewed by Kuenzler 1989). The results of the present study compare favorably in most regards with those from two other forested wetlands in North Carolina (Table 8) studied by similar methods. There were significant, often high, removal efficiencies of all nutrient forms, except that nitrate increased at Bridgers Creek. Bridgers Creek also showed the lowest efficiencies for removal of total N, phosphate, and total P (Table 8).

WETLAND NUTRIENT TRAPPING AND ESTUARINE WATER QUALITY

The results of this and other studies indicate that a variety of riparian wetlands within the APES watersheds have good potential for removing a large part of nutrients from point and non-point sources. These wetlands process nitrate and phosphate from wastewater effluents and from farm runoff (*e.g.*, Chesheir *et al.* 1987). A simple mass balance model illustrated how trapping of agricultural non-point source nutrients by riparian swamps and bottomlands may reduce eutrophication potential of the Chowan River (Kuenzler and Craig 1986). That model, however, omitted consideration of nutrients discharged to swamp systems from municipal outfalls or other point sources.

Although wetlands generally serve as nutrient sinks, we still cannot predict accurately how efficiently a particular wetland will remove a given load of nutrients, or for how long.

Table 8. Percentages of wastewater nutrients removed in North Carolina Coastal Plain swamps below secondary wastewater treatment plants. Values are net removals (median ± 95% C.I.). Brown Marsh Swamp and Cashie River Swamp data from Kuenzler (1987).

Parameter	Brown Marsh Swamp	Cashie River Swamp	Bridgers Creek	Deep Creek
			Background	
Treatment Type	Lagoon	Aeration	Lagoon	Oxidation ditch
Permitted Discharge (cfs)	0.100	0.100	0.300	0.675
Watershed Area (km^2)	294	102	9.2	108
Dist. below outfall (km)	4.42	4.55	3.75	1.26
			Removal Efficiencies (%)	
Nitrate	-84 ± 82	-98 ± 35	2,140 ± 2,990	-81 ± 28
Ammonium	-99 ± 1	-100 ± 8	-100 ± 9	-122 ± 50
Total N	-92 ± 31	-98 ± 8	-48 ± 33	-66 ± 18
Phosphate	-100 ± 1	-102 ± 6	-51 ± 17	-83 ± 17
Total P	-92 ± 3	-99 ± 11	-75 ± 17	-74 ± 25

There is evidence that removal efficiency tends to decline nonlinearly with both the loading rate and the duration of loading (Nichols 1983). The BOD and N in wastewater are removable in wetlands by fermentation/oxidation reactions and by denitrification, respectively. The P, however, is retained in the system and will eventually reach levels in the soil which prevent further removal from the water. Accordingly, Knight (1990) recommended maximum loadings of 4 kg ha^{-1} d^{-1} for BOD and 3 kg ha^{-1} d^{-1} for TN. He recommended that phosphorus be largely removed at the wastewater treatment plant before discharge.

Bottomland and swamp forests are inundated over their full floodplain widths for only part of the year, usually in the cool seasons. During the rest of the year, most of the water, natural or effluent, flows though one or more channels of varying widths and depths. The total area of flooded forest floor available for nutrient removal decreases as stream flow through the swamp decreases; given constant effluent flow, this gives greater loading at low stream stages. Over the short term, the total mass of nutrient removed per unit area increases with loading, but heavy, unnatural loading rates decrease the expected removal efficiencies over time (Nichols 1983). Channelization or other interferences with the hydrology, especially loss of periodic and extended floodplain inundation, will alter not only the plant community structure, but also the extensive contact with soil which is so important to nutrient processing, retention, and removal. It is apparent, however, that loss of riparian wetland area or significant damage to natural wetland processes will decrease their potential for water quality improvement.

Southeastern riparian forested wetlands generally are very effective in improving water quality by removing suspended sediments as well as nutrients (Kuenzler 1989). This capability depends on the area of contact between stream water and wetland surfaces, the duration of interaction, and the functional health of the wetland. Contact is probably best in relatively small, shallow, slow-flowing streams with broad floodplains. About half of the original wetlands in the United States has been destroyed since the mid-1950's (Tiner 1984) and losses are continuing. It is not as easy to quantify damages to the functional abilities of wetlands, but there is evidence that the nutrient removal abilities are decreased by nutrient loading (Kadlec 1985). In spite of their proven abilities, wetlands alone cannot be relied upon to remove sufficient nutrients to prevent eutrophication of our estuaries. We also need efficient municipal wastewater treatment plants and extensive use of agricultural best management practices. It is certainly in the public interest, however, to maintain as great

an area of undisturbed riparian wetlands as possible as a final filter to further reduce nutrient loading to the estuaries.

Finally, resource stewardship requires that we maintain all values of landscape units, including swamps and bottomland forests (Kuenzler 1990). We must not convert natural forested wetlands into engineered wastewater treatment facilities: irrefutable evidence can never be obtained that other functions and values are not being sacrificed. Additional nutrient removal (wastewater polishing) from well-treated wastewaters at rates that do not damage ecosystem structure and functioning is then an important additional value added by the wetland. However, dedication of natural wetlands for significant wastewater treatment will generate political and economic pressures to increase loadings until all other wetland values become secondary and therefore expendable. The use without abuse of our existing forested wetlands should be the goal.

APPENDICES

APPENDIX A. Descriptions of Extensive Study Sites and Stations. Sites are listed by name of town.

1. Clarkton. The town of Clarkton uses a lagoon for wastewater treatment (Table 2). The lagoon is dense with algae (Sutton 1988). During the period 1985-86 when the effluent was discharged through sprayers to heavily forested Brown Marsh Swamp, the amount of nutrient removal was studied by Kuenzler (1987). Because of tree mortality in the sprayfield, the wastewater flow (Station CL1) has been returned to an un-named ditch; slightly diluted effluent joins Big Foot Creek just below CL2 and CL3, as it did before 1985. There has been logging disturbance between CL3 and CL4 (766 m below the outfall), resulting in dense growth of brush on the floodplain. A beaver dam below Station CL4 may have impounded some water in the channel through part of the summer drydown period. The stream then continues down to join Brown Marsh Swamp.

2. LaGrange. Wastewater is treated by oxidation ditch and discharged to Mosely Creek, a watercourse with a relatively deep channel and narrow floodplains. Above Station LG1 were several beaver dams which retained the dilution water and permitted growth of duckweed (*Lemna* sp.). Downstream sampling (Stations LG3 and LG4) was done from bridges on Roads 1515 and 1518, respectively.

3. Enfield. The wastewater was pumped from the WTP (Station EN2) through a 200 m channel with high berms into Burnt Coat Swamp above the broad confluence with Marsh Swamp just above EN4. These extensive swamps are well forested with large bottomland hardwood trees (*Nyssa Aquatica, Taxodium distichum, Quercus michauxii, Acer rubrum*, and others). The stream is braided and the floodplain is wide and wet, with deep, soft sediments. The large receiving streams cause great wastewater dilution during wet seasons. The upstream station (EN1) on Burnt Coat Swamp was about 2 km above EN2 at the south bridge on Road 1001. Station EN3 was at the end of the channel mentioned above and EN4 was 730 m below the outfall at the Hwy. 301 bridge.

4. Lewiston-Woodville. This is the same site studied by Kuenzler (1987). The treatment plant delivers wastewater through a recently constructed pipe to an outfall (Station LW2) on the Cashie River. The upstream station (LW1) was at the Hwy. 42 bridge 250 m above the outfall. Below the outfall, the stream channel is braided as it passes through a mature bottomland forest (*Nyssa aquatica, N. sylvatica* var. *biflora*,

Taxodium distichum, Quercus michauxii, Q. falcata var. *pagodaefolia, Fagus grandiflora*, and other species) similar to that below Enfield. Stations were established at 119 and 289 m below the outfall. At the lowermost station (LW4), many of the overstory trees have been cut and abundant sunlight reaches the soil and shrubby growth.

5. Macclesfield. The effluent (Station MA2) discharges to a small, intermittent, un-named tributary to Bynum Mill Creek. The upstream station (MA1) is 110 m above the outfall. Stations MA3 and MA4 are 100 and 326 m downstream, and MA5 at the bridge on Road 124 is 1.27 km below the outfall. There is evidence of some channelization just below the outfall, but the floodplain is broad, wet, and well forested with trees such as *Acer rubrum, Liquidambar styraciflua, Magnolia virginica, Carpinus caroliniana, Quercus nigra*, and Q. *phellos* as well as dense growths of *Ligustrum* sp. and *Arundinaria gigantea*.

6. Pink Hill. The treatment plant discharges at Station PH2 to Cherry Tree Branch. Station PH1 is 65 m upstream and PH3 and PH4 are 100 and 306 m below the outfall; PH5 is at Road 1105 bridge 2.86 km below the outfall. The stream meanders through a wide, well forested floodplain with *Acer rubrum, Liquidambar styraciflua, Magnolia virginica, Ilex opaca*, and *Quercus nigra* trees. Further downstream there are also *Persea borbonia, Q. phellos*, and *Taxodium disticum* trees.

7. Walstonburg. The wastewater receives extended aeration treatment and travels down a shallow ditch for about 20 m before joining Thompson Swamp. The upstream station (WA1) is 100 m above, and WA3 and WA4 are 96 and 300 m below the outfall; WA5 is at Road 264 bridge 1.56 km below the outfall. The well-developed bottomland forest consists of *Acer rubrum, Liquidambar styraciflua, Ilex opaca, Quercus michauxii, Q. falcata, Q. phellos, Populus heterophylla*, and *Carpinus caroliniana* trees. The trees are often large and there is relatively little undergrowth. The stream is shallow with significant meanders. A tributary, Lighter Knot Swamp, draining from the town of Walstonburg and intermediate farms, enters 400 m below the outfall.

APPENDIX B. Descriptions of Intensive Study Sites and Stations.

I. RICH SQUARE/BRIDGERS CREEK SITE

The wastewater from Rich Square passed through 2 ha waste stabilization pond which supports dense phytoplankton populations. The discharge entered a small un-named tributary near the headwaters of Bridgers Creek Fig. 2). This immediate area is broad, flat, and forested (*e.g., Acer rubrum, Ulmus* sp., *Nyssa aquatica*), but becomes more shrubby and marshy (*Typha latifolia, Rosa palustris, Itea virginica, Polygonum hydropiperoides*, etc.) within about 50 m. The flow then entered Bridgers Creek just below Station 4 about 100 m below the outfall. The creek was more turbid than usual for a Coastal Plain stream because of recent clearcutting and site preparation, apparently for planting of pines. The broad, marshy area, with soft sediments and many dead and fallen trees, apparently resulted in part from beaver activity. Several low beaver dams blocked the channels between Stations 7 and 8 at about 520 m downstream. Below these dams, several braided channels pass through a well-stocked forest of *Acer rubrum, Nyssa aquatica, N. sylvatica* var. *biflora, Taxodium distichum*, and other swamp and bottomland trees again.

Bridgers Creek Stations

Station BC1: This station was on a small, slightly channelized un-named branch 84 m above the wastewater outfall. During very dry periods, wastewater may have backed up into this tributary.

Station BC2: The sampling point for effluent of the Rich Square wastewater lagoon.

Station BC3: Located 50 m below the outfall (BC2), this station was discontinued after May 1989 because of low nutrient removal over this short distance.

Station BC4: Located 98 m below the outfall, this station was just above the confluence of the sewage channel and Bridgers Creek.

Station BC5: This station was located 175 m below the outfall and designated Station BC4.5 until December 1988 when it was moved to position 200 m downstream.

Station BC6: This station was located 319 m below the outfall until December 1988 when it was moved to a location 291 m downstream.

Station BC7: Located approximately 405 m below the outfall. This station, along with stations BC5 and BC6, was heavily vegetated with emergents and other aquatic plants during the spring and summer months.

Station BC8: Located approximately 562 m below the outfall. Bridgers Creek flowed into a wooded area beyond station BC7. At the beginning of the wooded area were several fallen trees and an old, long, low beaver dam.

Station BC9: This tributary station was on Bridgers Creek about 630 m upstream of Station BC4. It was sampled from the Hwy. 258 bridge south of Rich Square.

Station BC10: This station about 3.75 km below the outfall was added in April 1989. A broad expanse of healthy swamp and marsh occurred above this station.

II. SCOTLAND NECK/DEEP CREEK SITE

Scotland Neck is the largest municipality and Deep Creek is the largest stream (watershed area of about 108 km^2) of the systems studied. The Scotland Neck WTP was recently upgraded and enlarged; about one-third of its flow may come from industrial sources. The substantial volume of effluent discharges directly into Canal Creek, a deep, straight channel with high, nearly vertical banks bordered by upland trees (*e.g., Pinus taeda, Acer rubrum, Liquidambar styraciflua, Ulmus* sp.). Because of Canal Creek's small watershed (4 km^2), its mean discharge rate is probably about the same as that of the effluent. The channel is very distinct to the south and then west onto the floodplain for more than 100 m below the outfall (Fig. 3). The channel gradually becomes less distinct; breaks in the low spoil-pile levees become more frequent as it merges into the broad, flooded bottoms of Deep Creek. The effluent is mixed with some swamp water provided by several small channels between Stations 6 and 8. *Acer rubrum, Taxodium distichum, Quercus nigra, Q. laurifolia, Q. michauxii, and Liquidambar styraciflua* trees are large and abundant on the Deep Creek floodplain from Station DC6 to DC10. The N.C. Division of Environmental Management studied this bottomland system in September 1979 and in June 1982, gathering data on stream velocities, cross-sectional areas, discharges, times-of-travel, and water quality. In September, a dye insertion showed time-of-travel was about 2 hr/km.

Deep Creek Stations

Station DC1: This station on Canal Creek about 75 m above the wastewater outfall was one of three stations on tributaries to

Deep Creek. The Canal Creek channel has been excavated about 2 m wide and deep, with a relatively flat bottom and steep sides at this point. The water was usually only about 10-50 cm deep.

Station DC2: This station was the outfall of the Scotland Neck wastewater treatment plant discharging to Canal Creek.

Station DC3: This station along Canal Creek, about 58 m below the outfall, was discontinued in May 1989 due to poor mixing of effluent and dilution water.

Station DC4: Located on Canal Creek about 121 m below the outfall. This station was discontinued in September 1989 because of poor mixing of effluent and dilution water.

Station DC5: Located about 220 m below the outfall along the channelized Canal Creek.

Station DC6: This station was located on channelized Canal Creek just above its confluence with Deep Creek on a broad floodplain about 308 m below the outfall (Fig. 3). As the water stage rose in Deep Creek, it flowed through holes in the spoil pile banks, then at higher stages over the banks of Canal Creek.

Station DC7: This tributary station on Deep creek was at the Road 1105 bridge about 5.8 km above its confluence with Canal Creek. Deep Creek here was often dry during the summer months.

Station DC7.5: This tributary station of Deep Creek, added in April 1989, was at the Road 1104 bridge about 5.38 km above the confluence with Canal Creek.

Station DC8: This station was about 500 m below the outfall on a relatively small channel approaching the main Deep Creek channel (Fig. 3). It was flooded during winter but became dry during summer. At this point along Deep Creek, there was a wide, wooded floodplain covered with leaf litter and sediments from the creek.

Station DC9: This main-channel station on the floodplain of Deep Creek was about 700 m below the outfall. The stream was considerably larger than at Station DC8, but the broad channel was not deep or scoured.

Station DC10: This station at the south bridge on U.S. 258 south of Scotland Neck was added in March 1989. Most stream flow went under this bridge and a smaller amount under the north bridge. Water was present under this bridge even when Stations 8 and 9 were dry and when discharge was undetectable.

Appendix C. Chloride and nutrient concentrations at the seven extensive-study sites.

DATE	STATION	DISTANCE m	TEMP. °C	COND. uS/cm	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	TN mg/L	PO4 mg/L	TP mg/L
25 May 89	Clarkton										
	CL1	0	26.0	342	28.0	0.217	2.762	8.92	9.14	0.245	2.82
	CL2	407	23.0	230	18.8	0.048	1.264	3.55	3.60	0.341	0.53
	CL3	487	22.0	96	20.2	0.449	0.230	1.08	1.53	0.022	0.85
	CL4	766	22.0	187	22.8	0.152	2.471	3.62	3.77	0.248	0.37
25 Aug 89	Clarkton										
	CL1	0	28.0	308	24.6	0.270	2.181	6.08	6.35	0.708	1.02
	CL2	407	25.0	165	13.0	0.488	0.332	1.14	1.63	0.117	0.24
	CL3	487	24.5	121	15.6	0.423	0.073	1.30	1.72	0.030	0.16
	CL4	766	25.0	150	13.7	0.421	0.301	1.86	2.28	0.105	0.24
3 Dec 89	Clarkton										
	CL1	0	9.0	258	23.3	0.369	1.888	4.73	5.10	0.378	0.60
	CL2	407	8.5	240	20.9	0.565	1.223	2.68	3.24	0.281	0.48
	CL3	487	7.0	135	21.5	0.390	0.052	0.11	0.50	0.009	0.16
	CL4	766	8.0	176	20.9	0.398	0.684	1.35	1.74	0.121	0.14
13 Feb 90	Clarkton										
	CL1	0	14.0	372	35.8	0.236	2.422	9.57	9.81	0.298	1.00
	CL2	407	11.0	220	20.4	0.528	0.665	2.41	2.94	0.106	0.26
	CL3	487	10.5	125	19.3	0.343	0.070	0.25	0.59	0.012	0.08
	CL4	766	12.0	168	19.9	0.427	0.440	1.34	1.77	0.047	0.17
25 May 89	LaGrange										
	LG1	-919	22.0	118	11.2	1.169	0.230	1.36	2.53	0.019	0.07
	LG2	0	26.0	234	22.0	10.857	0.002	0.89	11.75	0.953	1.72
	LG3	162	31.0	165	15.7	2.974	0.502	2.22	5.19	0.541	1.26
	LG4	2860	26.0	117	11.7	1.100	0.301	1.08	2.17	0.522	0.67
25 Aug 89	LaGrange										
	LG1	-919	27.0	91	12.1	-0.040	0.002	1.40	1.36	0.030	0.16
	LG2	0	27.0	382	35.1	12.295	0.002	0.27	12.56	1.820	2.40
	LG3	162	27.0	219	20.8	1.171	1.694	40.24	41.41	1.200	10.49
	LG4	2860	26.0	146	17.6	0.733	0.711	1.89	2.62	0.565	0.80
3 Dec 89	LaGrange										
	LG1	-919	8.0	132	14.7	0.028	1.496	6.65	6.68	0.240	1.36
	LG2	0	11.0	357	29.0	10.005	0.009	0.44	10.45	1.993	1.64
	LG3	162	6.5	213	20.0	3.777	1.653	2.49	6.27	0.710	0.76
	LG4	2860	9.0	72	10.4	0.159	0.034	1.25	1.41	0.006	0.16

Appendix C (cont.)

DATE	STATION	DISTANCE m	TEMP. °C	COND. uS/cm	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	TN mg/L	PO4 mg/L	TP mg/L
13 Feb 90	LaGrange										
	LG1	-919	12.0	107	13.1	0.072	0.023	0.73	0.80	0.016	0.01
	LG2	0	15.0	338	25.0	14.484	0.002	0.52	15.00	1.410	1.31
	LG3	162	14.0	231	19.3	4.739	0.282	1.41	6.15	0.644	0.65
	LG4	2860	14.0	115	14.1	1.289	0.034	0.60	1.89	0.308	0.21
25 May 89	Pink Hill										
	PH1	-65	21.0	126	11.5	2.801	0.031	0.41	3.21	0.026	0.48
	PH2	0	25.0	339	23.4	2.524	2.679	4.22	6.74	0.881	1.49
	PH3	100	22.0	150	12.3	2.714	0.418	0.79	3.50	0.144	0.35
	PH4	306	22.0	139	12.3	2.576	0.326	0.84	3.42	0.137	0.21
	PH5	2860	21.0	109	12.1	1.598	0.014	0.55	2.15	0.053	0.21
25 Aug 89	Pink Hill										
	PH1	-65	24.0	128	11.9	2.802	0.046	0.16	2.96	0.040	0.11
	PH2	5	28.0	345	28.6	2.258	4.169	7.32	9.58	0.600	1.15
	PH3	100	25.0	165	14.3	2.747	0.719	2.12	4.87	0.145	0.33
	PH4	306	24.0	163	13.9	2.693	0.510	1.04	3.73	0.165	0.29
	PH5	2860	25.0	135	12.3	2.403	0.011	0.21	2.61	0.090	0.16
3 Dec 89	Pink Hill										
	PH1	-65	9.0	115	11.0	2.643	0.071	1.32	3.96	0.020	0.16
	PH2	5	11.0	521	38.5	0.326	11.146	10.45	10.78	1.248	1.96
	PH3	100	9.0	165	14.9	2.276	1.418	2.02	4.30	0.199	0.24
	PH4	306	8.0	154	14.3	2.337	1.105	1.56	3.90	0.162	0.20
	PH5	2860	8.0	118	12.4	1.694	0.054	0.63	2.32	0.028	0.20
13 Feb 90	Pink Hill										
	PH1	-65	14.0	115	10.6		0.107	0.36		0.019	-0.01
	PH2	5	15.0	439	34.9	1.456	9.162	10.95	12.41	1.166	2.24
	PH3	100	14.5	152	13.3	3.165	0.885	2.26	5.42	0.157	0.21
	PH4	306	14.0	167	14.3	2.897	0.976	3.13	6.03	0.195	0.48
1 Jun 89	Walstonburg										
	WA1	-100	25.0	75	12.7	0.326	0.169	1.37	1.70	0.125	0.34
	WA2	0	25.0	210	22.9	5.870	0.002	0.15	6.02	0.303	0.48
	WA3	96	25.0	105	15.9	1.808	0.157	1.47	3.28	0.152	0.38
	WA4	300	26.0	99	14.3	1.432	0.126	1.32	2.75	0.152	0.34
	WA5		29.0	86	13.9	1.987	0.111	1.32	3.31	0.265	0.63
1 Oct 89	Walstonburg										
	WA1	-100	19.0	110	11.4	0.354	0.002	1.02	1.37	0.091	0.19
	WA2	0	19.0	307	21.8	14.983	0.002	1.13	16.11	2.132	2.62
	WA3	96	19.4	84	9.6	0.555	0.002	0.74	1.29	0.143	0.15
	WA4	300	19.0	119	9.2	0.395	0.002	1.02	1.41	0.117	0.15
	WA5		19.8	130	13.4	1.786	1.814	2.20	3.98	0.385	0.60

Appendix C (cont.)

DATE	STATION	DISTANCE m	TEMP. °C	COND. uS/cm	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	TN mg/L	PO4 mg/L	TP mg/L
17 Dec 89	Walstonburg										
	WA1	-100	2.0	56	14.1	1.486	0.017	0.60	2.09	0.025	0.11
	WA2	0	10.0	133	18.8	5.479	0.002	1.02	6.50	0.446	0.96
	WA3	96	2.0	56	13.9	1.427	0.005	0.27	1.70	0.040	0.19
	WA4	300	2.0	56	13.9	1.309	0.009	0.23	1.53	0.036	0.19
	WA5		2.0	56	13.9	1.353	0.029	0.51	1.86	0.036	0.11
10 Mar 90	Walstonburg										
	WA1	-100	16.0	66	13.4	0.678	0.017	0.25	0.93	0.032	0.02
	WA2	0	16.0	164	18.3	6.455	0.005	0.25	6.71	0.480	0.63
	WA3	96	16.0	76	13.2	0.993	0.025	0.61	1.61	0.049	0.06
	WA4	300	16.0	76	13.2	0.879	0.029	0.35	1.23	0.046	0.06
	WA5		17.0	76	13.5	0.879	0.027	0.22	1.10	0.046	0.06
1 Jun 89	Macclesfield										
	MA1	-110	27.0	108	14.5	0.487	0.372	1.13	1.61	0.136	0.24
	MA2	0	27.0	314	42.5	12.455	0.013	0.30	12.75	2.037	1.90
	MA3	100	24.0	257	28.5	6.335	0.122	1.08	7.41	1.057	1.26
	MA4	326	24.5	221	26.6	5.977	0.122	1.27	7.25	0.831	1.16
	MA5		27.5	156	20.4	3.284	0.259	0.96	4.24	0.547	0.63
1 Oct 89	Macclesfield										
	MA1	-110	18.6	79	9.0	0.360	0.027	0.96	1.32	0.165	0.27
	MA2	0	21.4	383	37.6	12.434	0.088	0.45	12.89	1.428	1.35
	MA3	100	19.0	95	9.6	0.583	0.030	0.90	1.49	0.180	0.27
	MA4	326	19.2	99	9.8	0.606	0.030	0.79	1.40	0.180	0.31
	MA5		19.0	78	11.0	0.580	0.040	0.90	1.48	0.154	0.36
17 Dec 89	Macclesfield										
	MA1	-110	2.0	75	18.0	1.398	0.381	0.69	2.09	0.033	0.19
	MA2	0	7.5	214	37.7	3.763	0.575	1.72	5.48	0.424	0.46
	MA3	100	2.0	88	4.3	1.575	0.405	0.60	2.17	0.058	0.15
	MA4	326	2.5	81	3.9	1.516	0.401	0.32	1.84	0.055	0.11
	MA5		3.0	74	3.1	1.545	0.379	0.48	2.03	0.051	0.15
10 Mar 90	Macclesfield										
	MA1	-110	17.0	97	14.6	0.621	0.045	0.10	0.72	0.066	0.06
	MA2	0	14.0	267	29.1	10.064	0.002	0.46	10.52	0.998	1.23
	MA3	100	17.0	108	17.0	3.084	0.037	0.30	3.39	0.187	0.19
	MA4	326	18.0	21	15.5	2.311	0.037	0.20	2.51	0.120	0.15
	MA5		18.5	64	12.1	0.764	0.081	0.30	1.07	0.036	0.02

Appendix C (cont.)

DATE	STATION	DISTANCE m	TEMP. °C	COND. uS/cm	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	TN mg/L	PO4 mg/L	TP mg/L
1 Jun 89	Lewiston-Woodville										
	LW1	-250	27.5	93	11.6	0.000	0.041	1.86	1.86	0.174	0.45
	LW2	0	25.0	580	51.4	26.341	0.064	2.25	28.59	1.849	1.87
	LW3	119	23.5	91	12.7	1.218	0.076	2.01	3.22	0.228	0.45
	LW4	289	26.0	84	12.1	0.789	0.064	1.81	2.60	0.228	0.45
1 Oct 89	Lewiston-Woodville										
	LW1	-250	18.2	81	9.6	0.003	0.052	0.68	0.68	0.093	0.15
	LW2	0	22.5	645	64.5	34.745	0.111	2.37	37.11	2.465	2.91
	LW3	119	18.7	96	9.6	0.513	0.068	1.80	2.32	0.128	0.23
	LW4	289	18.5	93	9.6	0.395	0.050	1.02	1.41	0.128	0.31
17 Dec 89	Lewiston-Woodville										
	LW1	-250	2.0	38		0.400	0.280	0.41	0.81	0.025	0.15
	LW2	0	10.0	232		7.727	0.550	1.81	9.54	0.195	0.46
	LW3	119	0.0	38		0.412	0.280	0.46	0.87	0.022	0.19
	LW4	289	2.0	38		0.404	0.286	0.67	1.07	0.025	0.15
10 Mar 90	Lewiston-Woodville										
	LW1	-250	15.0	55	9.8	0.008	0.003	0.07	0.08	0.038	0.06
	LW2	0	14.0	323	33.0	9.205	0.085	2.94	12.14	0.628	1.45
	LW3	119	14.0	56	10.6	0.420	0.005	0.56	0.98	0.056	0.06
	LW4	289	14.0	56	10.4	0.265	0.009	0.25	0.52	0.046	0.02
1 Jun 89	Enfield										
	EN1		23.0	102	9.9	0.258	0.274	1.52	1.78	0.094	0.20
	EN2	0	19.0	318	37.0	0.681	9.035	9.54	10.22	1.057	1.26
	EN4		23.0	204	24.2	0.610	4.338	5.47	6.08	0.982	0.31
1 Oct 89	Enfield										
	EN1		17.6	92	10.2	0.013	0.016	0.68	0.69	0.035	0.07
	EN2	0	22.0	364	37.0	2.997		21.46	24.46	1.205	1.51
	EN3	200	22.0	375	37.0	2.519				1.205	
	EN4		18.0	96	11.6	0.013	0.125	0.90	0.92	0.069	0.11
17 Dec 89	Enfield										
	EN1		0.0	45	9.5	0.566	0.001	0.46	1.03	0.022	0.11
	EN2	0	15.0	149	22.0	2.817	3.162	4.66	7.48	0.228	0.46
	EN3	200	6.0	169	23.9	2.255	3.889	5.12	7.38	0.276	0.42
	EN4		0.0	45	9.2	0.555	0.019	0.20	0.76	0.023	0.13
10 Mar 90	Enfield										
	EN1		11.5	69	13.0	0.354	0.037	0.56	0.91	0.039	-0.02
	EN2	0	14.0	212	30.3	1.900	4.568	7.85	9.75	0.440	0.80
	EN3	200	14.0	223	32.1	1.700	5.365	7.49	9.19	0.504	0.76
	EN4		7.0	95	15.3	0.389	0.523	0.97	1.36	0.096	0.02

Appendix D
extensive-
the efflue

extensive-study sites.
: concentrations.

SITE	STATION	DISTANCE. (km)	DATE 1989-90	NO3	NH4	TN	PO4	TP
CLARKTON	CL4	0.766	MAY 25	-300	149	-10	183	-120
			AUG 25	60	-148	-116	-148	-126
			DEC 3	-1	-203	-167	-190	-62
			FEB 13	b	b	b	b	b
LAGRANGE	LG3	0.162	MAY 25	-50	a	-25	31	67
			AUG 25	-75	a	748	71	1038
			DEC 3	1	21214	-47	-24	-115
			FEB 13	-38	a	-27	-14	-6
LAGRANGE	LG4	2.08	MAY 25	-101	a	-135	894	554
			AUG 25	-75	a	516	24	19
			DEC 3	-104	70664	132	-49	226
			FEB 13	-2	a	-11	141	81
PINK HILL	PH3	0.10	MAY 25	-41	119	13	105	-199
			AUG 25	8	11	67	26	38
			DEC 3	-76	-15	-42	2	-63
			FEB 13		-22	298	9	-16
	PH4	0.306	MAY 25	-123	67	-7	93	-341
			AUG 25	-15	-8	-4	77	32
			DEC 3	-80	-21	-68	-3	-74
			FEB 13		-37	218	0	39
	PH5	2.86	MAY 25	-951	-13	-371	-36	-434
			AUG 25	b	b	b	b	b
			DEC 3	-5148	-3	-370	-86	-51
			FEB 13	b	b	b	b	b
WALSTONBURG	WA3	0.096	JUN 1	-14	a	12	-31	-6
			OCT 1	-105	a	-89	-110	-84
			DEC 17	-50	a	59	-165	-261
			MAR 10	b	b	b	b	b
	WA4	0.3	JUN 1	22	a	37	-4	-29
			OCT 1	-99	a	-93	-101	-85
			DEC 17	-4	a	113	-147	-261
			MAR 10	b	b	b	b	b

Appendix D (cont.)

SITE	STATION	DISTANCE. (km)	DATE 1989-90	NO3	NH4	TN	PO4	TP
	MA5	1.526	JUN 1	141	a	151	326	457
			OCT 1	-49	a	-8	-25	-12
			DEC 17	-21	a	6	-147	-89
			MAR 10	b	b	b	b	b
MACCLESFIELD	MA3	0.10	JUN 1	2	1090	4	-3	21
			OCT 1	-6	104	-24	-36	-80
			DEC 17	-70	-40	-64	-101	-47
			MAR 10	51	-208	57	-21	-32
	MA4	0.326	JUN 1	6	-1686	15	-14	25
			OCT 1	-23	-60	-67	-49	36
			DEC 17	-67	-39	-55	-100	-35
			MAR 10	163	-3948	168	-11	13
	MA5	1.268	JUN 1	12	-1407	11	4	11
			OCT 1	-71	146	-71	-100	9
			DEC 17	-68	-33	-60	-98	-48
			MAR 10	-102	-8642	-113	-75	-74
LEWISTON-WOODVILLE	LW3	0.119	JUN 1	b	b	b	b	b
			OCT 1	b	b	b	b	b
			DEC 17	-94	-49	-89	-95	-33
			MAR 10	b	b	b	b	b
	LW4	0.289	JUN 1	b	b	b	b	b
			OCT 1	b	b	b	b	b
			DEC 17	-95	-45	-80	-87	-68
			MAR 10	b	b	b	b	b
ENFIELD	EN3	0.20	JUN 1					
			OCT 1	-16		-100	0	-100
			DEC 17	-28	6	-13	6	-18
			MAR 10	-17	7	-14	5	-14
	EN4	0.73	JUN 1	36	-12	-3	68	-68
			OCT 1	-100		-80	-46	-45
			DEC 17	b	b	b	b	b
			MAR 10	-68	-18	-56	8	-84

a. Effluent concentration below lowest detectable concentration.
b. Chloride FRi in range 0.05 to -0.05.

Appendix E. Physical factors and chloride and nutrient concentrations in Rich Square wastewater effluent and Bridgers Creek waters.

DATE	STATION	DIST. (m)	TEMP. (C)	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	FKN mg/L	TN mg/L	PO4 mg/L	FTP mg/L	TP mg/L
30-Oct-88	BC9	-630	12.0	255	2.6	7.21	11.4	0.028	0.027	2.67	1.63	2.70	1.267	0.34	0.76
30-Oct-88	BC1	-84	9.5	461	0.6	7.05	36.0	0.261	1.445	7.50	3.35	7.76	1.917	1.12	1.74
30-Oct-88	BC2	0	15.0	727	11.0	9.05	40.3	0.509	2.948	13.10	5.51	13.61	0.977	1.36	3.77
30-Oct-88	BC3	50	15.0	752	8.5	8.95	39.7	0.681	2.622	10.88	5.44	11.56	1.013	1.31	4.32
30-Oct-88	BC4	98	16.0	710	5.2	8.70	39.7	0.715	2.984	8.52	5.62	9.24	1.086	1.40	3.82
30-Oct-88	BC5	175	16.0	612	2.2	8.47	37.2	0.577	2.441	7.89	4.94	8.46	1.195	1.40	3.82
30-Oct-88	BC6	319	16.0	600	4.5	8.24	36.0	0.543	2.477	4.58	4.80	5.12	1.158	1.27	3.56
30-Oct-88	BC7	405	15.0	601	1.3	7.44	43.5	0.062	4.687	6.30	6.03	6.36	1.195	1.31	1.44
20-Nov-88	BC9	-630	15.5	149	3.2			0.008	0.093	3.39	0.52	3.40	1.311		
20-Nov-88	BC1	-84	11.5	231	1.4	6.10	16.5	0.008	0.147	3.74	2.76	3.75	0.458	0.48	1.43
20-Nov-88	BC2	0	16.5	606	8.2	7.73	39.9	0.029	5.577	10.24	9.00	10.27	1.311	1.60	3.06
20-Nov-88	BC3	50	14.5	659	8.1	7.84	41.2	0.106	5.851	40.96	8.93	41.06	1.354	1.54	5.39
20-Nov-88	BC4	98	16.0	674	7.2	7.85	49.2	0.081	6.230	8.73	9.94	8.81	1.268	1.49	2.16
20-Nov-88	BC5	175	17.0	533	6.3	7.57	35.4	0.013	4.651	2.94	4.27	2.96	0.884	1.18	1.67
20-Nov-88	BC6	319	16.0	533	5.1	7.48	36.1	0.018	4.798	7.73	7.32	7.74	1.012	0.96	1.76
20-Nov-88	BC7	405	14.5	520	3.0	7.36	37.3	0.008	5.430	8.53	7.17	8.53	1.226	1.40	1.76
20-Nov-88	BC8	562	13.0	498	3.9	7.16	37.3	0.004	4.377	8.07	7.32	8.08	1.524	1.71	2.11
16-Dec-88	BC9	-630	3.5	155	3.5	6.44	12.5	0.170	0.283	2.11	2.11	2.28	0.087	0.28	0.41
16-Dec-88	BC1	-84	3.5	244	0.8	6.40	14.9	0.077	0.264	2.80	2.29	2.88	0.525	0.57	0.89
16-Dec-88	BC2	0	3.5	732	4.2	7.69	40.1	0.281	5.407	4.59	17.52	4.87	2.005	2.27	2.51
16-Dec-88	BC3	50	4.0	708	4.6	7.70	38.3	0.502	10.476	3.72	1.31	4.22	2.097	2.31	2.54
16-Dec-88	BC4	98	4.0	724	5.1	7.77	38.3	0.502	10.324	3.81	15.50	4.31	1.622	2.27	2.45
16-Dec-88	BC5	200	3.0	658	5.5	7.57	37.8	0.244	9.333	3.21	11.35	3.45	1.914	2.11	2.13
16-Dec-88	BC6	291	3.0	642	5.5	7.61	39.5	0.244	8.571	4.31	15.05	4.56	1.914	1.81	2.18
16-Dec-88	BC7	405	2.5	649	4.0	7.54	36.1	0.207	8.571	3.90	15.32	4.11	1.951	2.13	2.22
16-Dec-88	BC8	562	3.0	625	2.9	7.46	36.1	0.244	8.113	1.28	1.10	1.53	0.087	2.22	2.36
09-Jan-89	BC9	-630	8.5	116	6.1	6.41	15.9	0.337	0.166	2.44	1.35	2.78	0.245	0.28	0.44
09-Jan-89	BC1	-84	11.0	185	0.7	6.84	19.1	0.503	1.131		2.03		0.376	0.42	0.57
09-Jan-89	BC2	0	10.0	526	6.6	7.58	39.3	0.009	7.052	15.32	14.91	15.33	1.586	1.89	2.94
09-Jan-89	BC3	50	10.0	491	9.6	7.53	34.9	0.053	13.625	16.82	44.89	16.87	1.428	1.81	3.17
09-Jan-89	BC4	98	11.0	439	5.5	7.10	32.7	0.096	0.925	2.52	9.51	2.61	1.007	1.27	1.77
09-Jan-89	BC5	200	10.5	423	9.8	7.16	29.5	0.074	3.450	6.65	7.97	6.73	0.866	1.08	1.52
09-Jan-89	BC6	291	8.5	494	7.3	7.30	30.6	0.104	4.490	10.78	7.79	10.89	1.042	1.27	1.81
09-Jan-89	BC7	405	8.5	494	4.0	7.18	30.6	0.038	6.718	10.88	8.70	10.91	1.147	1.43	1.85
09-Jan-89	BC8	562	9.5	483	2.2	7.18	32.7	0.023	6.050	12.60	9.06	12.62	1.569	1.85	2.39
29-Jan-89	BC9	-630	8.0	103	6.4		10.7	0.169	0.002	17.71	13.85	17.88	0.094	0.43	0.48
29-Jan-89	BC1	-84	7.5	892	0.8		41.6	0.010	27.840	43.28	30.01	43.29	3.231	3.52	4.34
29-Jan-89	BC2	0	10.0	618	12.8		36.1	0.016	3.481	15.78	9.99	15.80	1.051	1.32	1.87
29-Jan-89	BC3	50	9.5	656	13.6		38.5	0.061	8.601	20.61	12.40	20.67	1.307	1.56	2.30
29-Jan-89	BC4	98	10.0	653	15.0		37.3	0.445	11.062	19.16	12.40	19.60	1.417	1.56	2.17

Appendix E (cont.)

DATE	STATION	DIST. (m)	TEMP. (C)	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	PKN mg/L	TN mg/L	PO4 mg/L	PTP mg/L	TP mg/L
29-Jan-89	BC5	200	9.0	524	18.0		31.4	0.041	8.046	13.37	9.51	13.41	1.014	1.26	1.82
29-Jan-89	BC6	291	9.0	517	12.4		29.0	0.022	6.855	9.99	8.06	10.01	1.014	1.56	1.74
29-Jan-89	BC7	405	7.0	511	11.2		31.4	0.014	7.411	12.40	8.55	12.42	1.051	1.26	2.04
29-Jan-89	BC8	562	6.0	530	12.9		31.4	0.006	12.888	12.40	8.55	12.41	1.564	1.91	2.39
26-Feb-89	BC9	-630	2.0	93	10.3	6.00	15.6	0.287	0.085	9.84	0.00	10.13	0.049	0.04	0.04
26-Feb-89	BC1	-84	2.5	67	10.4	8.60	5.8	0.226	0.114	17.55	14.61	17.78	0.076		0.06
26-Feb-89	BC2	0	5.5	435	9.9	9.10	28.7	0.176	2.069	217.09	85.11	217.26	0.559	0.51	1.03
26-Feb-89	BC3	50	4.5	191	10.5	8.40	18.9	0.232	3.448	200.18	104.25	200.41	0.299	0.31	0.39
26-Feb-89	BC4	98	4.5	199	10.9	8.33	11.9	0.221	1.719	171.94	102.14	172.16	0.228	0.16	0.31
26-Feb-89	BC5	200	3.5	98	10.6	8.00	14.8	0.242	0.359	10.69	11.63	10.93	0.015	0.08	0.18
26-Feb-89	BC6	291	3.0	82	10.5	8.00	13.4	0.214	0.069	7.96	21.18	8.18	0.045		0.04
26-Feb-89	BC7	405	2.5	183	7.5	8.20	24.3	0.298	0.452	31.84	14.99	32.14	0.111	0.04	0.12
26-Feb-89	BC8	562	2.0	168	9.5	8.20	16.6	0.259	0.160	13.41	5.26	13.67	0.064		0.12
19-Mar-89	BC9	-630	13.5	45	7.8	6.13	9.6	0.053	0.432	0.79	0.97	0.85	0.050	0.07	0.22
19-Mar-89	BC1	-84	13.5	45	8.2	5.73	10.2	0.048	0.481	1.21	0.97	1.26	0.072	0.12	0.24
19-Mar-89	BC2	0	18.5	307	9.5		19.8	0.048	0.234				0.101		
19-Mar-89	BC3	50	14.0	51	8.2	5.83	18.5	0.048	0.035	1.93	2.11	1.98	0.094	0.22	0.32
19-Mar-89	BC4	98	14.0	51	8.0	6.04	18.5	0.053	0.085	1.87	1.63	1.92	0.138	0.22	0.32
19-Mar-89	BC5	200	13.0	52	7.2	5.99	15.9	0.040	0.258	0.91	0.79	0.95	0.060	0.14	0.24
19-Mar-89	BC6	291	13.0	52	7.8	6.01	19.8	0.014	0.135	1.75	0.85	1.77	0.040	0.12	0.27
19-Mar-89	BC7	405	14.5	51	8.3	6.01	8.3	0.005	0.481	0.85	0.73	0.86	0.045	0.12	0.22
19-Mar-89	BC8	562	14.0	51	8.4		8.3	0.031	0.432	1.03	0.73	1.06	0.074	0.12	0.32
09-Apr-89	BC9	-630			7.3		3.6	0.136	0.150	0.87	0.81	1.00	0.314	0.08	0.03
09-Apr-89	BC1	-84			10.3		4.3	0.024	0.064	1.28	1.08	1.31	0.052	0.02	0.02
09-Apr-89	BC2	0			4.9		17.6	0.017	4.208	10.34	7.48	10.35	0.425	0.67	1.17
09-Apr-89	BC3	50			7.5		14.2	0.035	2.994	7.87	5.49	7.90	0.416	0.47	1.02
09-Apr-89	BC4	98			7.8		13.7	0.035	2.060	6.56	4.13	6.60	0.393	0.38	0.72
09-Apr-89	BC5	200			7.0		3.9	0.092	0.176	1.37	1.13	1.46	0.372	0.10	0.05
09-Apr-89	BC6	291			7.0		3.6	0.088	0.159	1.34	1.05	1.43	0.374	0.08	0.18
09-Apr-89	BC7	405			5.6		4.7	0.101	0.211	1.64	0.99	1.74	0.365		0.23
09-Apr-89	BC8	562			7.9		3.6	0.088	0.164	1.05	1.05	1.13	0.337	0.08	0.28
30-Apr-89	BC9	-630				6.28	4.2	0.073	0.092	1.11	0.96	1.18	0.104	0.69	1.44
30-Apr-89	BC1	-84				6.19	4.8	0.090	0.066	1.63	0.88	1.72	0.112	0.39	0.49
30-Apr-89	BC2	0				7.98	21.3	0.030	1.183		4.20		0.283	2.88	2.98
30-Apr-89	BC4	98				6.52	5.9	0.086	0.319	2.80	1.91	2.89	0.146	0.65	0.81
30-Apr-89	BC5	200				6.12	4.7	0.069	0.173	1.38	1.13	1.45	0.139	0.65	0.80
30-Apr-89	BC6	291				6.04	4.6	0.056	0.121	1.36	1.31	1.41	0.115	0.22	0.31
30-Apr-89	BC7	405				6.09	4.3	0.056	0.168	1.21	0.96	1.26	0.173	0.79	0.85
30-Apr-89	BC8	562				5.98	5.4	0.064	0.191	1.66	0.86	1.72	0.204	0.33	0.60
30-Apr-89	BC10	1000				6.39	5.8	0.490	0.342	1.56	1.21	2.05	0.274	0.26	0.38
20-May-89	BC9	-630	24.0	51	3.2		8.1	0.080	0.143	1.39	1.12	1.47	0.085	0.08	0.26
20-May-89	BC1	-84	18.0	70	2.2		8.8	0.014	0.501	2.45	1.67	2.46	0.134	0.17	0.51
20-May-89	BC2	0	23.0	366	8.6		25.8	0.116	3.699	16.00	3.71	16.12	0.876	1.44	2.46

Appendix E (cont.)

DATE	STATION	DIST. (m)	TEMP. (C)	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	FKN mg/L	TN mg/L	PO4 mg/L	FTP mg/L	TP mg/L
20-May-89	BC4	98	23.0	334	1.9		23.5	0.045	4.820	3.10	2.85	3.14	0.756	1.08	1.21
20-May-89	BC5	200	22.0	118	2.4		15.6	0.017	4.858	5.06	2.85	5.08	0.742	1.14	2.53
20-May-89	BC6	291	22.0	214	2.5		15.6	0.002	3.390	5.09	4.12	5.10	0.482	0.71	1.42
20-May-89	BC7	405	19.0	194	1.5		15.6	0.009	3.776	4.99	4.40	5.00	0.635	0.94	1.36
20-May-89	BC8	562	18.5	191	1.7		15.6	0.019	3.235	4.99	4.24	5.01	0.566	0.80	1.24
20-May-89	BC10	3750	19.0	103	6.8		12.4	1.003	0.220	0.90	0.73	1.90	0.202	0.26	0.48
12-Jun-89	BC9	-630	24.0	71	3.1	7.21	7.5	0.001	0.002	1.93	1.27	1.92	0.058	0.37	0.59
12-Jun-89	BC1	-84	20.0	101	1.3	7.34	24.9	0.029	0.144	2.23	1.71	2.26	0.357	0.67	0.89
12-Jun-89	BC2	0	26.0	488	4.4	9.16	25.4	0.001	1.276	12.34	4.77	12.33	0.601	1.08	1.85
12-Jun-89	BC4	98	27.0	477	1.8	8.37	26.3	0.001	2.595	3.96	5.50	3.95	0.654	1.14	1.78
12-Jun-89	BC5	200	26.5	449	9.5	8.53	22.6	0.001	3.067	9.67	5.29	9.67	0.791	1.10	1.91
12-Jun-89	BC6	291	26.5	386	10.0	7.67	20.8	0.001	3.123	7.06	4.84	7.06	0.734	1.06	1.48
12-Jun-89	BC7	405	26.0	371	6.1	7.50	22.6	0.001	3.123	8.30	4.60	8.30	0.711	0.93	1.65
12-Jun-89	BC8	562	22.0	310	1.3	7.51	16.5	0.009	3.312	8.44	7.87	8.45	0.077	1.10	1.36
12-Jun-89	BC10	3750	22.0	128	6.2	7.26	13.1	0.708	0.002	1.62	0.86	2.32	0.151	0.37	0.54
29-Jun-89	BC9	-630	26.0	73	0.7		6.2	0.005	0.299	2.19	1.05	2.20	0.088	0.17	0.65
29-Jun-89	BC1	-84	23.0	731	0.2		32.1	0.001	16.050	19.72	17.12	19.71	2.474	2.64	3.21
29-Jun-89	BC2	0	29.5	437	4.6		29.7	0.049	0.550	8.05	4.80	8.10	0.588	0.99	1.34
29-Jun-89	BC4	98	27.5	519	0.4		34.8	0.001	4.179	9.53	8.26	9.52	1.073	1.40	1.70
29-Jun-89	BC5	200	29.0	438	0.6		27.1	0.001	4.013	8.24	7.05	8.23	0.841	1.26	1.46
29-Jun-89	BC6	291	28.5	387	2.0		20.0	0.001	3.625	7.50	6.17	7.50	0.646	1.09	1.43
29-Jun-89	BC7	405	28.0	382	1.3		17.7	0.001	3.958	7.16	6.84	7.15	0.665	1.05	1.77
29-Jun-89	BC8	562	25.0	359	1.3		18.5	0.005	3.791	7.41	6.17	7.41	0.776	1.09	1.74
29-Jun-89	BC10	3750	25.0	110	2.1		11.0	0.583	0.052	1.19	0.86	1.78	0.148	0.58	0.48
24-Jul-89	BC9	-630	26.0	102	1.6	6.58	10.1	0.012	0.079	2.75	0.98	2.76	0.120	0.21	0.37
24-Jul-89	BC1	-84	25.5	790	0.2	7.33	33.6	0.001	16.300	24.84	18.48	24.83	2.820	2.65	3.73
24-Jul-89	BC2	0	29.0	456	3.3	9.02	21.7	0.001	1.340	15.53	5.79	15.51	0.650	0.88	2.36
24-Jul-89	BC4	98				7.80	25.9	0.001	5.406	13.73	9.84	13.71	1.373	1.51	2.06
24-Jul-89	BC5	200	31.5	620		7.61	22.9	0.001	4.777	10.94	8.26	10.92	1.201	1.29	1.92
24-Jul-89	BC6	291	28.0	559		7.05	18.9	0.001	4.740		6.82		0.874	0.84	1.55
24-Jul-89	BC7	405	31.0	514		7.20	19.9	0.166	4.371	17.42	6.92	17.59	0.839	0.80	0.92
24-Jul-89	BC8	562	26.5	439		7.16	18.9	0.005	3.705	13.23	5.87	13.24	1.046	0.92	1.39
24-Jul-89	BC10	3750	28.0	121	2.8	6.69	13.7	0.383	0.045	3.25	1.03	3.63	0.189	0.25	0.49
14-Aug-89	BC9	-630	23.5	114	1.9		11.6	0.053	0.181				0.094	0.09	0.37
14-Aug-89	BC1	-84	24.0	827	0.2		41.4	0.001	16.001				2.349	2.24	2.81
14-Aug-89	BC2	0	25.0	599	4.4		33.1	0.051	7.613				1.271	1.39	1.96
14-Aug-89	BC4	98	26.0	703	0.4		36.9	0.001	13.779				1.879	1.90	2.61
14-Aug-89	BC5	200	25.0	549	0.4		27.6	0.001	8.427				1.483	1.59	1.92
14-Aug-89	BC6	291	23.5	475	0.2		27.0	0.001	7.006				1.126	1.23	2.69
14-Aug-89	BC7	405	24.5	454	0.4		27.0	0.000	5.222				0.972	1.04	1.31
14-Aug-89	BC8	562	23.0	407	0.7		27.0	0.010	3.787				0.692	0.88	1.31
14-Aug-89	BC10	3750	26.0	122	6.1		15.0	0.509	0.026				0.171	0.17	0.17
04-Sep-89	BC9	-630	23.0	71	0.8		8.2	0.048	0.040	4.71	1.38	4.76	0.010	0.17	0.70

Appendix E (cont.)

DATE	STATION	DIST. (m)	TEMP. (C)	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	PKN mg/L	TN mg/L	PO4 mg/L	PTP mg/L	TP mg/L
04-Sep-89	BC1	-84	21.6	841	0.2		38.8		17.181	19.88	16.29		2.688	2.76	3.16
04-Sep-89	BC2	0	25.0	624	1.8		35.4	0.001	5.668	16.29	9.48	16.28	1.428	1.70	2.42
04-Sep-89	BC4	98	24.0	664	0.3		34.1	0.005	8.977	25.54	9.67	25.55	1.018	1.31	6.22
04-Sep-89	BC5	200	21.4	650	0.6		42.3	0.001	9.596	296.86		296.85	1.323	1.50	73.87
04-Sep-89	BC6	291	21.6	701	0.3		44.5	0.159	5.765	26.68	6.83	26.84	0.388	4.76	9.67
04-Sep-89	BC7	405	20.4	399	1.2		24.7	0.001	0.544	4.18	3.12	4.18	0.283	0.40	0.93
04-Sep-89	BC8	562	20.0	453	0.8		38.1	0.001	1.317	3.12	2.86	3.11	0.619	0.74	0.97
04-Sep-89	BC10	3750	22.4	101	5.3		12.1	0.276	0.020	0.66	0.74	0.94	0.001	0.10	0.14
												0.00			
24-Sep-89	BC9	-630	20.0	101	1.2		10.4	0.004	0.388	3.40	2.34	3.41	0.065	0.49	1.11
24-Sep-89	BC1	-84	18.0	257	1.1		26.8	0.001	9.761	14.94	8.72	14.94	1.042	2.55	3.71
24-Sep-89	BC2	0	20.0	671	1.9		35.9	0.014	10.400	37.59	29.60	37.61	1.292	4.88	6.94
24-Sep-89	BC4	98	17.6	520	2.6		28.7	0.001	15.240	22.49	22.49	22.49	1.206	3.98	5.23
24-Sep-89	BC5	200	17.5	556	1.4		24.1	0.021	5.953	43.81	18.94	43.83	0.863	3.75	4.76
24-Sep-89	BC6	291	17.6	531	0.6		31.2	0.111	5.976	73.13	23.38	73.24	0.649	3.91	18.85
24-Sep-89	BC7	405	17.0	515	0.8		33.6	0.044	6.844	48.25	15.40	48.30	0.478	2.74	11.83
24-Sep-89	BC8	562	17.5	207	2.4		33.1	0.011	4.241	14.06	11.84	14.07	0.820	2.97	4.06
24-Sep-89	BC10	3750	18.6	139	8.7		15.4	0.198	0.004	0.74	0.56	0.94	0.082	0.49	0.80
15-Oct-89	BC9	-630	19.0	63	0.9	6.58	6.4	0.018	0.259	1.52	1.04	1.54	0.112	0.06	0.22
15-Oct-89	BC1	-84	17.0	778	0.3	7.33	46.0		2.459	34.96	17.40		2.642	2.76	3.43
15-Oct-89	BC2	0	18.5	544	6.5	9.02	30.2	0.001	4.398	13.80	3.46	13.80	1.001	1.25	1.96
15-Oct-89	BC4	98	19.0		5.6	7.80	30.8	0.037	5.117	13.80	7.78	13.84	1.077	1.14	2.09
15-Oct-89	BC5	200	17.5	320	2.6	7.61	28.3	0.074	4.028	55.64	7.68	55.71	0.848	1.12	5.82
15-Oct-89	BC6	291	17.0	503	0.7	7.05	27.1	0.062	3.484	12.36	6.09	12.42	0.772	0.87	2.40
15-Oct-89	BC7	405	17.0	461	0.7	7.20	25.8	0.072	3.095	7.25	5.61	7.32	0.619	0.72	1.06
15-Oct-89	BC8	562	16.0	392	1.9	7.16	24.6	0.091	2.240	5.08	4.07	5.17	0.581	0.52	0.72
15-Oct-89	BC10	3750	18.0	105	6.6	6.69	13.5	0.355	0.006	0.18	0.03	0.53	0.047	0.06	0.14
26-Nov-89	BC9	-630	8.0	51			6.9	0.108	0.015	1.11	0.81	1.22	0.037	0.05	0.05
26-Nov-89	BC1	-84	8.2	58			7.5	0.059	0.370	1.66	1.68	1.72	0.076	0.05	0.09
26-Nov-89	BC2	0	8.9	468			28.6	0.208	2.025	11.33	4.33	11.54	0.705	0.85	2.13
26-Nov-89	BC4	98	11.0	309			20.7	0.316	1.453	7.75	3.11	8.07	0.486	0.57	1.09
26-Nov-89	BC5	200	9.6	78			8.8	0.129	0.260	1.93	1.63	2.06	0.094	0.09	0.15
26-Nov-89	BC6	291	9.4	57			7.1	0.101	0.118	1.06	0.86	1.16	0.064	0.05	0.13
26-Nov-89	BC7	405	10.2	175			11.7	0.252	0.260	1.66	1.41	1.91	0.166	0.18	0.22
26-Nov-89	BC8	562	8.8	79			8.6	0.172	0.141	0.96	0.91	1.13	0.103	0.09	0.13
26-Nov-89	BC10	3750	9.8	85			9.9	0.353	0.007	1.51	0.71	1.86	0.092	0.05	0.13
19-Dec-89	BC9	-630	1.0	86		6.95	5.3	0.104	0.036	0.81	0.48	0.91	0.016	0.21	0.25
19-Dec-89	BC1	-84	1.0	189		7.56	8.4	0.070	1.267	2.58	2.03	2.65	0.083	0.28	0.40
19-Dec-89	BC2	0	4.0	434		7.87	27.0	0.218	3.820	5.99	6.65	6.21	0.421	0.98	1.32
19-Dec-89	BC4	98	3.0	321		7.69	19.9	0.197	3.091	6.93	4.90	7.13	0.280	0.64	0.94
19-Dec-89	BC5	200	1.0	103		7.43	8.4	0.078	0.537	1.89	1.52	1.97	0.059	0.21	0.25
19-Dec-89	BC6	291	1.0	86		7.26	7.6	0.067	0.689	1.54	1.36	1.61	0.046	0.25	0.25
19-Dec-89	BC7	405	1.0	86		7.39	7.6	0.082	0.589	1.41	1.17	1.49	0.038	0.21	0.21
19-Dec-89	BC8	562	1.0	86		7.31	7.9	0.111	0.570	1.36	1.13	1.47	0.042	0.25	0.25
19-Dec-89	BC10	3750	1.0	86		7.03	8.7	0.413	0.144	0.71	0.58	1.13	0.031	0.30	0.30

Appendix E (cont.)

DATE	STATION	DIST. (m)	TEMP. (C)	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	FKN mg/L	TN mg/L	PO4 mg/L	FTP mg/L	TP mg/L
09-Jan-90	BC9	-630	5.0	47	9.6		6.9	0.182	0.056	0.71	0.62	0.90	0.051	0.14	0.19
09-Jan-90	BC1	-84	5.5	101	10.6		8.8	0.683	1.369	2.83	2.16	3.52	0.199	0.31	0.44
09-Jan-90	BC2	0	7.5	475	8.4		28.3	0.082	5.383	8.75	4.38	8.84	0.880	1.29	1.82
09-Jan-90	BC4	98	6.5	84	11.2		8.0	0.257	0.703	2.28	1.87	2.54	0.173	0.27	0.36
09-Jan-90	BC5	200	5.5	54	10.6		6.4	0.182	0.124	1.08	0.74	1.26	0.070	0.14	0.23
09-Jan-90	BC6	291	5.5	47	11.2		5.6	0.122	0.100	0.81	0.62	0.93	0.058	0.10	0.19
09-Jan-90	BC7	405	5.0	71	8.8		7.7	0.276	0.289	1.41	1.27	1.68	0.129	0.23	0.31
09-Jan-90	BC8	562	5.0	55	9.4		6.6	0.193	0.129	0.90	0.67	1.09	0.081	0.14	0.23
09-Jan-90	BC10	3750	5.0	47	10.0		8.2	0.418	0.888	2.19	1.73	2.61	0.092	0.23	0.31
30-Jan-90	BC9	-630	10.5	62	7.9	6.12	8.5	0.080	0.116	0.84	0.70	0.92	0.065	0.02	0.07
30-Jan-90	BC1	-84	10.5	125	6.1	6.72	10.8	0.122	1.615	3.72	3.01	3.84	0.274	0.38	0.55
30-Jan-90	BC2	0	12.0	469	14.8	9.52	27.3	0.055	1.634	9.15	5.38	9.20	0.548	0.67	1.56
30-Jan-90	BC4	98	10.0	246	8.8	7.73	17.1	0.115	1.691	7.23	3.82	7.35	0.353	0.36	0.79
30-Jan-90	BC5	200	9.0	93	7.0	6.67	9.3	0.080	0.411	1.91	1.52	1.99	0.130	0.10	0.22
30-Jan-90	BC6	291	9.5	71	6.2	7.07	8.3	0.065	0.280	1.33	0.99	1.39	0.101	0.07	0.17
30-Jan-90	BC7	405	7.5	171	6.7	6.93	14.7	0.103	0.665	1.82	1.48	1.92	0.343	0.26	0.36
30-Jan-90	BC8	562	8.0	95	7.1	6.81	9.4	0.088	0.413	1.33	1.09	1.42	0.177	0.12	0.17
30-Jan-90	BC10	3750	9.5	78	8.7	6.33	10.8	0.459	0.440	1.23	0.94	1.69	0.137	0.07	0.12
20-Feb-90	BC9	-630	9.0	43	8.3		6.6	0.112	0.029	0.93	0.48	1.04	0.046	0.02	0.05
20-Feb-90	BC1	-84	10.0	154	9.1		6.5	0.070	0.048	1.00	0.80	1.07	0.051	0.02	0.08
20-Feb-90	BC2	0	9.0	460	8.4		59.8	0.256	5.577	19.35	16.15	19.61	1.144	1.33	2.00
20-Feb-90	BC4	98	10.0	309	10.2		6.4	0.065	0.081	1.47	0.88	1.53	0.064	0.10	0.14
20-Feb-90	BC5	200	10.5	132	9.6		6.4	0.085	0.059	0.90	0.63	0.99	0.060	0.05	0.10
20-Feb-90	BC6	291	11.0	55	9.4		6.1	0.075	0.051	0.78	0.48	0.85	0.049	0.01	0.05
20-Feb-90	BC7	405	10.0	98	9.9		6.4	0.108	0.044	0.83	0.58	0.94	0.086	0.05	0.05
20-Feb-90	BC8	562	10.5	76	9.7		6.4	0.115	0.048	0.78	0.53	0.89	0.082	0.01	0.05
20-Feb-90	BC10	3750	10.0	56	10.2		7.1	0.534	0.404	1.17	1.02	1.71	0.136	0.05	0.18
08-Mar-90	BC9	-630	10.0	56		5.44	6.7	0.059	0.046	0.65	0.42	0.71	0.047	0.02	0.03
08-Mar-90	BC1	-84	7.0	45		5.06	7.0	0.056	0.110	1.22	0.91	1.27	0.041	0.03	0.10
08-Mar-90	BC2	0	11.0	357		7.81	25.8	0.036	2.191	2.55	6.47	2.58	0.531	0.69	1.34
08-Mar-90	BC4	98	9.0	86		6.06		0.056	0.653	3.00	2.34	3.06	0.116	0.12	0.26
08-Mar-90	BC5	200	9.0	57		5.62	5.6	0.036	0.236	1.29	0.94	1.32	0.098	0.14	0.19
08-Mar-90	BC6	291	9.5	71		5.67	6.2	0.036	0.268	1.17	0.98	1.21	0.098	0.03	0.12
08-Mar-90	BC7	405	10.0	70		5.87	7.5	0.039	0.238	1.17	0.84	1.21	0.156	0.17	0.21
08-Mar-90	BC8	562	8.0	81	6.7	5.75	6.2	0.122	0.249	1.08	0.79	1.20	0.109	0.07	0.12
08-Mar-90	BC10	3750	9.5	78		6.01	8.6	0.565	0.019	0.33	0.28	0.89	0.138	0.12	0.17
03-Apr-90	BC9	-630	13.0	46	4.6		5.8	0.099	0.040	0.56	0.86	0.66	0.100	0.09	0.13
03-Apr-90	BC1	-84	14.0	38	5.1		5.3	0.055	0.031	0.74	0.56	0.79	0.074	0.05	0.16
03-Apr-90	BC2	0	15.0	313	5.1		17.1	0.104	1.936	6.09	4.50	6.19	0.443	0.70	1.28
03-Apr-90	BC4	98	15.0	44	5.3		5.4	0.059	0.059	0.86	0.41	0.92	0.097	0.02	0.13
03-Apr-90	BC5	200	14.0	45	4.9		5.5	0.104	0.046	0.63	0.25	0.74	0.082	0.07	0.13
03-Apr-90	BC6	291	14.0	38	5.0		5.4	0.117	0.044	0.51	0.35	0.62	0.115	0.05	0.09
03-Apr-90	BC7	405	14.0	26	4.8		5.4	0.120	0.044	0.30	0.10	0.42	0.093	0.05	0.13

Appendix E (cont.)

DATE	STATION	DIST. (m)	TEMP. (C)	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	PKN mg/L	TN mg/L	PO4 mg/L	PTP mg/L	TP mg/L
03-Apr-90	BC8	562	14.0	19	4.7		5.3	0.120	0.051	0.61	0.20	0.73	0.097	0.09	0.18
03-Apr-90	BC10	3750	14.0	51	5.1		6.2	0.240	0.070	0.61	0.30	0.85	0.093	0.09	0.22
24-Apr-90	BC9	-630	20.0	89	2.5	6.03	13.3	0.002	0.038	1.40	0.80	1.40	0.062	0.14	0.19
24-Apr-90	BC1	-84	18.0	76	1.3	5.94	12.9	0.053	0.605	2.59	1.68	2.64	0.100	0.16	0.32
24-Apr-90	BC2	0	23.0	428	5.4	8.79	29.8	0.053	2.120	15.42	7.06	15.47	0.623	1.17	2.34
24-Apr-90	BC4	98	24.0	245	2.2	6.96	22.4	0.013	2.787	8.57	5.64	8.58	0.477	0.67	1.10
24-Apr-90	BC5	200	24.0	194	3.2	6.31	18.0	0.024	1.417	5.08	2.68	5.10	0.217	0.27	0.75
24-Apr-90	BC6	291	21.0	208	4.1	6.40	18.1	0.035	1.565	5.03	3.78	5.07	0.273	0.32	0.80
24-Apr-90	BC7	405	21.0	191	1.7	5.79	18.1	0.031	1.639	3.31	2.71	3.34	0.586	0.62	0.84
24-Apr-90	BC8	562	21.0	164	1.6	5.74	17.3	0.219	1.787	3.78	2.75	4.00	0.341	0.45	0.62
24-Apr-90	BC10	3750	19.0	80	3.4	6.73	16.3	0.584	0.023	0.52	0.84	1.10	0.119	0.14	0.19
16-May-90	BC9	-630	23.0	94	5.5		12.7	0.226	0.059	2.14	0.90	2.37	0.077	0.04	0.18
16-May-90	BC1	-84	22.0	182	0.8		14.9	0.005	1.608	3.52	2.43	3.53	0.177	0.07	0.45
16-May-90	BC2	0	24.0	490	4.6		32.1	0.127	2.551	8.76	6.08	8.88	0.639	0.72	1.42
16-May-90	BC4	98	26.0	327	3.8		23.2	0.024	2.898	6.72	4.29	6.74	0.492	0.45	0.86
16-May-90	BC5	200	30.0	178	5.1		15.4	0.057	0.934	6.03	1.88	6.09	0.258	0.23	1.02
16-May-90	BC6	291	25.0	165	4.2		14.7	0.054	0.780	3.00	1.85	3.05	0.271	0.18	0.45
16-May-90	BC7	405	26.0	151	4.1		14.5	0.046	1.281	3.28	2.19	3.33	0.327	0.23	0.54
16-May-90	BC8	562	23.0	146	1.1		14.7	0.177	1.781	2.71	1.90	2.89	0.368	0.23	0.50
16-May-90	BC10	3750	25.0	80	6.8		15.4	0.674	0.055	2.71	0.28	3.39	0.148	0.09	0.23

Appendix F. Physical factors and chloride and nutrient concentrations in Scotland Neck wastewater effluent and Deep Creek waters.

DATE	STATION	DIST. m	TEMP. °C	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	FKN mg/L	TN mg/L	PO4 mg/L	FTP mg/L	TP mg/L
30-Oct-88	DC7	-5800	10.5	108	2.4	7.43	161.4	5.424	0.286	2.03	1.89	7.46	2.357	2.46	2.47
30-Oct-88	DC1	-75	10	140	4.2	6.33	178.8	1.224	0.757	0.19	0.16	1.42	0.063	0.09	0.08
30-Oct-88	DC2	0	16.3	1521	8.3	7.85	133.5	5.045	0.340	2.42	1.44	7.47	1.449	2.98	3.21
30-Oct-88	DC3	58	13	852	6.1	7.6	103.1	5.458	0.092	1.04	0.90	6.50	1.558	1.60	1.60
30-Oct-88	DC4	121	13	983	5.4	7.48	114.2	5.527	0.154	1.28	1.02	6.80	1.703	1.75	1.77
30-Oct-88	DC5	220	13	1049	5.0	7.54	122.0	5.836	0.161	1.34	1.21	7.17	2.139	1.91	1.97
30-Oct-88	DC6	308	13	1036	5.2	7.51	120.1	5.630	0.175	1.32	1.40	6.95	1.849	1.87	1.87
20-Nov-88	DC7	-5800	18	117	1.3	7.38	12.0	0.057	0.343	3.12	1.75	3.18	0.116	0.20	0.74
20-Nov-88	DC1	-75	17	150	8.1	6.77	22.1	0.514	0.799	0.54	0.36	1.06	0.157	0.13	0.16
20-Nov-88	DC2	0	16	1041	10.3	7.36	110.2	5.851	2.441	3.66	1.87	9.51	2.591	4.62	5.00
20-Nov-88	DC3	58	16.5	1315	12.0	7.4	129.6	6.516	2.862	4.13	3.62	10.65	3.231	3.05	3.34
20-Nov-88	DC4	121	16.5	1272	10.6	7.51	144.6	6.621	3.451	4.80	4.34	11.42	3.914	3.69	3.83
20-Nov-88	DC5	220	17.5	1160	9.2	7.63	140.2	6.271	3.030	4.63	3.88	10.90	4.170	3.77	3.74
20-Nov-88	DC6	308	16.5	1066	8.2	7.46	127.6	5.676	2.357	3.66	4.03	9.34	3.957	3.42	3.21
20-Nov-88	DC8	500	19.5	1131	1.6	7.45	133.8	0.006	2.020	3.97	3.83	3.98	5.536	5.29	5.25
20-Nov-88	DC9	700	18.3	1139	2.7	7.29	135.9	0.321	1.347	2.75	2.67	3.07	4.469	4.19	4.19
16-Dec-88	DC7	-580	3.8	137	0.9	7.59	13.9	0.019	0.721	2.57	2.27	2.59	0.196	0.28	0.29
16-Dec-88	DC1	-75	4.5	127	8.4	6.39	16.8	1.962	0.002	0.42	0.28	2.38	-0.059	0.03	0.04
16-Dec-88	DC2	0	9	1508	8.2	7.49	218.9	6.876	1.236	5.48	3.83	12.36	1.457	1.59	1.93
16-Dec-88	DC3	58	8.5	1452	8.5	7.44	163.5	6.008	0.931	3.89	3.11	9.90	1.512	1.28	1.41
16-Dec-88	DC4	121	7.5	1486	8.9	7.59	175.7	6.266	1.389	5.07	3.82	11.34	1.475	1.43	1.62
16-Dec-88	DC5	220	7.5	1337	8.1	7.55	161.1	5.823	1.427	4.71	3.57	10.53	1.402	1.35	1.66
16-Dec-88	DC6	308	7.5	1456	8.5	7.61	175.7	6.119	1.693	5.30	4.06	11.42	1.585	1.58	1.81
16-Dec-88	DC8	500	5.5	1399	8.0	7.61	173.2	5.786	1.693	5.62	4.34	11.41	1.768	1.71	1.90
16-Dec-88	DC9	700	3.5	1220	11.5	7.74	141.0	4.530	6.420	8.33	4.43	12.86	1.658	1.72	4.72
09-Jan-89	DC7	-5800	10	154	3.6	5.51	21.3	0.233	0.030	4.21	3.01	4.44	0.076	0.00	0.24
09-Jan-89	DC1	-75	11	82	8.2	6.58	8.5	1.091	0.425	0.90	0.87	1.99	0.182	0.29	0.16
09-Jan-89	DC2	0	12	778	8.5	7.22	88.9	11.563	0.388	16.98	1.55	28.55	1.375	1.68	5.56
09-Jan-89	DC3	58	12	590	8.0	7.09	65.5	8.862	0.425	11.73	1.23	20.59	1.007	1.17	2.7
09-Jan-89	DC4	121	12	617	7.4	7.16	65.5	8.643	0.463	10.92	1.23	19.56	1.007	1.15	2.73
09-Jan-89	DC5	220	11	508	6.5	7.06	46.1	6.110	0.425	14.62	1.27	20.73	0.796	0.93	2.9
09-Jan-89	DC6	308	11	357	5.8	6.96	34.7	4.613	1.057	9.42	1.83	14.03	0.656	0.81	1.8
09-Jan-89	DC8	500	11	357	6.8	7.11	40.9	4.431	3.545	8.15	2.01	12.58	0.796	0.93	2.41
09-Jan-89	DC9	700	10	421	9.1	7.21	51.4	3.664	1.020	4.78	2.15	8.45	1.042	2.47	1.85
29-Jan-89	DC7	-5800	7.5	119	3.6		17.5	0.041	0.226	1.24	1.08	1.28	0.021	0.15	0.1
29-Jan-89	DC1	-75	11.5	197	16.2		13.8	1.442	0.411	1.23	1.18	2.67	0.116	0.20	0.26
29-Jan-89	DC2	0	10.5	555	13.1		189.8	10.023	0.002	3.88	3.40	13.90	1.252	2.25	4.8
29-Jan-89	DC3	58		493	13.5		171.8	10.993	0.451	4.05	3.95	15.04	1.674	2.25	2.2

Appendix F (cont.)

DATE	STATION	DIST. m	TEMP. °C	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	FKN mg/L	TN mg/L	PO4 mg/L	FTP mg/L	TP mg/L
29-Jan-89	DC4	121	11	453	13.2		86.1	5.613	1.244	3.32	2.92	8.93	0.758	0.95	1.08
29-Jan-89	DC5	220	12	523	12.1		113.9	7.204	0.927	3.60	3.15	10.80	1.271	1.63	1.72
29-Jan-89	DC6	308	11.5	611	11.7		75.2	5.264	1.165	3.70	3.05	8.97	0.831	1.14	1.29
29-Jan-89	DC8	500	13	787	11.0		96.1	5.885	1.562	4.14	3.66	10.02	1.124	1.46	1.65
29-Jan-89	DC9	700	11.5	461	12.1		63.5	2.742	0.530	3.79	2.87	6.53	0.684	0.90	1.08
26-Feb-89	DC7	-5800	3	66	10.4	5.7	7.7	0.106	0.002	0.57	0.57	0.68	0.015	0.22	0.34
26-Feb-89	DC1	-75	9	187	8.5	6.6	18.9	1.495	1.698	4.35	3.93	5.85	0.272	9.93	16.83
26-Feb-89	DC2	0	9	187	8.4	6.5	18.3	1.844	1.616	3.63	4.69	5.48	0.174	9.03	17.81
26-Feb-89	DC3	58	9	194	10.5	6.7	17.7	1.583	1.843	4.23	3.55	5.81	0.213	12.88	25.45
26-Feb-89	DC4	121	9	215	8.4	6.4	18.9	1.513	1.719	4.57	4.31	6.08	0.253	14.31	23.53
26-Feb-89	DC5	220	10	211	7.9	6.5	20.1	0.884	2.871	5.50	4.74	6.38	0.057	15.05	25.45
26-Feb-89	DC6	308	9	230	7.8	6.8	20.1	1.199	2.954	6.26	5.41	7.46	0.292	13.58	28.47
26-Feb-89	DC8	500	10	232	7.4	6.7	23.7	1.443	2.913	6.60	5.84	8.05	0.448	19.06	32.77
26-Feb-89	DC9	700	4	72	11.4	5.8	9.7	0.643	0.155	2.31	2.08	2.95	0.409	0.40	2.68
19-Mar-89	DC7	-580	14.8	57	6.9	5.85	4.7	0.191	0.407	1.21	0.95	1.40	0.060	0.06	0.16
19-Mar-89	DC1	-75	12.2	103	7.7	6.21	14.6	0.626	0.481	1.80	1.65	2.43	0.104	0.17	0.16
19-Mar-89	DC2	0	14.5	114	8.2	6.21	15.9	0.654	0.002	2.13	2.16	2.78	0.133	0.18	0.21
19-Mar-89	DC3	58	14	167	8.1	6.24	22.5	0.662	0.002	3.03	3.03	3.69	0.182	0.25	0.31
19-Mar-89	DC4	121	14	205	8.2	6.48	19.8	0.636	0.002	3.51	3.03	4.14	0.216	0.25	0.36
19-Mar-89	DC5	220	14	179	8.1	6.55	18.5	0.636	0.002	3.36	2.65	4.00	0.206	0.23	0.34
19-Mar-89	DC6	308	14	179	7.8	6.54	18.5	0.636	0.531	2.94	2.68	3.58	0.211	0.14	0.20
19-Mar-89	DC8	500	14	154	6.7	6.54	18.5	0.623	0.481	2.91	2.65	3.54	0.226	0.20	0.31
19-Mar-89	DC9	700	15.5	75	8.5	6.05	7.1	-0.012	0.432	1.01	0.84	1.00	0.021	0.03	0.11
09-Apr-89	DC7	-5800	10	57	7.3		6.0	0.264	0.108	0.91		1.17	0.045	0.27	0.22
09-Apr-89	DC1	-75	14	70	7.8		10.3	0.674	0.218	1.30		1.97	0.094	-0.19	-0.15
09-Apr-89	DC2	0	12.5	99	8.0		10.8	0.687	0.255	1.64		2.33	0.111	0.58	1.07
09-Apr-89	DC3	58	13	131	7.8		15.6	0.700	0.584	2.36		3.06	0.160	0.39	0.92
09-Apr-89	DC4	121	13	131	7.9		16.2	0.700	0.598	2.71		3.41	0.164	0.29	0.63
09-Apr-89	DC5	220	13	144	7.8		16.2	0.700	0.556	2.51		3.21	0.164	0.15	0.10
09-Apr-89	DC6	308	13	138	7.9		5.9	0.700	0.131	2.31		3.01	0.160	-0.10	-0.15
09-Apr-89	DC8	500	12	74	8.0		6.3	0.427	0.075	1.21		1.64	0.090	0.00	0.19
09-Apr-89	DC9	700	10.5	56	8.6		0.7	0.193	0.099	1.01		1.20	0.052	0.00	-0.05
30-Apr-89	DC7	-5800				5.98	8.9	0.043	0.502	1.70	1.45	1.74	0.146	0.07	0.22
30-Apr-89	DC7.5	-5380				6.3	8.8	0.264	0.366	1.62	1.32	1.88	0.270	0.19	0.49
30-Apr-89	DC1	-75				5.88	9.1	0.482	0.236	1.89	1.50	2.37	0.220	0.26	0.36
30-Apr-89	DC2	0				7.29	60.0	0.592	1.089	2.52	1.71	3.11	1.579	2.93	3.04
30-Apr-89	DC4	121				6.14	15.4	0.699	0.304	1.83	1.80	2.53	0.486	0.53	0.71
30-Apr-89	DC5	220				6.17	14.7	0.694	0.272	2.01	1.83	2.70	0.463	0.53	0.71
30-Apr-89	DC6	308				6.2	13.3	0.690	0.290	1.80	1.71	2.49	0.436	0.53	0.68
30-Apr-89	DC8	500				6.28	14.9	0.686	0.403	2.76	1.68	3.45	0.474	0.58	1.39
30-Apr-89	DC9	700				6.15	8.6	0.099	0.206	1.56	1.44	1.66	0.146	0.12	0.24
30-Apr-89	DC10	1260				6.2	8.8	0.116	0.182	1.68	1.23	1.80	0.173	0.12	0.29

Appendix F (cont.)

DATE	STATION	DIST. m	TEMP. °C	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	FKN mg/L	TN mg/L	PO4 mg/L	FTP mg/L	TP mg/L
20-May-89	DC7	-5800	20	56	4.1		9.5	0.302	0.225	1.79	1.32	2.09	0.165	0.27	0.47
20-May-89	DC7.5	-5380	20	95	6.5		11.5	0.200	0.223	1.44	1.37	1.64	0.329	0.53	0.74
20-May-89	DC1	-75	20	112	10.6		13.5	2.391	0.084	0.48	0.32	2.87	0.041	0.05	0.12
20-May-89	DC2	0	20	699	10.7		93.5	10.939	0.018	1.13	0.84	12.06	2.513	1.87	1.87
20-May-89	DC4	121	20	419	9.8		45.0	4.983	0.095	1.34	0.60	6.32	0.645	0.76	1.21
20-May-89	DC5	220	20	492	9.8		57.5	5.567	0.072	0.96	0.65	6.52	1.029	1.02	1.09
20-May-89	DC6	308	20.5	398	10.1		52.4	5.145	0.084	0.91	0.65	6.05	0.736	0.77	0.87
20-May-89	DC8	500	19	446	9.1		52.8	5.275	0.281	2.69	0.86	7.96	0.756	0.87	1.96
20-May-89	DC9	700	23	167	5.2		23.1	1.678	0.277	2.18	1.51	3.86	0.300	0.42	0.83
20-May-89	DC10	1260	24	112	4.4										
12-Jun-89	DC7	-580	21	98	1.2	6.2	9.1	0.015	0.559	2.91	2.43	2.92	0.302	0.39	0.92
12-Jun-89	DC7.5	-538	23.5	103	2.3	6.38	12.3	0.246	0.861	2.06	1.61	2.31	0.850	0.48	0.73
12-Jun-89	DC1	-75	23	125	7.8	6.75	13.1	3.105	0.002	0.63	0.53	3.74	0.048	0.05	0.10
12-Jun-89	DC2	0	23.5	723	9.0	7.62	92.0	13.167	0.002	1.09	0.82	14.25	2.200	2.25	2.32
12-Jun-89	DC4	121	23.5	506	8.0	6.74	52.7	6.898	0.031	1.04	0.42	7.94	2.532	1.18	1.33
12-Jun-89	DC5	220	23	517	7.9	7.13	57.5	6.898	0.002	0.92	0.68	7.82	1.124	1.29	1.29
12-Jun-89	DC6	308	21	536	7.5	6.88	8.3	6.861	0.559	0.70	0.66	7.57	1.085	1.24	1.33
12-Jun-89	DC8	500	23	475	7.5	7.05	9.1	6.713	0.597	1.20	0.63	7.92	1.006	1.09	1.24
12-Jun-89	DC9	700	23	376	6.1	6.45	46.9	5.973	0.002	1.51	0.89	7.49	0.772	0.91	1.13
12-Jun-89	DC10	1260	22.5	275	4.5	6.65	38.2	3.198	0.106	1.56	1.56	4.76	0.459	0.55	0.66
29-Jun-89	DC7	-5800	25	60	1.3		7.4	0.417	0.271	0.47	0.10	0.88	0.239	1.33	2.11
29-Jun-89	DC7.5	-5380	27	86			9.0	0.619	0.241	0.69	0.15	1.31	0.389	1.38	1.60
29-Jun-89	DC1	-75	23	84	4.4		13.1	2.998		-0.17	-0.32	2.82	0.074	0.58	0.63
29-Jun-89	DC2	0	26	586	6.2		91.2	6.599	0.049	1.32	1.32	7.92	1.645	1.03	1.19
29-Jun-89	DC4	121	26	244	4.7		39.1	3.527	0.169	0.41	0.24	3.93	0.408	0.82	1.17
29-Jun-89	DC5	220	25	399	4.9		53.3	4.996	0.191	0.62	0.50	5.62	0.638	1.05	1.09
29-Jun-89	DC6	308	24	460	5.3		53.3	5.471	0.116	0.86	0.69	6.33	0.498	0.88	1.12
29-Jun-89	DC8	500	24.5	389	4.4		47.3	5.194	0.232	0.98	0.48	6.17	0.630	0.87	1.51
29-Jun-89	DC9	700	25	90	2.3		17.2	0.753	0.232	0.41	0.12	1.16	0.293	1.55	1.53
29-Jun-89	DC10	1260	27	81	2.4		10.1	0.242	0.130	0.22	0.00	0.46	0.237	1.48	1.72
24-Jul-89	DC7	-5800	26		2.1	6.09	7.4	0.443	0.149	1.96	1.27	2.40	0.207	0.19	0.30
24-Jul-89	DC7.5	-5380	27	86	4.7	6.54	8.2	0.177	0.097	1.29	1.24	1.46	0.278	0.39	0.44
24-Jul-89	DC1	-75	23.5	176	7.4	6.68	14.1	3.100	0.084	0.36	0.25	3.46	0.113	0.08	0.11
24-Jul-89	DC2	0	25	649	7.6	8.23	94.4	18.215	0.127	1.24	0.94	19.45	2.299	2.16	2.19
24-Jul-89	DC4	121	25.5		7.3	7.6	58.0	9.757	0.112	0.81	0.64	10.57	1.162	1.15	1.27
24-Jul-89	DC5	220	25.5	642	6.9	7.67	63.6	10.128	0.123	0.96	1.16	11.09	1.369	1.23	1.40
24-Jul-89	DC6	308	25	599	6.8	7.64	59.4	9.757	0.130	0.79	0.74	10.54	1.265	1.19	1.23
24-Jul-89	DC8	500	25	649	6.6	7.75	66.5	10.437	0.160	1.44	0.66	11.87	1.369	1.23	1.56
24-Jul-89	DC9	700	25	250	4.8	7.05	28.0	3.827	0.134	1.41	1.29	5.24	0.443	0.46	0.56
24-Jul-89	DC10	1260	26	146	4.7	6.6	16.8	1.093	0.086	1.31	1.46	2.40	0.330	0.38	0.44
14-Aug-89	DC7	-5800	22	123			8.2	0.117	0.565				0.080	0.11	0.63

Appendix F (cont.)

DATE	STATION	DIST. m	TEMP. °C	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	PKN mg/L	TN mg/L	PO4 mg/L	PTP mg/L	TP mg/L
14-Aug-89	DC7.5	-5380	23	141			8.3	0.010	0.433			0.01	0.052	0.09	0.28
14-Aug-89	DC1	-75	23	340			18.6	1.708	0.072				0.113	0.11	0.23
14-Aug-89	DC2	0	24	766			174.9	20.170	0.199				3.237	2.63	22.90
14-Aug-89	DC4	121	24	725			35.6	4.074	0.002			4.07	0.503	0.34	2.96
14-Aug-89	DC5	220	24	1021			81.0	9.264	0.002			9.26	1.403	1.23	5.94
14-Aug-89	DC6	308	24	1001			86.1	9.461	0.002			9.46	1.481	1.33	3.44
14-Aug-89	DC8	500	24	817			95.1	9.461	0.219			9.46	1.596	1.54	4.30
14-Aug-89	DC9	700	23	1013			104.5	6.209	0.355			6.21	1.365	1.36	1.84
14-Aug-89	DC10	1260	23	1045			91.4	4.632	0.006			4.63	0.708	0.77	0.87
04-Sep-89	DC7	-580	DRY												
04-Sep-89	DC7.5	-538	20.2	107	1.3		7.5	0.717	0.074	1.24	1.07	1.96	1.994	0.44	0.59
04-Sep-89	DC1	-75	21.4	130	7.4		15.3	2.208	0.045	0.58	0.61	2.79	0.019	0.12	0.25
04-Sep-89	DC2	0	23.2	978	8.0		110.7	27.639	0.025	1.37	1.06	29.01	3.780	7.59	9.29
04-Sep-89	DC4	121	22.6	928	7.5		85.3	25.237	0.054	0.90	1.28	26.14	2.498	5.73	4.41
04-Sep-89	DC5	220	23	940	7.5		89.0	24.574	0.054	1.47	0.45	26.04	2.624	4.78	6.18
04-Sep-89	DC6	308	23	940	7.3		89.0	7.593	0.058	1.24	0.96	8.83	2.624	5.92	6.15
04-Sep-89	DC8	500	DRY												
04-Sep-89	DC9	700	22.2	745	6.4		76.5	7.096	0.074	1.07	1.11	8.17	1.868	4.44	4.63
04-Sep-89	DC10	1260	21.8	934	3.9		98.5	6.475	0.047	1.24	1.09	7.71	1.574	3.73	3.76
24-Sep-89	DC7	-5800	19	114	1.3		9.6	0.014	0.148	2.05	1.05	2.06	0.056	0.05	0.31
24-Sep-89	DC7.5	-5380	17.5	83	7.2		8.0	0.014	0.018	1.36	0.98	1.38	0.086	0.20	0.26
24-Sep-89	DC1	-75	18	111	9.6		12.9	1.348	0.102	0.50	0.24	1.84	0.041	0.03	0.11
24-Sep-89	DC2	0	18.5	208	10.1		36.1	5.538	0.132	0.28	0.45	5.82	0.478	1.19	1.16
24-Sep-89	DC5	220	19	744	10.9		86.2	12.859	0.100	0.76	0.45	13.62	2.277	3.17	3.21
24-Sep-89	DC6	308	19	561	10.7		76.4	11.120	0.114	0.98	0.67	12.10	1.806	2.61	2.43
24-Sep-89	DC8	500	DRY												
24-Sep-89	DC9	700	DRY												
24-Sep-89	DC10	1260	DRY												
15-Oct-89	DC7	-5800	18	99	1.1	6.09	12.6	0.004	0.168	1.71	1.07	1.72	0.119	0.15	0.26
15-Oct-89	DC7.5	-5380	18	115	2.7	6.54	12.8	0.062	0.193	1.58	1.15	1.64	0.146	0.15	0.24
15-Oct-89	DC1	-75	19.8	124	7.5	6.68	14.6	2.659	0.028	0.22	0.20	2.88	0.042	0.06	0.08
15-Oct-89	DC2	0	21	1006	8.0	8.23	106.6	12.193	0.044	1.07	0.68	13.27	3.978	4.05	4.05
15-Oct-89	DC5	220	20	872	7.6	7.67	160.5	6.585	0.025	0.76	0.62	7.35	2.375	2.73	2.75
15-Oct-89	DC6	308	20.2	1002	7.4	7.64	160.5	6.513	0.025	1.29	0.67	7.80	2.451	2.86	2.81
15-Oct-89	DC8	500	DRY												
15-Oct-89	DC9	700	DRY												
15-Oct-89	DC10	1260	20	481	2.2	6.6	59.7	2.172	0.063	1.68	1.19	3.85	0.772	0.87	0.91
26-Nov-89	DC7	-5800	8.8	58			9.3	0.142	0.031	0.62	0.52	0.76	0.029	0.06	0.08
26-Nov-89	DC7.5	-5380	9.8	85			10.5	2.312	0.287	1.20	0.93	3.52	0.092	0.09	0.13
26-Nov-89	DC1	-75	12.8	90			12.0	1.248	0.035	0.65	0.57	1.90	0.037	0.07	0.07
26-Nov-89	DC2	0	13	131			60.5	10.116	0.076	11.66	0.70	21.77	1.364	1.68	4.14
26-Nov-89	DC5	220	13	197			22.9	3.834	0.070	4.00	1.28	7.83	0.424	0.41	1.18

Appendix F (cont.)

DATE	STATION	DIST. m	TEMP. °C	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	FKN mg/L	TN mg/L	PO4 mg/L	FTP mg/L	TP mg/L
26-Nov-89	DC6	300	13	170			20.1	3.043	0.074	2.23	1.00	5.27	0.303	0.33	0.63
26-Nov-89	DC8	500	14	186			22.3	2.967	0.204	1.28	1.13	4.25	0.435	0.41	0.52
26-Nov-89	DC9	700	9	65			10.3	0.210	0.002	0.80	0.58	1.01	0.041	0.04	0.07
26-Nov-89	DC10	1260	8.5	70			9.9	0.195	0.002	0.70	0.48	0.90	0.037	0.04	0.07
19-Dec-89	DC7	-580	7	83		7.05	7.1	0.164	0.008	0.40	0.43	0.57	0.009	0.07	0.06
19-Dec-89	DC7.5	-538	7	90		6.98	9.9	0.677	0.171	0.77	0.73	1.45	0.031	0.05	0.08
19-Dec-89	DC1	-75	9	158		7.02	52.9	1.803	2.457	4.49	3.80	6.29	0.484	1.23	1.34
19-Dec-89	DC2	0	8	264		7.29	62.3	4.353	2.265	9.21	2.88	13.57	0.756	1.81	3.28
19-Dec-89	DC5	220	8	264		6.82	38.8	2.938	1.017	4.26	2.45	7.20	0.351	0.73	1.69
19-Dec-89	DC6	300	8	235		6.67	34.8	3.087	0.979	5.41	1.85	8.50	0.306	0.68	2.07
19-Dec-89	DC8	500	7	240		6.58	36.4	3.125	1.324	7.03	1.97	10.15	0.328	0.66	1.96
19-Dec-89	DC9	700													
19-Dec-89	DC10	1260	7	68		6.61	8.1	0.353	0.006	0.59	0.45	0.94	0.012	0.02	0.08
09-Jan-89	DC7	-5800	5.5	70	10.5		9.6	0.281	0.104	0.86	0.60	1.14	0.040	0.04	0.09
09-Jan-89	DC7.5	-5380	5.5	78	9.6		11.8	0.433	0.721	1.49	1.30	1.92	0.129	0.16	0.24
09-Jan-89	DC1	-75	9	122	10.3		20.1	0.778	0.333	1.62	1.26	2.40	0.195	0.52	0.59
09-Jan-89	DC2	0	8	264	10.1		75.3	4.781	0.944	3.28	2.04	8.06	3.377	3.64	3.90
09-Jan-89	DC5	220	9	180	10.4		27.3	1.743	0.437	1.83	1.51	3.57	0.580	0.86	1.01
09-Jan-89	DC6	300	9	136	10.5		21.0	0.993	0.329	1.53	1.26	2.52	0.254	0.58	0.65
09-Jan-89	DC8	500	9	158	10.2		24.5	1.480	0.433	1.72	1.37	3.20	0.510	0.73	0.88
09-Jan-89	DC9	700	6	69	11.3		9.7	0.137	0.015	0.68	0.61	0.82	0.036	0.05	0.07
09-Jan-89	DC10	1260	6	61	10.8		10.6	0.066	0.015	0.70	0.52	0.77	0.040	0.05	0.09
30-Jan-90	DC7	-5800	8.5	58	6.9	5.85	10.3	0.151	0.064	0.84	0.69	0.99	0.050	0.06	0.12
30-Jan-90	DC7.5	-5380	9	72	7.4	6.33	12.4	0.474	0.081	1.21	0.93	1.68	0.104	0.08	0.18
30-Jan-90	DC1	-75	10.5	90	10.2	6.78	13.0	0.935	0.049	0.62	0.54	1.56	0.038	0.04	0.06
30-Jan-90	DC2	0	12	456	9.6	7.44	73.7	10.251	0.032	1.17	0.82	11.43	2.343	2.45	2.49
30-Jan-90	DC5	220	10.5	194	9.2	6.45	30.1	4.054	0.059	1.00	1.00	5.06	0.685	0.62	0.68
30-Jan-90	DC6	300	11	185	10.1	6.59	27.3	3.825	0.066	1.14	0.75	4.96	0.588	0.59	0.68
30-Jan-90	DC8	500	10	218	8.6	6.71	30.9	4.284	0.066	0.96	0.79	5.24	0.710	0.73	0.80
30-Jan-90	DC9	700	11	206	9.1	7.13	28.9	3.671	0.108	1.19	1.02	4.86	0.678	0.70	0.76
30-Jan-90	DC10	1260	8	73	10.2	7.13	12.0	0.103	0.040	1.26	0.84	1.36	0.029	0.06	0.08
20-Feb-90	DC7	-5800	9.5	50	8.5		8.6	0.219	0.053	0.82	0.61	1.04	0.057	0.09	0.14
20-Feb-90	DC7.5	-5380	9	65	8.8		9.4	0.557	0.363	1.25	1.08	1.81	0.132	0.13	0.24
20-Feb-90	DC1	-75	11	69	9.0		11.8	0.646	0.062	0.87	0.81	1.52	0.062	0.08	0.11
20-Feb-90	DC2	0	12.5	398	8.9		56.4	4.752	1.505	5.37	2.80	10.12	1.686	1.72	2.86
20-Feb-90	DC5	220	11	137	7.9		19.5	1.580	0.499	4.11	1.60	5.69	0.411	0.40	1.11
20-Feb-90	DC6	300	10.5	118	8.3		18.1	0.644	0.404	2.41	1.30	3.05	0.353	0.37	0.63
20-Feb-90	DC8	500	11	137	9.2		19.7	1.513	0.547	2.63	1.50	4.14	0.443	0.11	0.18
20-Feb-90	DC9	700	10	56	8.8		9.7	0.417	0.169	1.23	1.00	1.64	0.075	0.11	0.16
20-Feb-90	DC10	1260	9.5	57	8.6		10.1	0.390	0.169	1.08	0.98	1.47	0.075	0.08	0.55
08-Mar-90	DC7	-580	9.5	50		6.32	8.4	0.139	0.014	0.54	0.43	0.68	0.049	0.08	0.12

Appendix F (cont.)

DATE	STATION	DIST. m	TEMP. °C	COND. uS/cm	D.O. mg/L	pH	Cl mg/L	NOx mg/L	NH4 mg/L	TKN mg/L	PKN mg/L	TN mg/L	PO4 mg/L	PTP mg/L	TP mg/L
08-Mar-90	DC7.5	-538	10	77		6.19	10.2	0.438	0.344	1.12	0.94	1.56	0.134	0.13	0.20
08-Mar-90	DC1	-75	13	92		5.93	11.1	2.653	0.010	0.30	0.24	2.96	0.027	0.04	0.04
08-Mar-90	DC2	0	11	823		7.36	135.6	5.979	0.777	2.88	1.89	8.86	1.892	2.08	2.24
08-Mar-90	DC5	220	12.5	259		6.84	30.9	3.984	0.208	0.89	0.66	4.87	0.573	0.54	0.61
08-Mar-90	DC6	308	10	274		6.77	33.5	4.117	0.227	1.12	1.05	5.24	0.580	0.59	0.66
08-Mar-90	DC8	500	12.5	332		6.68	36.9	4.084	0.423	1.41	1.24	5.49	0.761	0.84	0.89
08-Mar-90	DC9	700	10	126		6.2	8.8	0.428	0.136	0.94	0.77	1.37	0.087	0.06	0.13
08-Mar-90	DC10	1260	9	65		6.04	9.0	0.378	0.102	0.73	0.47	1.10	0.058	0.06	0.11
03-Apr-90	DC7	-5800	14	58	4.5		8.0	0.222	0.040	0.67	0.52	0.90	0.050	0.08	0.13
03-Apr-90	DC7.5	-5380	14	77	4.7		10.1	0.566	0.226	1.20	0.89	1.76	0.115	0.11	0.28
03-Apr-90	DC1	-75	15	100	5.1		12.9	0.786	0.250	1.26	1.06	2.05	0.117	0.13	0.18
03-Apr-90	DC2	0	16	410	6.3		47.6	5.574	0.340	2.34	1.06	7.91	0.601	0.61	0.93
03-Apr-90	DC5	220	15	175	5.4		20.3	2.255	0.260	1.78	1.50	4.04	0.228	0.25	0.51
03-Apr-90	DC6	308	15	175	5.5		20.6	2.219	0.264	1.78	1.40	4.00	0.232	0.25	0.38
03-Apr-90	DC8	500	15	188	5.7		20.3	2.074	0.336	2.04	1.20	4.11	0.285	0.28	0.46
03-Apr-90	DC9	700	15	63	5.3		8.4	0.414	0.032	0.99	0.56	1.41	0.059	0.00	0.07
03-Apr-90	DC10	1260	14.5	63	4.5		8.6	0.425	0.048	1.07	0.56	1.49	0.063	0.03	0.09
24-Apr-90	DC7	-5800	18	94	7.1	5.84	11.4	0.288	0.192	1.70	1.18	1.99	0.211	0.25	0.38
24-Apr-90	DC7.5	-5380	19.5	107	7.3	6.13	12.3	0.158	0.082	1.47	1.05	1.63	0.289	0.33	0.51
24-Apr-90	DC1	-75	22	112	7.8	6.06	14.1	0.280	0.064	0.36	0.35	0.64	0.416	0.06	0.07
24-Apr-90	DC2	0	19	492	7.6	6.91	74.8	6.710	0.034	2.31	1.18	9.02	7.014	3.88	4.17
24-Apr-90	DC5	220	20	291	6.8	6.51	35.5	6.601	0.082	0.96	0.79	7.56	1.227	1.35	1.42
24-Apr-90	DC6	308	18.5	289	6.9	6.43	32.6	6.276	0.090	1.07	1.00	7.35	1.000	1.07	1.20
24-Apr-90	DC8	500	DRY												
24-Apr-90	DC9	700	DRY												
24-Apr-90	DC10	1260	21	109	7.4	5.87	13.8	0.233	0.090	3.52	1.17	3.75	0.138	0.18	0.57
16-May-90	DC7	-580	23	94	2.5		11.7	0.572	0.915	3.34	2.34	3.91	0.258	0.26	0.50
16-May-90	DC7.5	-538	21	98	3.9		12.5	0.443	0.367	2.14	1.48	2.59	0.443	0.45	0.72
16-May-90	DC1	-75	24	112	7.5		14.6	2.219	0.066	0.50	0.28	2.72	0.063	0.03	0.07
16-May-90	DC2	0	23	1149	7.3		111.2	18.388	0.092	2.08	1.21	20.47	8.034	6.88	6.77
16-May-90	DC5	220	23	481	6.5		52.5	7.081	0.109	1.09	0.88	8.18	2.897	2.89	2.98
16-May-90	DC6	308	22	556	6.6		62.4	7.206	0.132	1.05	0.97	8.25	3.271	3.21	3.43
16-May-90	DC8	500	DRY												
16-May-90	DC9	700	DRY												
16-May-90	DC10	1260	21	284	3.1		36.5	3.528	0.220	1.88	1.71	5.41	1.065	1.13	1.29

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