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THE EFFECTS OF SECONDARILY TREATED SEWAGE EFFLUENT ON THE WILLIMANTIC/SHETUCKET RIVER

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by

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A C K N O W L E D G M E N T S

This report is based on the research and ideas of members of the Willimantic River Study Group of the Institute of Water Resources at the University of Connecticut. Professor Wilbur Widmer first proposed the study, and Dr. William Kennard developed it into the interdisciplinary study group that was necessary for so complex a problem. During the duration of the study, Dr. Kennard and Dr. Victor Scottron served terms as directors of the Institute of Water Resources, and Drs. Theodore Helfgott and Carroll Burke served as acting directors. The group itself was directly overseen first by Professor Widmer and then by Dr. Francis Trainor, with Roy Deitchman and Frances de Lara acting ably as liaisons between the Institute and the study group.

The investigators and first class assistants of the study group who put much time and thought into this report are many. Sally Hornor, Ernest Matson, John Buck, Pat Bubucis, Janice Ibbison, Mark Hines and Bill Rogers worked on the bacteriological and related aspects. Stephen Edwards, Ron Klattenberg, Ray Costello, Douglas Miller and Professor Widmer did the chemical and physical analyses, as well as invertebrate and some algal analyses. Robert Goldstein, Robert Schmidt and Dr. Walter Whitworth surveyed the fish populations by several methods. Rod Heisey and Dr. Antoni Damman measured aquatic macrophyte production and the uptake of lead and copper by these plants. Jerome Cain, Loel Meckel, Dr. Trainor and the author utilized algal assays and river algal collections to determine the dynamics of the dominant plants in the river. Cherry Villegas analyzed samples for pesticides.

It is impossible to adequately express in writing the contributions made by the above members of the study group, those who swam the river system from end to end, counting fish; those who kept Dunkin' Donuts in operation at 3:00 a.m. between samples of a 24-hour study; those who fell into the river in December collecting rocks; and those who dared to fly in the helicopter while taking aerial photographs of the effluent plume.

Many helped with the preparation of the report itself, including Frances de Lara for organizing, Tracey Weeks and Molly Hubbard and her staff for the illustrations, and Laurie Kile and Arlene Michaud for typing. Laurie Oracle provided expert computer assistance and guidance.

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DIRECTOR'S STATEMENT

It is interesting to review the descriptions of our rivers as written by our early settlers - rivers which were abundant with fish, and whose shorelines were populated with wildlife. These historic writings offer sharp contrast to the description of our rivers today.

Necessity is, admittedly, the mother of invention and this is clearly seen in that it has taken environmental tragedy to bring about significant efforts in correcting the intense and prolonged misuse of these waterways. We have realized, finally, that if we kill our rivers, the land will also die.

Now that we have made the commitment to clean water, there is keen interest in the effectiveness and speed with which we can accomplish the reversal of past damage. We must know, therefore, the "before" and "after" of the various efforts now being employed in water management.

The Institute of Water Resources is very pleased to present this report for the use of interested citizens and public officials who wish to be aware of those methods which detect changes in water quality, and those which are not suitable for such determinations. This report was produced by a complex team of investigators who evaluated water quality using a number of parameters. Their findings and recommendations should be most helpful in guiding all future evaluations of the effectiveness of various water treatment systems.

-Carroll N. Burke-*

*Acting Director of Institute of Water Resources, U-37, The University of Connecticut, Storrs, Connecticut 06268

GENERAL INTRODUCTION

Rivers provide many services for today's society. They serve as recreational and esthetic areas for the sportsman and occasional stroller, as a refuge for the wide variety of plants and animals which are necessary for the proper functioning of a healthy environment and as a water supply for businesses and many communities. Rivers also serve as disposal areas for the wastes of industries and municipalities. Such varied and conflicting uses placed upon the riverine resource require that precise guidelines be established for each user so that one doesn't impinge heavily on any others. To this end, the effects of a group on another must be carefully measured and analyzed so that the various government agencies and private citizens involved can determine the regulatory policies best suited for society as a whole.

This report presents findings of a four-year interdisciplinary study on the effects of a municipal secondary (activated sludge) sewage treatment plant upon the biology and chemistry of the Shetucket River in Eastern Connecticut. The extent to which this waste disposal impinges upon and alters the other functions of the river resource was determined by rigorous scientific methods. The findings reported here are interpreted and discussed for the purpose of assisting those establishing guidelines for the disposal of wastes into this and similar rivers. The results are timely, since many municipal, state and federal agencies are currently involved in a massive program providing for the establishment of secondary sewage treatment plants across the country.

The implementation of secondary sewage treatment on a statewide basis is planned for 1983 in Connecticut. Progress toward this goal has been rapid in the last 10 years due to the more stringent environmental laws and financial aid to the municipalities constructing the plants. During this time period, 26 new treatment plants have been built, and 36 more have been renovated to provide secondary treatment. Now, in 1976, over 90% of the wastes from the population served by sewerage facilities in Connecticut are secondarily treated, compared with 19% in 1965 (Starr, 1975). The extent to which secondarily treated sewage affects the natural processes of a typical Connecticut river system is reported here.

This report has been especially prepared for governmental policy-makers and the educated or informed layman. The extent to which the findings and recommendations are translated into regulatory policies will depend on the efforts of you, the reader. Data presented here have been excerpted from manuscripts prepared for scientific journals and from theses presented to the Graduate School of the University of Connecticut. Appropriate references are given for those seeking more detail. Metric units are used throughout, but conversions to common units of measurement are also provided. Scientific notation, with exponents, is used in some cases. Thus, mg l^{-1} means milligrams per liter, cells cm^{-2} means cells per square centimeter.

HISTORICAL BACKGROUND

Man's impact on the rivers of the Shetucket River system (Fig 1) is not a recent occurrence. The history of the disruption of the natural river environment has been determined for fish (Goldstein, 1975), and similar trends probably occurred for other animals and plants. Originally, migratory fish, such as the American shad, Atlantic salmon and the blueback herring utilized the Willimantic, Natchaug and Hop Rivers and their tributaries as spawning and nursery areas. The Nipmuck Indian Tribe, located in the past in this region, utilized some of these organisms for food, as did the European colonists who settled the area in the late 1600's and early 1700's (Larned, 1880; Cole, 1888; Bayles, 1889). This taking of fish did not deplete the supply, for there are recorded accounts of Atlantic salmon and American shad being caught in the Willimantic River near the present-day site of the city of Willimantic in 1814 (Larned, 1880; Bayles, 1889). The construction of the Greenville Dam on the lower Shetucket River in Norwich about 1830 excluded all migratory fish from the Shetucket River system (Anon., 1893).

The Natchaug River flows through the towns of Eastford, Ashford, Chaplin and Willimantic (Fig 1). After colonization, most of this area was agricultural (Larned, 1880; Bayles, 1889), but during the 1800's, dams were built on the Natchaug River for paper, saw and grist mills. In 1884, the Willimantic Reservoir, a public water supply, was formed by construction of a dam, and in 1947, Mansfield Hollow Dam was built for flood control. By construction of these dams, man limited the upstream movement of fishes. Any effluents from the old mills, none of which function now, did not seem to have lasting effects.

The Willimantic River flows from Stafford through Willington and Coventry into Willimantic (Fig 1). Mills have been in operation in Stafford since the 1800's (Cole, 1888) and are still active today. The city of Willimantic grew as a mill town due to the natural falls on the Willimantic River. Mills were first built there in 1706, with the first dam constructed on the falls in 1727 (Larned, 1880; Bayles, 1889; Lincoln, 1920). The American Linen Company, the major user of the river in the late 1800's with four mills, was bought by the American Thread Company in the early 1900's and today dominates the industrial use of the river in Willimantic. There are five dams in the city and one that impounds Eagleville Lake in Coventry and Mansfield. In the past, the effect of these textile industry dams on the life of the river has been to limit the upstream movement of fish. Today, the American Thread Company routes its effluent through the Willimantic Sewage Treatment Plant.

The Shetucket River flows from Willimantic south through Windham to Norwich (Fig 1). Although the river is impounded in Scotland, Occum, Taftville and Norwich for hydroelectric power, there has been little industrial use of the upper river, excepting a mill in Baltic whose dam was washed out in the 1955 flood. Man's effect on the fishes of the upper Shetucket River has been to limit upstream movement and probably reduce populations periodically by effluents from the Willimantic River (Goldstein, 1975).

Factories, mills and power plants still maintain dams in this river system, as they have for the past 200 years, and have continued to discharge effluents into the river throughout this time. However, with the increasing human population of the area (Table 1), a new stress has been placed upon the river, in the form of increased discharge of raw and treated domestic sewage. This study was concerned with the effects of this treated domestic sewage on river water quality. Up until the 1950's, there was little research in the field of stream pollution, with the notable exception of the Ohio River pollution survey (Anon., 1943).

National attention was given to stream pollution problems by three seminars on Biological Problems in Water Pollution, organized by the former Division of Water Supply and Pollution Control of the U.S. Public Health Service in 1956, 1959 and 1962 (Tarzwell, 1957; 1960; 1965). From this attention began the crystallization of a nationwide research program to define specific problems and initiate enforcement procedures at state and federal levels.

In Connecticut, enforcement activities have kept pace with national trends. In 1967, the Connecticut Legislature passed the Clean Water Act, which aided pollution control enforcement procedures and provided state financial assistance, along with increased federal funds, to municipalities constructing secondary sewage treatment plants. The ultimate goal of this act was making all Connecticut waters suitable for swimming and fishing by 1983.

Despite the innovative nature and strict enforcement measures provided for by the Clean Water Act, little was known of the biological effects associated with the discharge of secondary sewage into Connecticut's waters. The present study was undertaken to determine the biological effects of water pollution on an inland Connecticut river system and to determine the effects of secondarily treated domestic sewage from the city of Willimantic on the biology of the Shetucket River.

TYPES OF DOMESTIC SEWAGE TREATMENT

The treatment of domestic sewage is generally considered in three stages: (1) primary, (2) secondary and (3) tertiary treatment. Primary treatment removes most of the settleable solids through screening and sedimentation. Secondary treatment utilizes bacteria and other organisms to break down organic materials in the waste water. Organics, if allowed to remain in the effluent, could lead to the harmful proliferation of disease-causing bacteria in the receiving waters. Nitrates and phosphates, which cause nuisance growth of algae when present in concentrations greater than in most natural waters, are not removed by secondary treatment. Tertiary or advanced treatment does remove nitrates and phosphates by chemical, physical or biological means.

The Willimantic Sewage Treatment Plant utilizes the most common type of secondary treatment, the activated sludge process. Essentially, this system is an engineered biological process in which microorganisms decompose the organic matter. The oxygen necessary for the decomposition activities of the microorganisms is supplied in an aeration tank by agitation. Solids (flocs, activated sludge) are formed in the degradation processes and are later removed by sedimentation. In the Willimantic system, the remaining clarified effluent is treated with hypochlorite from May through September to kill the microorganisms before discharge into the Shetucket River.

MATERIALS AND METHODS

The discharge of a pollutant into a natural water body causes biological, chemical and physical changes. However, it is primarily a biological phenomenon because its effect is on living organisms (Hynes, 1960). The chemical and physical properties of the effluent determine the response of the plants and animals. Therefore, biotic changes caused by the effluent become a good measure of the quality of the water for human use and enjoyment. In this study, biological measurements were made to assess water quality; in a majority of cases chemical and physical analyses were made concurrently to determine what specific effects these properties have on the biological composition.

Study Area

Samples were collected from two general study areas. The condensed study area (Fig 2) consisted of sites in the Willimantic, Natchaug and Shetucket Rivers within about 10 km (6.2 mi) of the Willimantic Sewage Treatment Plant. The extended study area (Fig 1) included the condensed study area as well as tributaries of the three rivers, the upper reaches of the Willimantic and the Natchaug Rivers and the lower reaches of the Shetucket River.

The extended study area comprised the entire 1331 km^2 (514 sq mi) Shetucket River watershed except for some small tributary streams. The State Department of Agriculture estimates that 68% of Connecticut is privately owned or state-owned forest, 16% is agricultural and the remainder is lightly to moderately developed residential area (Stroh, 1975). The two largest population centers within the watershed are Norwich and Willimantic with 41,739 and 14,402 inhabitants, respectively, in 1970 (U.S. Bureau of Census, 1973). An average 114 cm (44.5 in) of precipitation falls on the watershed area each year. Evaporation returns about 50 cm (19.5 in) of water per year; the rest flows out of the basin in the Shetucket River or as underflow (United States Geological Survey, 1967).

Although the elevation of the extended study area varies from 400 m (1310 ft) in the upper watershed to less than 3 m (9.8 ft) at Norwich, nearly the entire region is below 300 m (984 ft). Mean air temperature ranges from approximately 21 C (70 F) in July to -3 C (27 F) in January, with a yearly average of 9 C (48 F) (Brumbach, 1965).

The entire region was ice covered during the last glaciation and effects of this are presently evident. Bedrock within the area is predominantly metamorphic schist, gneiss and quartzite. Economically significant deposits of metal-bearing ores are apparently absent, although a number of metal-containing minerals have been found (Schon, 1951). It is doubtful that the river waters are appreciably affected by these naturally occurring minerals.

The effect of human influence along the three rivers varies. The Natchaug flows through the most rural part of the region and has a primarily forested watershed with a few small settlements. Near Willimantic, the river is dammed, once as a municipal reservoir and once for flood control; but over nearly the entire length, it is free flowing. Within the watershed are several well-traveled roads, but overall traffic volume is comparatively light. No major sources of domestic or industrial effluents are known along the Natchaug River.

Although the uppermost part of the Willimantic River watershed is rural, the majority of this area is moderately populated. Stafford Springs and Willimantic are the two largest towns, but a number of smaller settlements are also present. The Willimantic is dammed to form two moderate-sized impoundments, one at Eagleville (32 hectares) and one near Staffordville on Furnace Brook (66 hectares) and a number of smaller ones, especially in Willimantic. Effluent reaches the river from the North American Tyco plant in Stafford and the Stafford Springs, Mansfield Training School, and the University of Connecticut sewage treatment plants. A sluice from an apparently inoperative mill at Hall's Pond, South Willington, enters the river but probably carries clean pond overflow. It is likely that other residential or industrial sources of pollution occur. Automobile traffic within the Willimantic River watershed is moderate.

The Natchaug and Willimantic Rivers converge at the city of Willimantic to form the Shetucket River. Although considerably influenced by man in its first several kilometers, the river is predominantly rural downstream to Baltic. From there to Norwich, settlement pressure is high. Four hydroelectric dams are present on the Shetucket, one each at Scotland, Occum, Taftville and Norwich. Daily or frequent changes in river flow occur upstream and downstream of these sites. Effluent is added to the river at the Willimantic sewage treatment plant, Rogers' Corporation in South Windham, Karen Textile in Occum, and Norwich. Other industrial and residential sources of pollution are likely, especially in the lower reaches. Traffic in the region is heavy near Willimantic but low from there to Baltic.

The condensed study area (Fig 2) encompasses the area around the Willimantic Sewage Treatment Plant. The Natchaug and Willimantic Rivers converge to form the Shetucket River and contribute about 35% and 64%, respectively, to the flow of the Shetucket. The effluent from the Willimantic Sewage Treatment Plant is discharged at the convergence of the Willimantic and Natchaug Rivers and annually accounts for about 1% of the discharge of the Shetucket River. The percent contribution of the effluent to the total Shetucket River discharge for representative dates from September 1973 to December 1974 is given in Fig 3. Within this study area, excluding Scotland Impoundment (Fig 2), the river bottom is approximately 60% cobble and 40% sand and silt. Water depth ranges greatly both longitudinally and seasonally, from 0.1 m (4 in) in riffles in summer to 2.5 m (8.2 ft) in open reaches in winter. Mean width is 50 m (169 ft) for the Shetucket and is about 25 m (82 ft) at the sampling sites in the Willimantic and Natchaug Rivers. In this area, the river gradient is 1.33 m km^{-1} (7.03 ft $mile^{-1}$). The Scotland Impoundment begins just below Site 6 (Fig 2) and is about 5.4 km (3.3 mi) long. The impoundment is shallow (maximum depth 7 m; 23 ft), rarely stratifies, and water residence time is short. Ten percent of the 32 million m^3 (8.5 billion gallons) volume is drawn down twice daily for power generation, which causes radical fluctuations in depth. Site 7 was located within the impoundment.

Two small streams, the Potash and Obwebetuck, enter the Shetucket River within the condensed study area and were infrequently monitored. At peak discharge, following severe storms, their combined volume accounted for not more than 0.1% of the total Shetucket River volume.

The extended study area was utilized for the study of the fish and higher aquatic plants. Heavy metal and pesticide levels in the river water, sediments, and plant life were also measured in this extended study area. Nutrient, physical and chemical measurements were made in the condensed study area, along with the biological parameters of bacteria, algae and aquatic insects. The measurements and the area and time period for which they were taken are summarized in Table 2. They are described now in detail, beginning with nutrient measurements.

Nutrient Measurements

Algal Growth Potential. The algal growth potential (AGP) of a water sample is determined by directly quantitating the growth of a selected alga in that water over a selected period of time, a technique known as an algal assay. In recent years, algal assays have shown themselves to be potentially significant tools for analyzing the effects of nutrient or toxicant loading in lakes and streams. In addition to their simplicity, algal assays are valuable in that they directly measure the effects of pollutants on algal growth in the river system. The algal assay technique used (procedure described fully below) was specifically designed for this study, and the procedure and results published in greater detail elsewhere (Cain and Trainor, 1973; Klotz *et al*., 1975; Cain *et al*., in prep.). Samples were collected biweekly at Sites 1 - 6 (Fig 2) for AGP determinations.

An axenic culture of *Selenastrum capricornutum* Printz, obtained from T. Maloney, (F W Q A, Pacific Northwest Water Laboratory, Corvallis, Oregon 97330) was used for all experiments. Bacteria-free stock cultures were maintained in the medium specified by proponents of the provisional algal assay procedure (PAAP) (Weiss and Helms, 1971) at 22 C under continuous overhead illumination of 4000 Lux. Stock cultures were transferred every two to three weeks. The PAAP medium, as well as the water samples tested, were routinely sterilized by vacuum filtration through ultrafine sintered glass filters. River water samples were always filtered on the collection day and kept under refrigeration for use throughout the test period.

Cells for the inoculum were routinely prepared as follows: five days before the inoculum was needed, a small aliquot of stock culture was placed in 25 ml of sterile PAAP medium in a 125 ml Erlenmeyer flask and incubated under the same conditions of light and temperature as the stock cultures. Two days later, 25 ml of sterile medium were added to the flask. On the fifth day, the cells were harvested by centrifugation, and washed by suspension, centrifugation and resuspension in small amounts of sterile water sample being tested. Culture tubes were incubated at 22 C on a roller tube rotator at 9 rpm, where they received continuous bilateral illumination of 4000 lux. Each day, optical density readings were taken and the original cell number of the cultures was re-established by dilution with sterile test water to the initial optical density value. Growth was expressed as the number of population doublings/day. Growth measurements were made in replicate tubes for five successive days, after which each culture tube was checked for bacterial contamination.

Algal Nutrients. The specific chemical parameters measured for comparison with the algal growth potential of the water sample were those considered most likely to influence algal growth: nitrate-nitrogen, conductivity, ortho-phosphates, poly-phosphates and total phosphates.

Nitrogen, an important plant nutrient and a component of domestic waste, is present in rivers in several forms which are interconvertible by natural processes. Nitrate-nitrogen is the form used by most algae for growth. It was measured by the Brucine method (APHA, 1971) using a wavelength of 410 nm. Two other forms of nitrogen, ammonia and organic nitrogen, are important because they are readily converted by aquatic organisms to nitrate-nitrogen, the important algal nutrient. Measurements of ammonia and organic nitrogen were not made on the same water samples as the algal assay and, therefore, were not used in statistical comparisons with the assay. Analyses were performed on water samples to determine the organic nitrogen and ammonia nitrogen content by the Kjeldahl digestion and distillation method described in Standard Methods (APHA, 1971).

Conductivity is the ability of the water sample to conduct an electric current. It is a measure of the ionic concentration, and thus provides a practical estimate of the dissolved-solids concentration of a water sample. Conductivity was measured as parts per million (ppm) NaCl using a Hach Chemical Company conductivity meter.

Phosphorus, like nitrogen, is an important component of sewage, as it is always present in animal waste. Millions of tons are also introduced by synthetic detergents (Wetzel, 1975a). It is most likely to be present in natural waters in the form of phosphate anions at very low concentrations. Experiments have shown that phosphorus is the element which, when introduced into many freshwater environments, most likely will stimulate nuisance growth of algae (Wetzel, 1975a). However, freshwater environments vary greatly and therefore each type of system must be studied to determine which nutrient is in short supply and will lead to algal blooms if added as a pollutant. Phosphorus abatement will not return all polluted freshwaters to their previously natural clean condition; but it is the removal measure to undertake first in clean-up procedures, and the one most likely to succeed (Wetzel, 1975a). The scientific evidence implicating phosphorus with many instances of nuisance algal growth has been so great that the 19th Congress of Theoretical and Applied Limnology in 1974 ratified an international resolution emphasizing the need to control the input of phosphorus into any freshwater by any means available (Wetzel, 1975b).

With increased domestic and agricultural input of phosphorus into streams, large quantities are lost downstream to the oceans. At the present time, this phosphorus is not being returned by cyclical processes to the land as quickly as it is lost to the ocean (Odum, 1971).

The ortho-phosphate ion is considered most important for algal growth. Ortho-phosphates were determined either by the Stannous Chloride method (APHA, 1971) (reading transmittance at 690 nm) or by the StannaVer IV method (Hach Chem. Co., Ames, Iowa). Concentrations of ortho-phosphate were determined from calibration standards subjected to the same procedure. Total phosphates were measured after conversion to ortho-phosphates by nitric-sulfuric acid hydrolysis (APHA, 1971). The derived ortho-phosphate was then determined using the above-mentioned procedures. Poly-phosphate values were derived from the total and ortho-phosphate data by subtraction.

The algal assay and algal nutrient tests were run on the same water samples collected from sampling Sites 1-6 biweekly from July 1, 1973 through December 31, 1974.

Physical and Chemical Measurements

Various other chemical and physical parameters were also measured biweekly from July 1973 to December 1974 at sampling Sites 1-6. The turbidity of, and suspended solids in, the water column were measured with a Hach Model 2100 turbidity meter and gravimetrically, respectively (APHA, 1971). Alkalinity, or the capacity of the water to neutralize acid, is basically a measure of dissolved carbonate and bicarbonate ions. It was determined titrametrically using the methyl orange indicator method (APHA, 1971). Air and water temperatures were recorded using a standard 75 mm immersion-type mercury thermometer. Dissolved oxygen measurements of the water samples were made in 300 ml BOD bottles using the Azide modification of the Winkler method (APHA, 1971).

The presence of dissolved organic carbon, pesticides and the heavy metals copper and lead were also determined. These analyses were made in conjunction with certain biological measurements and each will be discussed in detail in following sections. Dissolved organic carbon was determined with bacterial measurements, pesticides with attached algae, and copper and lead with higher aquatic plants.

Biological Measurements

Bacteria. Contamination of water by human wastes has been known to be associated with pathogenic microorganisms since the mid-1800's, when a cholera epidemic was linked to a sewage contaminated well (Adams and Spendlove, 1970). Since then, the presence or absence of certain microorganisms has become an important indicator of the sanitary quality of water. In this study, microbial populations were monitored biweekly during the same period as the algal assay and chemical analyses. Subsurface water samples were taken in sterile, wide-mouthed, one liter brown polyethylene bottles. Bacteria and yeasts isolated from these samples are referred to as plankton. Influent and effluent samples from the sewage treatment plant were retrieved with a plastic bucket and rope. Subsamples were poured into brown bottles. All samples were iced immediately, returned to the lab within three hours, and enumeration procedures were completed within nine hours.

The water samples were examined for various types of bacterial groups (Matson, 1975). There are several groups of bacteria abundant in the feces of warm-blooded animals, and some of these serve as indicators of fecal contamination of natural waters. The coliform group includes bacteria that possess the ability to ferment lactose with the production of gas and acid. Fecal coliforms are a member of this group whose origin is the feces of warm-blooded animals. The presence of another bacterial group, the fecal streptococci, also specifically indicates fecal contamination. Another group, plate count bacteria, are those organisms which are able to grow in the presence of oxygen on an organically enriched food source.

Populations of total (TC) and fecal (FC) coliforms and fecal streptococci (FS) were enumerated using accepted membrane filtration techniques

(APHA, 1971) with Millipore brand filters. Plate count bacteria (PC) were enumerated by the spread plate technique (Buck and Cleverdon, 1960). Yeasts were enumerated by filtration and incubation on a medium containing 2.3% Bacto Nutrient Agar pH 6.0, 2.0% glucose, 0.1% yeast extract, 0.2% Diamalt (Standard Brands) and 50 mg% chloramphenicol (later reduced to 30 mg%). Duplicate plates were incubated at 20 and 37 C. The 20 C plates were transferred to a 2 C refrigerator when filamentous forms began to grow. Countable plates (100-120 CFU/plate) were obtained within five days.

Epilithic bacterial populations, those attached to rocks, were removed using a modification of the method of Batoosingh and Anthony (1971). Several 100 ml portions of sterile distilled water were added to brown bottles containing the rocks and glass beads. The bottles were then shaken vigorously, the supernatant aseptically decanted into another sterile container and the process was repeated until the supernatant was clear. To avoid regrowth, the removal period lasted no longer than 5 to 10 minutes and the samples were returned to the ice chest. Residual organisms capable of growth on plate count agar were an insignificant percent of the total. Combined supernatants were serially diluted and processed as the planktonic samples.

Sediment organisms were enumerated by suspending 1.0 g sediment in 99 ml of sterile dilution water and processed as above.

River conductivity and temperature were measured in the field with a YSI model 33 SCT meter at the same time water samples were collected for bacterial analysis.

Dissolved Organic Carbon. The dissolved organic carbon content of a water sample is a measure of the food supply in the water column for certain bacterial groups, especially the plate count group. Secondary treatment removes much of the organic carbon fraction from sewage before it is discharged into the river. In this study, the dissolved organic carbon (DOC) concentration was monitored biweekly through 1974, and also diurnally once a month throughout that year. By these methods, the effect of the effluent on the DOC concentration of the river was determined seasonally and was compared to natural inputs. Subsamples for DOC analysis were taken from brown bottles during microbiological sampling or from acid cleaned milk dilution bottles during diurnal studies. The thermal combustion technique of Van Hall et al., (1963) was used, as modified by Rich et al., (1974). Briefly, a 70 ml sample was filtered through a Reeve Angel 984 H Ultra 4.25 cm glass fiber filter as a filter wash. Another 30 ml were filtered, decanted into a glass vial. acidified to pH 2 with 2 drops of conc. H_3PO_4 (diluted 1:4), capped with indented Polyseal caps and stored at 0 C until analysis. For analysis, the DOC sample was combusted at 550 C for one minute, and the resulting CO_2 measured on a Mine Safety Appliance Co. Model 202 LIRA infrared CO_2 analyzer.

Algae. In flowing water environments, the organisms attached to the bottom or to a stable object often are the most important in the function of the system (Duffer and Dorris, 1966; Grzenda et al., 1968; Brehmer et al., 1969). For this reason, some emphasis was placed on sampling this environment throughout the study. As mentioned previously, the epilithic and sediment bacteria were enumerated. The algae attached to the rocks were also monitored throughout 1974 at Sites 1 - 6 as well as at 4 sites located within the unmixed plume of the effluent from 20 to 400 m (66 to 1320 ft) below the treatment plant outfall (Fig 2).

Five rocks removed from a representative area at each site were brought back to the laboratory immersed in river water, and the epilithic algae were then removed according to the procedure of Douglas (1958). Initially, each rock was rinsed under low force tap water to remove any planktonic algae that may have settled on the rocks in the transfer process. A total of 23 areas per site were brushed from all sides of the exposed surfaces of the 5 rocks, each area delimited by the round $0.72 cm^2$ hole of a nalgene plastic bottle. The brushed areas were then washed clean with tap water from a plastic squeeze bottle; this water with the detached algae was collected and the algae enumerated. The epilithic diatoms were ashed and identified to species (Patrick and Reimer, 1966; Hansmann, 1973), all other algae to genera (Prescott, 1964). A laboratory algal assay similar to the one described for this study was developed for the two dominant attached algae of the river system to determine the conditions of their dispersal (Klotz, 1975).

Pesticides. The need for control of agricultural and forest pests has made the use of pesticides widespread. Use of poisonous chemical compounds has warranted monitoring to determine their presence in and effects on the environment after application. Federal control and elimination of the use of some pesticides has been necessitated by their persistence in the environment and their buildup in living material. The presence and persistence of pesticides in this river system were monitored by periodic water and sediment sampling; the buildup of pesticides in living tissue was analyzed by determining the concentrations in attached algae. In all cases, the material was collected and the pesticides (if present) were extracted with organic solvents and separated by column chromatography. The pesticides were further separated and analyzed with a Hewlett Packard gas-liquid chromatography electron capture detector.

Aquatic Insects. The aquatic insects are another important group of organisms either attached to or sequestered in the river bottom. They consume particulate organic matter in the form of plant fragments, single-celled algae, bacteria and detritus that are either produced within the stream or are supplied to the stream from outside sources. Sewage effluent would provide particulate organic material to the aquatic insects for food.

Insects are generally present in the riverine system in their immature stages. They have been used extensively as water quality indicators because many are sensitive to changes in their environment (Olsen and Rueger, 1968). In the present study, immature aquatic insect distribution was correlated with the levels of various forms of nitrogen from the secondary sewage effluent deposited in the bottom sediments. For sampling ease, a sediment trap was devised for retrieval of interstitial water and sediment samples as well as aquatic insects at the same site. The trap was constructed from a lightweight, unbreakable, non-toxic polyethylene tray mearuring 33 cm x 21 cm x 12 cm (13 in x 8 in x 5 in) with a locking cover (Republic Molding Corp.). To ensure an unrestricted flow of water through the trap, a series of 0.96 cm (0.37 in) diameter holes were punched into the trap and cover. The trap was filled with washed gravel to a depth of five centimeters (two inches) to provide a site for the absorption/adsorption of nutrients simulating the naturally occurring phenomena which take place at the river bottom. With the cover tightly in place, the trap was then attached to a 32 kg (70 lb) concrete block by means of clips at the four corners. This method proved successful in ensuring position of the traps on the river bottom.

Interstitial waters (water between the sediment grains), water columns and sediment samples were analyzed biweekly in 1974 for organic nitrogen and ammonia using the Kjeldahl digestion and distillation method (APHA, 1971). A modified Hester Dendy 6-plate artificial substrate sampler (Hester and Dendy, 1962) was secured to the inner surface of the sediment trap cover and the sediment accumulating on the trap was analyzed qualitatively and quantitatively biweekly in 1974 for immature aquatic insects. Identification was made to the lowest taxonomic level possible using a Bausch and Lomb binocular dissecting microscope and standard taxonomic keys (Usinger, 1970; Pennack, 1953; Johannson, 1960; Peterson, 1960). Details of the aquatic insect study are presented in Costello (1976).

Aquatic Macrophytes. Aquatic plants other than algae represent another group of organisms that survive in running water by attachment to the bottom. Due to the paucity of these aquatic macrophytes in the condensed study area delimited by Sites 1 - 7, sampling was extended to the upper reaches of the Willimantic and Natchaug Rivers and the lowermost reaches of the Shetucket River. The aquatic macrophyte research was tied to a study of the heavy metals, copper and lead, in the river system. Heavy metals can be concentrated in plants to many times the concentration found in the surrounding water. Aquatic plants, therefore, act as natural sampling receptacles which collect and store heavy metals which may have appeared in the water column only at one previous point in time. High copper and lead concentrations in the environment are produced by combustion of fossil fuel, use of lead additives in gasoline and smelting. Copper levels in river water at the concentration of 120 ppb are toxic to natural animal communities (Hynes, 1960); lead levels as low as 100 ppb are toxic to some fish in laboratory tests (Aronson, 1971).

It was necessary to correlate several associated factors to fully determine the effects, if any, of the Willimantic secondary sewage treatment plant on the copper and lead concentrations in aquatic macrophytes. First, it was necessary to know the average concentrations in plant tissues from throughout the river system, for then it could be determined whether the observed concentrations were actually a measure of the availability of the metal in the environment. Second, since heavy metal uptake is related to growth, knowledge of plant production was required. Third, the availability of heavy metals in the river water needed to be determined for comparison with concentrations in the plants. For these three purposes, plant samples were collected for metal analyses and production estimates, and water samples were collected for metal availability in the environment.

Two plant species widely distributed in the extended study area were chosen for intensive study: *Pontederia cordata* L., pickerelweed, with stems and leaves extending up out of the water and with well-developed underground storage organs firmly rooted in the sediment and *Potamogeton epihydrus* Raf., leafy pondweed, a floating-leaved plant with almost its entire biomass in contact with the water and having a poorly developed root system. Several less widely occurring species were also sampled, but less extensively.

Entire *Pontederia* and *Potamogeton* plants were gathered from July through November 1973 for analysis of their heavy metal concentration and were harvested at three and four week intervals during the latter half of the 1973 growing season and throughout the 1974 growing season for determination of growth rates. For this purpose, biomass determinations were made by the harvest method (Milner and Hughes, 1968) in which entire plants are collected from a known area of the river bottom delimited by a quadrat. Dry weights were then determined in the laboratory. *Potamogeton* and *Pontederia* samples were gathered from all parts of the extended study area, particularly just downstream of the Willimantic sewage treatment plant to determine possible effects of this facility. All water samples were collected in August 1973. Plant and water samples were prepared for analysis by standard, controlled procedures (Heisey, 1975) and then analyzed for copper and lead with a Perkin Elmer 306 atomic absorption spectrophotometer. Minimum concentrations of heavy metals in the water samples which could be accurately determined were 4.5 parts per billion (ppb) copper and 25 ppb lead. Values below these levels were presented if it was felt they were of reasonable accuracy; otherwise, zeroes were assigned.

Fish. The fish populations were also examined in the extended study area used in the aquatic macrophyte research. Methods of determining indirect effects of man on fish can be classified as either single or multiple species techniques. Single species techniques are those that determine changes in some aspect of the life history of a species, such as fecundity and growth rates or bioassays. Multiple species techniques are those that determine changes in fish community composition. A combination of single species techniques (growth rates and relationships, and individual species abundance) and multiple species techniques (historical information, and present composition and abundance) were chosen to determine man's effects, especially the effects of the city of Willimantic, on the fish of the upper Shetucket River system (Fig 1). For a detailed discussion of this aspect of the study, see Goldstein (1975). Due to the wider movement of fish as compared to the other (attached) organisms studied in this report, it was not possible to determine specifically the effect upon the fish of the sewage effluent. However, the research was designed to study the effects of the city of Willimantic, notably the sewage treatment plant which was the primary contributor.

To critically evaluate the effect of the city of Willimantic on the fish populations, it was necessary to compare fish populations from sections of the extended study area upstream of the city of Willimantic with those populations downstream and also to compare this river system with 15 other rivers in Connecticut and Rhode Island. Various techniques were used in these evaluations (for specifics, see Goldstein, 1975). For comparison of the river sections upstream and downstream of the city of Willimantic, both seining and direct observation by snorkeling were performed. Fishes were collected from all sections of the extended study area (including tributaries and reservoirs) throughout 1973 and 1974 with woven-mesh nylon seines (1 - 10 m long x 1 - 4 m deep x 6 mm mesh). The sexual condition, sexual activity and habitat of the fish were determined.

The four major rivers of the extended study area were divided into upper and lower sections (3.0 to 14.6 km; 1.9 to 9.1 mi) above and below the major dams at (1) Willimantic Reservoir and Mansfield Hollow Reservoir - Natchaug River, (2) Hop River Road - Hop River, (3) Eagleville Lake - Willimantic River, and (4) Scotland Impoundment - Shetucket River (Fig 1). These sections were snorkeled by 1 to 4 people at a time, depending on river width and available water, who either floated with the current or swam at an intermediate speed (<1.5 km hr^{-1}; <0.9 mi hr^{-1}) looking for fish in all parts of the river. The fish observed were counted and identified to species (Goldstein, in prep.). The data obtained from the seining and snorkeling operations were used to compute differences in fish populations due to the city of Willimantic.

The fish populations of the extended study area were compared to those of 15 other rivers in Connecticut and Rhode Island (Fig 13). The rivers were rated as to the extent they were influenced by man by calculating a human influence index (HII). Factors influencing this index included dams, mills, reservoirs, sewage outfalls and surrounding land use. The degree of divergence of fish populations in the Shetucket River from the average populations in rivers of similar watershed size was assumed to be caused by man.

The effects of the city of Willimantic on the fish populations of the extended study area were also determined by comparing two impoundments above and below the city. Willimantic Reservoir (Fig 1) located on the Natchaug River above the city, is a public water supply and all other uses are prohibited. Scotland Impoundment (Fig 1), located below the city, is used for hydroelectric power generation; water levels can vary over one meter twice daily because of alternate impounding and flowing of water through turbines during periods of low water. To evaluate the fish populations, seining, gillnetting and angling were undertaken from May to September 1973. Age and growth characteristics and the length-weight relationships of fish species were obtained according to Whitworth and Sauter (1973) and Whitworth and Goldstein (1975). In this way, the fish populations in impoundments above and below the city of Willimantic were quantitatively analyzed and compared.

River Metabolism. In the preceding description of methods, the use of indicator organisms, the study of environmental factors and the measurement of community structure and size all provide valuable information about pollution stress. Another approach to the study of sewage enrichment involves analysis of the overall function of plants and animals in the river, or river community metabolism. The community metabolism was determined by measuring the amount of oxygen that is produced by the plants in the river by photosynthesis (P), compared with the amount of oxygen consumed by both plants and animals during respiration (R). This production to respiration ratio (P/R) is a measure of the metabolic state of the river. A low P/R value (less than 1) reveals that the river community is dependent on an external source for organic compounds used in respiration; in this instance, the external source could be the sewage effluent. A high P/R value (greater than or equal to 1) means the river produces enough organic compounds during photosynthesis to supply its needs for respiration. The community metabolism of a stretch of the Shetucket River below the Willimantic sewage treatment plant was measured monthly from March to December 1974.

Ideally, the P/R value for a stretch of river above and below the sewage treatment plant should be calculated for comparative purposes. Small mountain streams have been found to be almost totally (99%) dependent on organic matter in the form of leaf litter produced outside the river; therefore, they possess a very low P/R ratio. However, this is their natural state. The natural state in terms of the P/R ratio for larger rivers is dependent on watershed characteristics (Daubner, 1969), degree of tree shading (Hall, 1970) and natural organic enrichment (Cole, 1973). The natural P/R ratio for larger rivers similar to the Shetucket River has not been determined because these larger rivers are generally influenced by man. In this study, the Willimantic River possesses characteristics similar to the Shetucket but receives effluents from three domestic sewage treatment plants. The Natchaug is smaller than the Shetucket, and, unlike the Shetucket, is shaded by overhanging trees much of the time. Therefore, it was not possible to collect data on the natural metabolic state of an unpolluted river similar in size to the Shetucket for comparative purposes. Diurnal studies were performed monthly from March to December 1974 using the upstream-downstream technique described by Odum (1956) to measure river community metabolism. The minimum flow time allowed between stations was 30 minutes; thus, sampling sites were determined by river discharge. Studies were always performed in a totally mixed reach of the Shetucket River at least 1.1 km (.68 mi) below the effluent (Site 4). Flow time was determined using 2/3 filled plastic gallon jugs in series and taking the mean flow time of each series. Radiant energy data were obtained from the University's College of Agriculture recording pyranometer located about 15 km (9.3 mi) north of the study area.

Oxygen was measured using either the Winkler or probe method, or both (APHA, 1971). Percent light transmission through the water column was determined using a Beckman Model EV3 Enviroeye. River morphometry was measured in the field and checked against tax assessor maps at a scale of 1:200.

Stream flow rates for the Shetucket and Natchaug Rivers were obtained from stream gauging stations monitored by the Surface Water Branch of the United States Geological Survey Office, Hartford, Connecticut. These gauging stations were located on the Shetucket River at Plains Road (Site 5) and on the Natchaug River at Route 195. The flow for the Willimantic River was determined by the difference between the Shetucket River and the Natchaug River less the Willimantic sewage treatment plant flow which was monitored on a daily basis by the superintendent of the sewage treatment plant.

RESULTS AND DISCUSSION

The effects of secondary sewage effluent from the Willimantic sewage treatment plant were analyzed by many methods in this study. Of greatest concern to the investigators on this project was the effect of the effluent on the life of the river. The effluent alters the chemical and physical properties of the water, which in turn influence the biological systems. For this reason, the chemical and physical changes imparted to the river water by the effluent are of prime importance, and are discussed first.

Nutrients and Algal Growth Potential

Secondary sewage treatment was installed in Willimantic in late June 1973. Initial problems with oxygen deficiency in the aeration tanks occurred during the summer and early fall of 1973 and were remedied by late October 1973. The characteristics of the Willimantic secondary sewage treatment plant and effluent are presented in Table 3.

The volume of effluent discharged from the plant averaged about 1% of the Shetucket River volume annually, with values up to 7% during low summer flows (Fig 3). The most dramatic chemical and physical effects occurred during these low flow periods due to the high effluent concentration. However, a common water quality measure, the biochemical oxygen demand (BOD), a measure of the organics in the water available for bacterial utilization, was not found to be significantly elevated even during low river flows. The results of BOD tests were generally below the accuracy range of the test, and, therefore, were not made through the entire project.

The algal growth potential of the water and the nutrient measurements made on the same water sample are presented in Table 4. Since all parameters in this table are concentration dependent, the large range values reflect the seasonal and sporadic variation in river flow. During periods of low stream flow, the river water is largely groundwater, during high flow periods, the river water is largely direct runoff. Groundwater, after percolating through the soil and leaching minerals from the rocks and soil, has a higher concentration of dissolved minerals than direct overland runoff.

Therefore, during low flows, the increased proportion of groundwater creates higher mineral and nutrient concentrations in the river water (U.S.G.S., 1967). The increased nutrient levels in the Shetucket River water in the summer are therefore caused by both a higher proportion of groundwater and by higher effluent concentrations (Fig 3). As a general rule, concentration values for all the tests in Table 4 were lowest during the high January to March flows and highest during the low July to September flows.

Except for nitrate-nitrogen at Site 1 (Fig 2) and poly-phosphate, sampling stations upstream from the sewage treatment plant (Sites 1, 2 and 3) showed lower mean values for all nutrient tests than sites below the effluent outfall. With the exception of poly-phosphate data, the lowest mean values for all tests were obtained at Site 3 in the Natchaug River. Site 3 received a minimum of pollution, being located about 4 km (2.9 mi) below the Willimantic public water supply reservoir.

The measurements, when compared statistically (Table 3), showed that the parameters related to the growth of algae (conductivity, ortho-phosphate and nitrate-nitrogen) significantly increased from upstream to below (Site 5) the sewage treatment plant. The algal growth potential (AGP) likewise significantly increased. The "upstream" values were computed by weighting the measurements taken at Sites 2 and 3 for their percent contribution to the total discharge of the Shetucket River at Site 5.

Downstream in the Shetucket (Sites 5 to 6, Table 5), the river underwent natural purification processes with the conductivity, total- and ortho-phosphates and the algal growth potential all decreasing from Sites 5 to 6. The lack of a change in nitrate-nitrogen between 5 and 6 will be discussed later.

A major difficulty in analyzing the data of this study is that the Willimantic River received domestic effluents from three sources upstream of the Willimantic Sewage Treatment Plant. Therefore, nutrient values are high even before the discharge of secondary effluent by the Willimantic plant. The Natchaug River, which drains forested land and supplies drinking water to the city of Willimantic, must then act as a natural, undisturbed river for comparative purposes. The limitations of using the Natchaug as a control are discussed in the introduction. Table 6 shows the Natchaug is significantly lower in all algal growth stimulating nutrients than the Willimantic (Site 2) and the Shetucket (Sites 5, 6, 7, 8). Tables 5 and 6 will be discussed in more detail with regard to dissolved organic carbon (DOC).

High nutrient levels in natural waters are of concern because they promote nuisance algal growth. Therefore, it is important to know for pollution control purposes how the algal growth potential relates to certain chemical parameters. For this reason, statistical analyses were carried out to determine what relationships exist. Table 7 presents data that show the algal growth potential of the water is positively correlated with ortho-phosphates most strongly and at the greatest number of sampling sites. The lack of correlation of all parameters at Site 3 is due to the nutrient level of that water being at times below the sensitivity of the assay technique and the chemical analyses. Table 7 shows the degree to which the two variables are related but does not reveal cause and effect phenomena, such as increased algal growth potentials caused by increased ortho-phosphate concentrations. Laboratory experiments must be performed to determine cause and effect processes, and these were not done in this study. However, knowing that ortho-phosphates and algal growth potentials are strongly related in this extensive, two-year study does indicate where emphasis should be placed in cleaning up these waters. Removal of ortho-phosphates from the sewage would probably lead to reduced algal numbers below the sewage treatment plant.

Algal blooms (large concentrations of algae in a water sample) are harmful to a natural water body because they often cause taste and odor problems, interfere with recreational use, and sometimes lead to fish kills when the bloom dies and decomposes, thereby depleting the oxygen supply of the water. Algal blooms are most often associated with lakes and ponds, for the still water environment allows time for a buildup of planktonic algal populations. The impoundment of the Shetucket River at Scotland Dam (Site 7, Fig 2) creates such a lake-type situation conducive to algal blooms if the nutrient levels and other factors are sufficient. Nutrients for Scotland Impoundment are mainly supplied from the upstream Shetucket River. The algal growth potential data (Table 5) for the Shetucket River show that algal nutrients are removed from the river downstream of the treatment plant (note lower algal growth potential values at Site 6 as compared to Site 5, Table 5).

However, at the average rate of nutrient removal by natural processes, it would take a river 12.3 km (7.6 mi) long to remove the algal growth potential increase contributed by the Willimantic secondary sewage treatment plant (Klotz, unpublished). Since Scotland Impoundment is only 8.3 km (5.1 mi) downstream of the treatment plant, the algal growth potential of the impoundment waters will be increased due to the secondary effluent. An algal bloom of Microcystis causing odor problems did occur in Scotland Impoundment in August 1973. The above evidence suggests that since natural processes in the Shetucket River do not diminish the algal growth potential of the water at a sufficient rate, the increased nutrient loading of the impoundment caused by the Willimantic secondary sewage treatment plant could lead to algal blooms.

Dissolved Organic Carbon

Despite continued high plant nutrient levels, secondary treatment does remove organics (carbon compounds) from sewage which are not removed by primary treatment. In fact, there was a significant decrease in the concentration of DOC between the computed upstream value and Site 5, 1.9 km (1.2 mi) below the effluent outfall (Table 5). In contrast, the algal growth potential of the water and the concentration of algal nutrients in the water all significantly increased along this stretch due to the input of effluent (Table 5). DOC concentration in the secondary effluent averaged 45 g m^{-3}. Calculations figuring in this value reveal that much DOC is removed by natural river processes in the first 1.9 km (1.2 mi) below the sewage effluent input (average annual removal rate = 19 g DOC m^{-2} day^{-1} (Klotz and Matson, in press). The Shetucket River has the capacity to remove the input of DOC from the effluent (as well as additional upstream DOC) to the extent that the DOC concentration at Site 5 is lower than the computed upstream value. DOC is probably removed from the water by bacteria added with the effluent itself (during non-chlorination periods) or by bacteria attached to rocks within the effluent plume in the river. The DOC levels in the unpolluted Natchaug are equal to or greater than levels in the Willimantic and Shetucket Rivers (Table 6).

The DOC increase between Sites 5 and 6 was associated with a decrease in algal nutrients (except nitrate-nitrogen), indicating that the algae are utilizing the nutrients to produce organic matter in this zone. The lack of a decrease in nitrate-nitrogen concentration might be explained by interactions with other forms of nitrogen. There are high levels of ammonia (7-18 g N m^{-3}) and organic nitrogen (0.6-8.5 g N m^{-3}) (Costello, 1976) in the effluent which could be converted to nitrate by certain bacteria in the river. Therefore, while the algae may be utilizing some nitrate-nitrogen, more may be added to the water through the action of these bacteria. The nitrate-nitrogen added by the bacteria would mask that taken up by the algae.

The significant decrease in DOC from Site 7, located in an impounded area to Site 8, approximately 1.0 km below the dam, suggests that impoundments may reduce the DOC concentration in the water column, possibly at the expense of increased sediment organic content.

There was a natural seasonal cycle for DOC concentration in the river (Fig 6) with higher values in the summer and fall due to increased biological activity and input of terrestrial leaf material.

Other Physical and Chemical Measurements

Of the other chemical and physical parameters measured, suspended solids, total alkalinity and pH showed no significant variation from upstream to downstream stations, denoting no appreciable effects due to the sewage treatment plant. Temperature fluctuations observed were natural for this region of the country, with occasional partial ice cover in the winter months and water temperatures reaching the upper 20 C range in mid and late summer.

Biological Effects

The above results have shown that the effluent directly affects the river's chemical and physical properties. The plants and animals in the river are directly and indirectly affected by changes in the chemical and physical properties, while their growth processes in turn influence the water quality.

Many studies on other rivers have dealt with pollution zones in rivers downstream of an input of sewage. Typical changes which occurred in the polluted area were a proliferation of sewage fungus, resistant animals and bacteria; an increase in ammonia, dissolved and suspended solids, and biochemical oxygen demand (BOD); and a decrease in dissolved oxygen and the numbers of algae and clean water fauna (Fig 4 and 5). These changes are inherent with sewage containing large amounts of organics. The drastic changes noted above did not occur in the Shetucket River. The suspended solids, dissolved organic carbon and biochemical oxygen demand (BOD) did not increase from above to 1.9 km (1.2 mi) below the treatment plant at Site 5, nor did the oxygen concentration decrease (Matson, 1975; Costello, 1976). The algal biomass did not decrease but increased sharply after the sewage input (Fig 7) and will be discussed later in detail. Organic pollution and the inherent biological changes associated with it (Fig 4 and 5) did not occur in the river.

The biological changes which are associated with the high organic pollution of rivers by primarily treated sewage are due to a proliferation of organisms which decompose the organics in the effluent into CO_2 and inorganic nutrients. Part of this decomposition process occurs within the sewage treatment plant in municipalities possessing secondary treatment. The disruption of the natural river community by the increase of organic decomposer organisms, some of which are harmful to health, does not take place, for the decomposition processes and organisms are confined to the secondary treatment plant.

However, the effluent that is discharged from these secondary plants does contain high levels of inorganic nutrients, products of the decomposition of organic material. Table 5 shows that this discharge of nutrients increases the algal growth potential of the water. These nutrients would have been released from the downstream end of the organic decomposition zone in rivers receiving primary waste, leading to increased algal growth downstream of this zone (Fig 4 and 5). This increased algal growth removes the inorganic nutrients further purifying the river water. However, increased algal growth can deplete the supply of oxygen in the river at night to harmfully low levels (O'Connell and Thomas,1965). Secondary treatment, therefore, shortens the length of river needed to purify an effluent discharge, the length being equal to the length of the organic decomposition zone depicted in Fig 4 and 5.

Algae. The algal assay procedure showed that the effluent promoted the algal growth potential of the water as measured by a national standard test organism. The endemic algae in the river showed a similar trend, with a tenfold increase in the concentration of algae attached to the rocks in the effluent plume (EFF-1-In, Fig 2) compared with outside the plume (EFF-1-Out, Fig 2) (Fig 7) (Klotz, 1975). The two dominant epilithic algae (see below) which account for nearly 90% of all the algae in the river, were studied in the laboratory and the growth of each was found to be greatly stimulated by Willimantic secondary effluent (Klotz, 1975). Therefore, both field enumeration of algae and laboratory assays with the two dominant algae, as well as with the national standard algal assay organism, have shown the secondarily treated effluent from the Willimantic sewage treatment plant significantly stimulates algal growth above natural levels.

Increased cell numbers (biomass) of algae is one measure of pollution; another measure is the kinds of algae present. In the algal field study, 89.7% of all attached algae were of just two unicellular species, Achnanthes deflexa, a diatom, and Chlorella sp., a green alga. At the sampling sites within the effluent plume, Chlorella accounted for 95.1% of all algae, while A. deflexa was present as 1.1% of the total. At the EFF 1 - 3 Out stations the Chlorella accounted for 36.9% of all algae, while A. deflexa was 46.8% of the total. The numbers of Achnanthes deflexa greatly decrease within the effluent plume from cleaner waters, while the numbers of Chlorella greatly increase. As the effluent gradually mixes with the surrounding water, becoming more dilute, the ratio of the two algae is normalized to the value obtained for the clean EFF 1 - 3 Out stations. These two algae are, therefore, excellent field indicator species for sewage pollution. The Chlorella is present in much greater numbers than the Achnanthes in polluted water; the two are present in relatively equal numbers in cleaner water. Determination of the proportion of the two species in a sampling of the attached algae on the rocks in the study area will give the observer a good indication of the effluent concentration in the water.

Further laboratory studies showed that the cause for the different ratios of the two algae was competition between the two. For algae to colonize a running water habitat, they must remain attached to the rocks. In this river, it was found that the rocks on the bottom were in short supply. As shown above, different algae are suited to different nutrient concentrations. The Chlorella, more suited to polluted water, will dominate the Achnanthes within the effluent plume. The two will share dominance in cleaner waters. This type of situation works to the benefit of the river and to man. The Chlorella will utilize the nutrients within the effluent plume maximally, therefore removing nutrients from the water and decreasing algal growth downstream.

Bacteria. The effect of the secondary treatment plant on the bacteria of the river was also evaluated by sampling upstream and downstream of the effluent outfall. It is evident from data in Fig 8 - 10 that the downstream seasonal averages were usually higher than upstream, except during chlorination periods. The only indicator groups which were higher at some downstream stations during chlorination were the 37 C yeasts, total coliforms and plate count bacteria. Since chlorination procedures did not eliminate all of the plate count group (about $10^5 l^{-1}$ survived), a downstream increase in the size of this group is predictable. Thus, during chlorination periods, the indicator populations encountered below the effluent were generally derived from the Willimantic and Natchaug Rivers. The 37 C yeasts and total coliforms may be more resistant to standard chlorination procedures, and some "regrowth" may have occurred. Dilution of the effluent and its percent of the river volume (Fig 3) are critical factors determining the size and structure of downstream microbial populations.

The total coliform group included many non-fecal organisms (Geldreich, 1964) as well as fecal coliforms from warm-blooded animal feces. Enumeration procedures for total coliforms recover both groups, and selective procedures are used to further separate the coliforms of fecal origin. It is interesting to note the difference in the ratios above and below the effluent. At upstream stations, the fecal group accounts for greater than 30% of the total coliform population, while below the effluent, the percentage is much lower (Table 8). Perhaps this indicates the necessity of a reevaluation of the significance of total coliforms as indicators, or a reevaluation of the enumeration procedures. Also, Table 9 reveals that the likelihood of encountering a member of the total coliform group in a given population of plate count bacteria is quite similar both above and below the effluent. Perhaps this group includes some naturally occurring organisms which are not significant health hazard indicators.

Predation, sedimentation and natural mortality will reduce population sizes of indicator organisms in an otherwise stressed environment (Allen et al., 1962; Hanes et al., 1965; Hendricks, 1972) but the most important factor in the downstream decrease in numbers is time. As discharge increases, the time of travel between Sites 5 and 6 (2.7 km) decreases. At a discharge of 50 m^3sec^{-1} (common during cold winter months) travel time between stations is about 45 minutes. At a discharge of 20 m^3sec^{-1} (common during fall and spring months) travel time increases to about 100 minutes. Thus, with an increased travel time (low discharge) natural die-off and other factors will take a greater toll of the population. These relationships are important in establishing water use policies downstream of an effluent.

In applied terms, chlorination and relative effluent volume (Fig 3) seem to have the most dramatic effect on pollution indicator population size downstream of this sewage plant. In order to upgrade the use classification of the Shetucket River, chlorination should be a year-round practice.

Aquatic Macrophytes, Heavy Metals. The influence of heavy metals in the extended study area was investigated in relation to the aquatic macrophytes. As mentioned earlier, many organisms are capable of concentrating heavy metals within their tissues to many times the concentration found in the surrounding water. Also, they can absorb and retain heavy metals that may have appeared in the environment only at one point in time. Aquatic macrophytes were used in this study as a collection receptacle for heavy metal samples. Since river animals feed upon these plants, the presence of heavy metals within the plants would suggest the heavy metals would enter the animals and be concentrated in them, although this was not determined in this study.

The results of the heavy metal analyses of aquatic macrophytes are given in Table 10. Copper concentrations in both species studied, Pontederia and Potamogeton, are lowest in the Natchaug, intermediate in the Shetucket and highest in the Willimantic River. The mean lead concentration found in the above-ground Pontederia parts is least in the Natchaug, intermediate in the Willimantic and highest in the Shetucket River, while concentrations in the below ground plant parts are again least in the Natchaug, but higher in the Willimantic than the Shetucket. The lead concentrations in Potamogeton are lowest in the Natchaug and Willimantic and highest in the Shetucket.

River water samples from the extended study area were analyzed for lead and copper to aid in interpreting the concentrations in plants (Fig 11 and 12). These results show an obvious pattern of copper concentration differences within the river system, but a less obvious one for lead. Copper levels (Fig 11) are below accurate instrument sensitivity throughout the Natchaug River. Water from the Willimantic River shows much higher concentrations, with a peak of 317 parts per billion (ppb) copper being observed in a sample taken 0.5 km downstream of the North American Tyco printed circuit plant in Stafford. A sample taken from a tributary just upstream of this plant had very low copper levels. A decreasing gradient in copper concentration occurs from the upper Willimantic in Stafford to the lower part in the city of Willimantic. The Shetucket River has intermediate concentrations of copper.

The results of the lead analysis (Fig 12) showed only the sample collected below the North American Tyco factory had a measurable concentration. Since water samples were only collected once for heavy metal analysis, the values presented above are not likely to be accurate representations of average conditions over the entire growing season but are useful for comparison with macrophyte concentrations.

Interpretation of the aquatic macrophyte and water analysis data reveals important differences in copper and lead behavior in the extended study area. Copper concentrations in plant tissue were lowest from the Natchaug River and highest in the upper and middle Willimantic River. Since analyses of water samples implicated the North American Tyco printed circuit factory in discharging copper on one date, the high copper concentrations in plants from the upper Willimantic River was at least in part due to this factory. Plants from the Shetucket River had copper contents intermediate to those from the Natchaug and Willimantic Rivers. An appreciable amount of copper in the Shetucket was likely carried down from the Willimantic, although local input was suspected in maintaining the copper concentrations observed (Heisey, 1975). Analyses done in 1975 did show the Willimantic effluent to contain low levels of lead and copper (Table 3). Potamogeton and other submersed and floating-leaved plants had higher copper concentrations than Pontederia tops, which grow above the river water level. This was probably due to the greater leaf area of the submersed plants in contact with the water surface, providing a greater capacity to adsorb and absorb copper from the water.

Lead distribution in the extended study area showed a somewhat different pattern (Table 10). In this case, Pontederia tops had roughly comparable concentrations to those of whole Potamogeton plants. Since other studies have indicated that little lead is taken up by plant roots and translocated to tops, the equally high (as Potamogeton) lead concentrations in Pontederia tops extending above the water must have come from aerial fallout. Therefore, the major source of lead in the extended study area appeared to be emanating from the atmosphere; the original source was probably leaded gasoline.

As important as the presence of heavy metals in plant tissue was the fate of the heavy metals after the growing season of the plants. Information obtained in this study provided some insight into the role played by vascular aquatic plants in the cycling of heavy metals in a riverine environment. The path of copper and lead appeared largely determined by the fate of the organic matter produced by the plants, since a large proportion of both metals was relatively immobile in or on plant tissues. Much organic matter produced by Potamogeton was washed downstream, thereby precluding an appreciable buildup of metals in the stream sediments. The situation was probably similar for other floating-leaved and submersed aquatics, but detritus of those plants growing in slower water might not have been so readily washed away and would have remained in the sediments and increased the sediment heavy metal concentrations.

Pontederia is found in more slowly flowing water than Potamogeton. Plant beds occurring in areas subject to high current during the dormant season would have much of the previous season's above-ground growth, and the metals contained therein, washed downstream. Above-ground organic matter might accumulate in Pontederia beds occurring in protected water such as inlets. Although nutrients appear to be transported from overwintered old rhizomes into new, it is doubtful whether heavy metals are similarly moved, especially since much of this may be in or on cell walls or epidermal tissues.

As a result, metals in old below-ground Pontederia parts probably remain with the organic matter until freed by decomposition. It is possible that an appreciable amount of these metals are then taken up by the new below-ground organs, and as a result, accumulate within the stream sediment. In this way, heavy metals which may have appeared briefly in the water column are sequestered to the sediments by the aquatic macrophytes to remain in the river environment for lengthy periods.

The above interpretation of the lead and copper data from the extended study area shows that the major sources of copper and lead are the North American Tyco printed circuit factory in Stafford and lead from leaded gasoline deposited on the river via the atmosphere. The input of copper and lead from the Willimantic secondary sewage treatment plant (Table 3) was not great enough to be evidenced in the Shetucket River.

The second part of the aquatic macrophyte study, a measurement of the production of Pontederia and Potamogeton, showed values greater for the Willimantic and Shetucket Rivers than for the Natchaug. Pontederia production was considerably greater in the middle Willimantic and upper Shetucket Rivers than in the Natchaug and lower Shetucket. Though variable from one year to the next, Potamogeton production was greater in the Willimantic and Shetucket Rivers than in the Natchaug. Due to the infrequent nature of the beds of aquatic macrophytes in the extended study area, it was impossible to determine the effects of the Willimantic secondary sewage treatment plant on aquatic macrophyte production. The paucity of the plants precluded finding beds in similar environments just above and below the treatment plant to accurately compare data.

Pesticides. Pesticides were found to remain in the study area long after they were introduced into the environment, a longevity effect similar to that of heavy metals. Pesticide residues were found in the sediments in the Natchaug and Shetucket Rivers in values below 1.0 ppb (parts per billion), while no detectable trace of pesticides was found in water samples from the same location. Water samples at Site 2 in the Willimantic River were found to contain very low levels (less than 0.10 ppb) of the pesticide residues 2,4-D(ME) and 2,4-D(BE)I. It should be emphasized that pesticide sampling was done very infrequently, with water samples and sediments collected on only two dates, and epilithic algae only on one date.

Some of the sediment transported downstream by river flow settles out of the water column in Scotland Impoundment, forming deposits with the most recently transported sediment on top of older layers. In this way, the impoundment bottom acts as a chronological catch basin for changes that have taken place upstream. Scotland Impoundment sediments were sampled once in September 1974 to determine pesticide levels at varying depths. Since no attempt was made to date the different sediment layers and since sampling was only done once, no conclusions can be made concerning the longevity of pesticides in the sediment. However, pesticides were found from the surface to as deep (25 cm) as samples were taken.

Epilithic algae from the three rivers of the condensed study area were analyzed and were found to contain pesticides at the levels of 3 to 78 ppb, significantly higher than concentrations in the sediment. A list of the pesticides found, and their location and concentration, is given in Table 11.

Knowledge of the origin of some of these pesticides and their breakdown products lends insight into their behavior in the river environment. Hydroxychlorodine, found in the attached algae and in Scotland Impoundment sediments, is a non-toxic breakdown product of the insecticide heptachlor which was used ten years ago in the study area to kill insects in alfalfa fields but has not been widely used since. Heptachlor-epoxide, formed when the insecticide, heptachlor, is exposed to the air at the time of application, was found to be widespread in the river system in the epilithic algae and in sediments from Scotland Impoundment and the Natchaug and Shetucket Rivers. Chlorbenside, found in the impoundment sediments and the algae, is a miticide which has been off the market for three years. The presence of these pesticides is significant in that they are still a part of the river system after not being used for three to ten years prior to this study, especially considering the fact that when heptachlor and chlorbenside were used, they were only applied to fields once a year.

The pesticide analyses were performed to determine the extent of pesticide pollution in the river system, for their presence might influence any effects on the river organisms caused by the secondary sewage plant. The limited data show that the Willimantic secondary sewage treatment plant does not add to the pesticide concentrations in the river system.

However, the increased concentrations of pesticides in the algae, and perhaps into those organisms which consume the algae, is important for the increased stress placed upon these organisms may make them more sensitive to sewage pollution. The implications of such a stress, or even its presence, were not determined in this study, but the widespread presence of pesticides in the river system warrants future study of the stress they cause organisms.

Aquatic Insects. The aquatic insect study was combined with a study of organic nitrogen and ammonia levels at Sites 1 - 6 in the condensed study area during 1974 (Costello, 1976). In all, a total of 91 samples were retrieved and around 7,000 organisms captured, examined and identified. Degree of pollution was evaluated by determining the structures of the insect community; pollution tending to restrict the wide variety of organisms found in clean waters, leading to dominance by those resistant to the pollutants. Classification of insects in this study was at the family level.

The Natchaug River exhibited a comparatively diverse community with no particular dominance by any one organism. Of the organisms encountered in the Natchaug River, the family Chironomidae composed only 16 percent of the total number of organisms observed, the remainder of which was comprised of trichopteran larvae *Hydropsyche* sp. and *Cheumatopsyche* sp., and ephemeropteran nymphs *Isonychia* sp. and *Stenonema* sp.

Unlike the Natchaug River, the Shetucket and Willimantic Rivers displayed a far less diverse macro-invertebrate community with the dipteran larvae Chironomidae and to a lesser extent, the trichopteran larvae *Hydropsyche* sp. and *Cheumatopsyche* sp. dominating. In terms of insect community structure then, the Natchaug River behaved as a clean river, the Willimantic and Shetucket behaved as polluted rivers.

Costello (1976) found the treatment plant to be associated with a decreased biomass of insects at sites below the secondary treatment plant as well as with changes in the above-mentioned community structure index. Multiple regression analyses showed the insect biomass and community structure to be significantly related to the concentrations of ammonia-nitrogen found in the interstitial waters and organic nitrogen in the sediments. The origin of these nitrogen compounds was the Willimantic sewage effluent.

Fish. Population dynamics were also used in the evaluation of the secondary sewage treatment plant on the fish of the extended study area. Various sampling and evaluation techniques, discussed in the materials and methods, were used to determine if the populations of fish in the rivers of the extended study area behave as expected. The expected trends are listed in Table 12, and the actual trends for the rivers are listed in Table 13. Table 13 shows that man has affected, to some degree, the fish of each of the rivers of the extended study area. The most agreement found with the expected trends was less than 70 percent (Goldstein, 1975). The Shetucket River possessed only a 23 percent agreement with the expected trends, the lowest for all the four rivers sampled. This lack of agreement with expected trends for the Shetucket River was due to the city of Willimantic and/or the Willimantic secondary sewage treatment plant. Of all the rivers sampled by snorkeling in Southern New England (Fig 13), the Shetucket had the highest human influence index (HII), as calculated from the various components in Table 14. The high HII for the Shetucket was primarily due to the number of mill buildings in, and the volume of sewage effluent from, the city of Willimantic.

The high number of white suckers in the Shetucket River was disproportionate to what would be expected in that type of habitat. This was probably due to the fluctuating water levels in Scotland Impoundment; Scotland Dam generates hydroelectric power by routine draw down of the water in the Impoundment. The numbers of predatory fish are limited by the fluctuating water level, for their nests built when the water is high may become dry when the water is low, and those predatory fish which spawn amongst vegetation are limited due to the paucity of submerged littoral plants. Sucker spawning occurs in the tributaries, so their reproduction is not limited by fluctuating water levels. Therefore, juvenile suckers can use Scotland Impoundment as a nursery area with little loss to predation. The sucker populations increased due to the lack of predatory fish.

Evidence acting as proof of the above evaluation of sucker population dynamics are data from the Yantic River, which had the second highest (to the Shetucket) HII. However, the Yantic possessed a greater amount of habitat for predatory fish and lacked water level fluctuations. Sucker populations were at normal levels. Therefore, the water level fluctuations controlled by Scotland Dam and the lack of aquatic macrophytes for predator habitats limited the sucker predator populations, which in turn contributed to unnaturally large sucker populations in the Shetucket River.

Fish production in the Shetucket River was probably increased over natural levels by the effluent from the secondary treatment plant. The effluent was a source of nutrients, and nutrients increase fish production (Forney, 1968; Barraclough and Robinson, 1972; and Haines, 1973). The sewage effluent may have acted to increase the sucker populations below the sewage treatment plant in either or both of two ways. Either the suckers were the fish best adapted to utilize the extra nutrients from the effluent, and/or the lack of sucker predators which would have utilized the nutrients for fewer individuals, allowed the suckers to accumulate the nutrients into more individuals.

River Metabolism. The metabolism of the Shetucket River was measured and the ratio of the amount of oxygen produced (P) and consumed (R, respired) by the river biota was determined. The river below the Willimantic secondary sewage treatment plant was dependent upon an external source of organics for energy in 8 of the 9 times it was measured in 1974 (Fig 14; Klotz and Matson, 1975). August was the only month when river algal production was sufficient to maintain river respiration. However, since it was impossible to sample a similar river for comparison (see Materials and Methods), it was not determined if this P/R ratio deviated from the natural value for an unpolluted river with similar characteristics as the Shetucket. Therefore, it was not determined in what way the secondary sewage treatment plant affects natural river metabolism through most of the year. However, some conclusions were made for August.

Low dissolved oxygen values (4.1 mg $O_2 l^{-1}$; 55% saturation) may have inhibited nighttime respiration during the August study (Matson, 1975). The high biomass of algae in the Shetucket River upstream of the stretch studied may have removed sufficient oxygen (by nighttime respiration) from the water column in August to inhibit the respiration of the biota in the stretch studied, a process evidenced in other studies (O'Connell and Thomas, 1965).

The high concentration of effluent in the Shetucket River during August (Fig 3) produced high nutrient concentrations, increased algal biomass immediately downstream of the effluent outfall (Klotz, 1975), and perhaps reduced community respiration further downstream due to the above-mentioned process. In this way, the secondary effluent may have altered natural Shetucket River metabolism during August 1974.

CONCLUSIONS

The results of this study show the Willimantic secondary sewage treatment affects the Shetucket River in the following ways:

1) While pollution zones typical of high organic pollution (Fig 4 and 5) were not present (BOD did not increase 1.9 km downstream of the plant from upstream values; effluent DOC was rapidly processed; there was no oxygen sag), the inorganic nutrients significantly increased due to the secondary sewage discharge. Downstream of the treatment plant, significant increases were found in nitrate-nitrogen, total phosphates, ortho-phosphates, conductivity and the algal growth potential.

2) The increase in inorganic nutrients result because the input of secondary sewage was too great for the natural purification processes of the river. As a result, the nutrients remained unnaturally high downstream in the Shetucket River and in Scotland Impoundment and probably contributed to an algal bloom and odor problems in the impoundment in August 1973.

3) The endemic algae of the river, those attached to the rocks, responded to the increased algal growth potential produced by the secondarily treated effluent by a ten-fold increase in numbers and biomass, as well as a change in composition. However, this composition change and greater biomass increased the rate at which the river organisms removed effluent nutrients.

4) The seasonal averages of all bacterial and yeast groups downstream of the treatment plant were always substantially higher than upstream, except during chlorination periods, when most groups were equal to or reduced from their upstream numbers.

5) The treatment plant was not found to contribute significantly to the presence of heavy metals and pesticides which were found in the water, plants and sediment of the extended study area.

6) Increased ammonia-nitrogen in interstitial waters and organic nitrogen in the sediments of the Shetucket River was correlated with a decrease in the diversity of the aquatic insects and with a decrease in their biomass.

7) The Shetucket River fish community was found to be affected more by humans, as measured by a human influence index, than that of any other river analyzed in southern New England. This was due to the amount of sewage effluent from, and the number of mill buildings in the city of Willimantic.

RECOMMENDATIONS

The results and conclusions from this study have led to recommendations by the members of the study team for alleviation of some of the problems associated with the discharge of secondary effluent into the Shetucket River.

1) Emphasis in the past has been placed on removing nutrients from waste water to limit algal growth. In other studies with algal species used in the algal assay described here, it has been found that the algal growth potential of water receiving tertiary sewage was the same as natural, unpolluted lake water (Payne, 1975). However, secondary treated water, as well as primary, greatly stimulated algal growth. That study concluded that nutrient removal by tertiary treatment greatly reduces the algal growth stimulating properties of sewage. Therefore, tertiary treatment is a benefit to man purely from the standpoint of reduced algal blooms.

However, another factor has entered the picture in recent years. With the rising costs of agricultural fertilizers in part responsible for soaring food costs, new sources of nutrients are needed. Human wastes are a very natural part of the cycling of nutrients in the environment. Loss of these nutrients to the river environment is not a natural phenomenon; witness the low nutrient load in a relatively undisturbed, unpolluted river system as the Natchaug River of this study. A law of the natural world is that wastes are not to be disposed of, but they are to be recycled for future use. In human societies, cost becomes an important factor in the course of events. Table 15 presents data that show the cost of nutrients lost from the people of Willimantic, Connecticut, through their secondary sewage treatment plant. For two of the most important agricultural fertilizer components, nitrogen and phosphorus, this loss comes to approximately $129,000 per year (Table 15).

Tertiary treatment removes many of these nutrients before they are lost. Calculations show that the cost of operation of a tertiary treatment plant would be totally offset if all nutrients could be successfully recycled (Table 16). Problems remain with the technology for the complete recycling of nutrients from human waste, however, the data presented here show a good part of the cost of such an operation can be regained through nutrient utilization. Reuse of the nutrients through land disposal of the waste to produce cultivated crops is being practiced elsewhere, with problems associated with the technique being minimized (Flack, 1973).

2) At present, 1.9 km of river are needed for natural mixing of the effluent plume. This distance could be shortened by use of a dispersal mechanism at the effluent outfall. The increased mixing rate thereby created would allow more of the organisms attached to the rocks to purify the water, leading to a quicker natural purification time.

3) Chlorination procedures should be used year round, not just May to September, in order to upgrade Shetucket River water use classification. However, chlorination should not be considered the ultimate solution to sewage disposal problems since some organisms (viruses, yeasts, protozoa) may become selectively resistant to chlorination.

4) The following set of recommendations were developed from the findings of the fish studies of this project and were made from the sport fishery point of view. If it is decided that recreational fishing should be a major function of this river system, then the following are pertinent. Since man has been unintentionally controlling both white suckers and centrarchids (Goldstein, 1975) in Scotland Impoundment by fluctuating water levels, it may be possible to intentionally control them by manipulation of the flow regime. Regular fluctuations of over one meter twice a week during predator spawning seasons could reduce egg hatching by desiccation whereas maintenance of a constant pool level would protect nests and allow for predator populations to increase. By increasing the predator population the sucker population could be reduced.

The upper Shetucket River system should be managed to provide the maximum benefit not only for fishing but also for other water activities. Dams on the Willimantic, except those on the natural falls, and on the Hop River should be removed and water quality improved. This would allow the rivers to regain some of their natural beauty, especially in the small gorge that runs through the city of Willimantic and provide more aesthetically pleasing locales for fishing and water sports. Fish management should be a shift from put-and-take trout to smallmouth bass in the lower section of the Willimantic River and all of the Shetucket River.

The Natchaug River receives a large amount of trout fishing pressure and should be maintained as a put-and-take trout fishery. There is a small reproducing smallmouth bass population in the Natchaug, but it does not seem to sustain a fishery. Unless habitat management to increase secondary production and forage fish is undertaken in the Hop River, it should remain a put-and-take fishery as well. The lower section of the Willimantic River and all of the Shetucket River should be converted to a smallmouth bass fishery. Although smallmouth bass populations were present in the Hop and Natchaug Rivers, either no or very few individuals were found downstream in the Willimantic or Shetucket Rivers, respectively. Scotland Impoundment should be stocked with largemouth bass. Populations from both largemouth and smallmouth bass stocking, either an initial large plant or several successive year small plants, would require protection for several years to allow them to increase to a level that could support a fishery. Water quality in the system and fluctuating flow in and below Scotland Impoundment would have to be changed since these are probably the causes of the present low populations. Existing dams could be used to separate upstream trout fisheries in the Hop, Willimantic and Natchaug Rivers from the bass fisheries below. The Hop River probably cannot support large fish populations because its basin is primarily sand and these basins typically have low fish production (Carbone and Kelley, 1961; Tebo, 1955).

GLOSSARY

Anions: A negatively charged ion.

Aquatic Macrophytes: Vascular plants floating on, or growing in a body of water.

Biochemical Oxygen Demand (BOD): A measure of the amount of dissolved oxygen needed for the biological oxidation of the organic material in a water sample.

Biomass: The weight of living material.

Brucine Method (for Nitrate-Nitrogen determination): A standard method for determining Nitrate-nitrogen. Briefly, a brucine-sulfanilic acid reagent is added to the water sample, and this is mixed with sulfuric acid. After 10 minutes in the dark, distilled water is added, and when cool the color of the solution is quantitated on a photometer.

Coliform Bacteria: (see Total Coliform Bacteria)

Diatom: A group of algae characterized by possessing silicate walls.

Direct Runoff: Surface water, originating from precipitation, which enters water bodies without percolating through the soil.

Dissolved Organic Carbon (DOC): Compounds of carbon dissolved in water, many of which provide a food source for the aquatic biota.

Epilithic: Organisms growing attached to rocks.

Fecal Coliform Bacteria: Those members of the coliform group which are present in the gut or feces of warm-blooded animals. They are isolated and enumerated by their ability to produce gas from lactose.

Fecal Streptococci: A group of bacteria of the genus *Streptococcus* generally found in the intestinal tract of man and animals.

Fecundity: Ability to produce offspring.

Groundwater: Subsurface water.

Hypochlorite: The ion of a chlorine compound used in the disinfection of effluents before discharge into the environment.

Interstitial: Situated within the spaces between things. As used in this study; that water present in the spaces between the river sediment grains.

Kjeldahl Method: A method for determining the organic nitrogen concentrations in a water sample (APHA, 1971).

Methyl Orange Indicator Method (for alkalinity determination): A method for determining the alkalinity of a water sample. Briefly, 2 drops of the methyl orange indicator are added to the water sample and this solution is titrated with acid (APHA, 1971).

Miticide: A chemical material used specifically to kill mites (small arachnids often deleterious to animals and plants).

Nutrient: A substance utilized by a plant or animal for life processes.

Plankton: Organisms freely drifting in the water column.

Quadrat: A rectangular plot of known area used in field studies.

Stratify: The property of a body of water forming layers due to the different densities of water at different temperatures.

Total Coliform Bacteria: A group of bacteria present in the intestines of warm-blooded animals.

Underflow: The movement of water downstream through the deposits underlying a stream.

Winkler Method, Azide Modification (for dissolved oxygen determination): A method for determining the dissolved oxygen concentration in a water sample. Briefly, aliquots of a manganese sulfate solution and an alkali-iodide-azide reagent are added to the water sample, then after proper shaking and settling, sulfuric acid is added. This is then titrated with thiosulfate solution to determine the dissolved oxygen (APHA, 1971).

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Table 1. Census* of towns in the upper Shetucket River watershed**.

Town	Watershed	Year 1790	1850	1910	1940	1970
Andover	Hop		500	371	560	2,099
Ashford	Natchaug	2,583	1,295	668	704	2,156
Chaplin	Natchaug		796	435	489	1,621
Columbia	Hop		876	646	853	3,129
Coventry	Hop and Willimantic	2,130	1,984	1,606	2,102	8,140
Eastford	Natchaug		1,127	513	496	922
Mansfield	Willimantic and Natchaug	2,635	2,517	1,977	4,559	19,994
Stafford	Willimantic	1,885	2,940	5,231	5,835	8,680
Willington	Willimantic	1,212	1,388	1,112	1,233	3,755
Windham***	Willimantic and Shetucket	2,765	4,503	12,604	13,824	19,626
TOTALS		13,210	17,926	25,163	30,655	70,122

* Secretary of the State. State of Connecticut Register and Manual 1973. Hartford, Connecticut, 924 p.

** Does not include Norwich and vicinity.

*** Includes the city of Willimantic.

Table 2. Parameters measured for the study.

Parameter	Where Studied*	When Studied	Method
Nutrient Measurements			
Algal Growth Potential	Sites 1 - 6	July 1973-Dec 1974 Biweekly	Growth of Selenastrum. (Cain & Trainor, 1973)
Nitrate Nitrogen	Sites 1 - 6	July 1973-Dec 1974 Biweekly	Brucine (APHA, 1971)
Organic Nitrogen	Sites 1 - 6 and Effluent (Interstitial, water column, sediments)	May-Dec 1974 Biweekly	Kjeldahl (APHA, 1971)
Ammonia Nitrogen	"	May-Dec 1974 Biweekly	Distillation and titration (APHA, 1971)
Conductivity	Sites 1 - 8	July 1973-Dec 1974 Biweekly	Hach Chem Co Conductivity Meter & YSI meter
Ortho-phosphates	Sites 1 - 6	July 1973-Dec 1974 Biweekly	Stannous Chloride (APHA, 1971)
Poly-phosphates	Sites 1 - 6	"	Total - Ortho
Total phosphates	Sites 1 - 6	July 1973-Dec 1974 Biweekly	Acid Hydrolysis, Stannous Chloride (APHA, 1971)
Physical & Chemical Measurements			
Turbidity	Sites 1 - 6	July 1973-Dec 1974 Biweekly	Hach Chem Co Turbidity Meter
Suspended Solids	Sites 1 - 6	July 1973-Dec 1974 Biweekly	Gravimetrically (APHA, 1971)
Alkalinity	Sites 1 - 6	July 1973-Dec 1974 Biweekly	Methyl Orange Titration (APHA, 1971)
Temperature	Sites 1 - 6	"	Mercury Thermometer
Dissolved Oxygen	Sites 1 - 6	July 1973-Dec 1974 Biweekly	Winkler, Azide Modification (APHA, 1971)
Dissolved Organic Carbon	Sites 1 - 8	Jan-Dec 1974 Biweekly	Thermal Combustion, Infra-red analyzer (Rich et al, 1974)

Table 2. continued

Parameter	Where Studied*	When Studied	Method
Pesticides	Condensed Study Area (water, sediment and algal)	Irregularly 1973-1974	Gas-liquid chromotography
Copper, Lead	Extended Study Area	1973 growing season	Atomic Absorption Spectrophotometer
Biological Measurements			
Bacteria	Sites 2 - 8 & Effluent (Planktonic, epilithic & sediment bacteria)	July 1973-Dec 1974 Biweekly	Membrane, Filtration (APHA, 1971) Plate Count Bacteria according to Buck and Cleverdon, 1960
Yeasts	"	"	Filtration
Algae	Sites 1 - 6 and Effluent Plume (Epilithic only)	Jan-Nov 1974 Monthly	Natural Substrate Rock Brushing (Douglas, 1958)
Aquatic Insects	Sites 1 - 6 (Benthic only)	May-Dec 1974 Biweekly	Artificial Substrate (Costello, 1976)
Aquatic Macrophytes	Extended Study Area (Submerged, Emergent and Floating leaved plants)	1973 and 1974 growing seasons	Harvest Method, (Milner & Hughes, 1968)
Fish	Extended Study Area	July 1973-Dec 1974	Seining, gill netting, angling, direct observation (Goldstein, 1975)
River Metabolism	Stretch between Sites 4 and 6	Mar-Dec 1974 Monthly	Upstream-downstream technique (Odum, 1956)

*In water column, unless otherwise noted.

Table 3. Willimantic Secondary Sewage Treatment Plant Characteristics

Facility Characteristics	
Population Served	25,000 (projected for 1987)
Type System	Activated Sludge
Effluent Volume Capacity	5.5 MGD (million gallons day^{-1})
Average Daily Volume*	3.4 MGD (July 1973 - Dec. 1974)
Effluent Characteristics	
Settleable Solids*	0.011 ml/liter (1974 average)
Suspended Solids*	56 mg/liter (1974 average)
Biological Oxygen Demand (BOD)*	39.1 mg/liter (1974 average)
Dissolved Oxygen (D.O.)*	1.6 mg/liter (1974 average)
Phenols+	0.007 mg/liter (Composite sample for 24 hours, taken 12/12/75)
Cyanide+	none detected "
Nitrate Nitrogen+	0.6 mg/liter "
Ammonia Nitrogen ≠	13.2 mg/liter "
Organic Nitrogen≠	5.3 mg/liter "
Hydrocarbons+	none detected "
Copper+	0.13 mg/liter "
Chromium+	0.18 mg/liter "
Cadmium+	0.004 mg/liter "
Lead+	0.03 mg/liter "
Nickel+	0.10 mg/liter "
Zinc+	0.15 mg/liter "

*Data gathered by the Willimantic Sewage Treatment Plant Chemist and supplied by the Conn. Dept. of Environmental Protection, Water Compliance Unit, Hartford, Conn.

+Data gathered by the Conn. State Health Dept., Laboratory Division and supplied by the Conn. Dept. of Environmental Protection, Water Compliance Unit, Hartford, Conn.

≠Values represent averages for biweekly sampling of the effluent from July through November 1974 (Costello, 1976)

Table 4. Ranges and means of the nutrient parameters measured at sampling sites 1 - 6, July 1973 through December 1974

Site	Algal Growth Potential Doublings/5 days		Conductivity≠ ppm NaCl		NO_3-N mg l^{-1}		Total PO_4 mg l^{-1}		Ortho - PO_4 mg l^{-1}		Poly - PO_4 mg l^{-1}	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
1	2.74-6.41	4.40	24-64	37	0.27-2.49	1.38	0.36-2.40	1.19	0.10-1.25	0.28	0.15-2.15	0.90
2	3.10-6.42	4.45	24-53	36	0.40-2.39	1.17	0.47-2.80	1.17	0.10-0.90	0.24	0.20-2.40	0.92
3	1.66-3.38	2.46	13-40	29	0.12-1.44	0.90	0.04-1.90	1.02	0.05-0.30	0.11	0.03-1.80	0.91
4	3.44-8.46	5.45	28-110	51	0.09-2.08	1.18	0.50-3.20	1.63	0.10-1.80	0.69	0.08-2.70	0.91
5	3.61-8.40	5.29	29-82	46	0.45-2.39	1.20	0.70-3.20	1.49	0.10-1.30	0.58	0.10-2.10	0.88
6	3.45-6.78	4.84	27-77	43	0.32-2.30	1.24	0.30-3.30	1.37	0.10-1.20	0.41	0.20-2.25	0.95

≠Measured with a Hach Chemical Co. Conductivity meter.

Table 5. The behavior of DOC concentration and nutrient parameters along various stretches of the condensed study area. Upstream represents the sum of the measurements taken at Sites 2 and 3 weighted for their contribution by volume to the Shetucket River total. T-values for paired data were calculated for each specie along each stretch of river. No significant difference at the 0.10 level from x to y is represented by "0"; an increase from x to y is represented by "+"; a decrease from x to y is represented by "-".

	Upstream to 5	5 to 6	6 to 7	7 to 8
DOC	- **	+ *	0	- *
Conductivity≠	+ ***	- *	0	0
NO_3 - N	+ *	0		
Total - PO_4	+ ***	- *		
Ortho - PO_4	+ ***	- ***		
Poly - PO_4	0	0		
Algal Growth Potential	+ ***	- ***		

Degree of significant increase or decrease

* = 0.05
** = 0.01
*** = 0.001

≠ Measured with a YSI Model 33 S-C-T meter, values expressed as μmhos cm^{-1} at 25 C.

Table 6. A comparison of unpolluted Site 3 (Natchaug River) with other sites in the condensed study area. T-values for paired data were computed for each specie between Site 3 and all other sites. No significant difference at the 0.01 level between Site 3 and the other site is represented by "0"; a greater value in Site 3 is represented by "+"; a lesser value in Site 3 is represented by "-".

Site 3 Compared to	DOC	Conductivity≠	NO_3-N	Total PO_4	Ortho-PO_4	Poly-PO_4	Growth Potential
Site 2	0	- ***	- *	- **	- ***	0	- ***
4	0	- ***	- ***	- ***	- ***	0	- ***
5	+ **	- ***	- ***	- ***	- ***	0	- ***
6	0	- ***	- ***	- ***	- ***	0	- ***
7	0	- ***					
8	+ *	- **					

Degree of significance, greater than 0 less than:

* = 0.05
** = 0.01
*** = 0.001

≠ Measured with a YSI Model 33 S-C-T meter, values expressed as μmhos cm^{-1} at 25 C.

Table 7. Pearson product-moment correlation coefficient values and significance of correlation derived by comparison of the algal growth potential to the chemical nutrients for each sampling site.

Site	Conductivity	NO_3-N	Total PO_4	Ortho PO_4	Poly PO_4
1	286	235	291	375	090
2	174	220	148	383*	056
3	-263	113	-052	007	-054
4	882***	632***	592**	924***	-274
5	806***	545**	517*	699***	-010
6	877***	739***	255	807***	-090

* Indicates 0.05 significance level
** Indicates 0.01 significance level
*** Indicates 0.001 significance level

Table 8. Percent of the mean number of total coliforms which are of fecal origin[a].

Site	1973 Oct-Dec	Jan-Apr	May-Sept	1974 Oct-Dec
2	100	50	44	33
3	30	68	53	35
4	14	17	22	10
5	9	26	24	8
6	13	9	31	7
7	26	15	41	8
8	---	8	27	14

a FC/TC X 100 (seasonal mean numbers from Fig 8, 9)

Table 9. Ratios of the means of total coliforms to plate count bacteria; the probability of encountering an indicator organism in a given number of bacterial isolates[a].

Site	1973 Oct-Dec	Jan-Apr	May-Sept	1974 Oct-Dec
2	0.0006	0.0004	0.0010	0.0020
3	0.0010	0.0001	0.0019	0.0010
4	0.0003	0.0020	0.0007	0.0050
5	0.0001	0.0010	0.0007	0.0070
6	0.0004	0.0010	0.0004	0.0060
7	0.0006	0.0006	0.0001	0.0070
8	------	0.0050	0.0003	0.0060

a TC/PC since the total coliform group is usually the most numerous of the accepted indicator organisms.

Table 10. Mean copper and lead concentrations of the aquatic macrophytes, *Pontederia* and *Potamogeton*, from the three watersheds.*≠ (Values in ppm)

		Natchaug River			Willimantic River			Shetucket River		
		range	$\bar{x}$	n	range	$\bar{x}$	n	range	$\bar{x}$	n
Copper	Pontederia	3/3-7/12	5/6	8	6/13-46/382	17/74	10	8/16-25/64	14/37	8
	Potamogeton	10-14	12	5	198-215	206	3	70-74	72	2
Lead	Pontederia	3/5-10/34	7/20	8	4/15-23/201	11/53	10	8/11-47/94	20/43	8
	Potamogeton	6-22	13	5	9-17	12	3	17-18	18	2

* For *Pontederia* values, numerator is concentration in tops; denominator in below ground parts. Values of each fraction not necessarily from same site.

≠ Means include concentration in first biomass sample at each site.

Table 11. Pesticides found in the extended study area.

Location	Date	Pesticides	Average Concentration (ppb)
Sediments, Scotland Impoundment	9/30/74	Ronnel	16.08
"	"	2,4,5 T (ME)	4.25
"	"	2,4 D (ME)	0.0465
"	"	2,4 D (BE)I	0.0894
"	"	Heptachlor-epoxide	5.25
"	"	Chlorobenside	15.84
"	"	Hydroxychlordene	74.93
"	"	Dilan	0.31
Sediments, Natchaug River*	1973 (2 samples)	Chlordene	0.633
"	"	Aldrin	0.580
"	"	Methylparathion	0.071
"	"	Heptachlor	0.107
Sediments, Shetucket River* (Route 203)	1973 (1 sample)	Chlordene	0.921
"	"	Aldrin	0.165
"	"	Methylparathion	0.0549
"	"	Methoxychlor	0.0032
Epilithic Algae Site 2	3/13/74	Heptachlor-epoxide	5.62
"	"	Chlorobenside	11.04
Epilithic Algae Site 3	3/13/74	Heptachlor-epoxide	3.05
"	"	Chlorobenside	26.01

Table 11. (continued)

Location	Date	Pesticide	Average Concentration (ppb)
Epilithic Algae Site 5	3/13/74	Chlorobenside	7.47
Epilithic Algae Site 6	"	Chlorobenside	9.63
Epilithic Algae Site 8	2/27/74	1-Hydroxychlorodine	78.841

* Water samples from these sites on same date showed no trace of pesticides.

Table 12. Expected trends or value of multiple species composition statistics for analysis of fish populations.

Multiple Species Composition Statistic	Composition	Expected Trend or Value
# Species Not Present	Mainstream to Tributaries	Lower
Occurrences of 5 Common Species	Mainstream to Tributaries	Higher
Mean Size	Mainstream to Tributaries	Higher
Diversity	Mainstream to Tributaries	Higher
# Species	Mainstream to Tributaries	Higher
Total # Specimens	Mainstream to Tributaries	Higher
# Species	Lower Section to Upper Section	Increase
#/Km	Lower Section to Upper Section	Increase
Prey/Predator	Lower Section to Upper Section	Constant or Decrease
Diversity	Lower Section to Upper Section	Increase
# Species > 50/Km	Lower Section to Upper Section	Increase
(Cyprinidae + Catostomidae) / Centrarchidae	Lower Section to Upper Section	Constant or Decrease
Species/Family	Lower Section to Upper Section	Constant or Decrease

Table 13. Effects of man on fish populations determined by multiple species composition comparisons in the upper Shetucket River system. Plus indicates agreement and minus, disagreement, as defined in Table 12.

Species Composition Statistic	River System				
	Natchaug	Hop	Willimantic	Shetucket	Above-Below
# Species Not Present	+	-	+	-	+
Occurrences of 5 Common Species	+	+	-	-	-
Mean Size	-	-	+	-	-
Diversity	-	-	-	+	+
# Species	+	-	+	-	+
Total # Specimens	+	+	-	-	-
# Species	+	+		-	-
#/km	+	-		+	+
Prey/Predator	+	-		-	-
Diversity	-	-		-	-
Species/Family	+	-		-	-
# Species > 50/km	-	-		+	+
(Cyprinidae + Catostomidae / Centrarchidae	+	-		-	-
Percentage Agreement of Expected Trends	69	23	50	23	29

Table 14. Summary of human influence indexes (HII) for rivers snorkeled in southern New England.

	Watershed Size Group 1							Watershed Size Group 2						Watershed Size Group 3				
	Ashaway River	East Branch Salmon Boook	Fenton River	Mount Hope River	Aspetuck River	Eightmile River	Mean	Fivemile River	Hop River	Wood River	Saugatuck River	Yantic River	Mean	Salmon River	Shepaug River	Natchaug River	Shetucket River	Mean
HII	10	2	4	4	7	3	5.0	11	6	5	12.8	24	11.8	2	5	8	27.5	10.6
Component																		
Industrial	2								1			3				1	1	
Residential	2	1	1	1	3	2		1			4	3				1	1	
Sand & Gravel								1								1	2	
Agricultural			2	3	2			3	3			3			3	1	2	
Dams & Impoundments	2	1			1	1		4	1	2	3	5		1	1	2	7	
Water Supply Reservoirs											1					1		
Mill Bldgs.	4		1		1			2	1	3	2	10			1	1	9	
Sewage (MGD)											2.8			1			5.5	

Table 15. Amounts and values of nutrients lost to the Shetucket River from the Willimantic sewage treatment plant.

Nutrient	Amount of nutrient lost from sewage treatment plant	Market price of nutrient[3]	Cost of nutrient lost from sewage treatment plant
Nitrogen[1] (as Kjeldahl nitrogen)	532 lbs day^{-1} 194,000 lbs $year^{-1}$	\$0.23 lb^{-1}	\$122.00 day^{-1} \$44,600.00 $year^{-1}$
Phosphorus[2] (as total phosphates)	1,220 lbs day^{-1} 445,000 lbs $year^{-1}$	\$0.19 lb^{-1}	\$232.00 day^{-1} \$84,700.00 $year^{-1}$
Total			\$354.00 day^{-1} \$129,000.00 $year^{-1}$

1. Determined by the Kjeldahl method (APHA, 1971). Values used in calculations represent the average of measurements taken biweekly in the effluent from July - November 1974.

2. Determined as the difference between the mean value for Site 5 and the sum of the mean values at Sites 2 and 3 weighted for their percent contribution to the flow at Site 5. This difference was due to the loss of nutrients from the Willimantic sewage treatment plant. Mean values determined for data from 7/73 - 12/74.

3. Figures represent values for nitrogen and phosphorus for 1/19/76, Agway, Inc., Willimantic, Connecticut.

Table 16. Estimated cost of tertiary treatment at Willimantic, Connecticut.

	Effluent Volume (gallons)	Increased Cost[1] Secondary to Tertiary	Value of Reclaimed Nutrients (From Table 15)
Per Day	2.76×10^6	$276.00	$354.00
Per Year	1.01×10^9	$100,000.00	$129,000.00

1. Assuming a $0.10/1,000 gallons cost increase from secondary to tertiary treatment (Stephens and Weinberger, 1968).

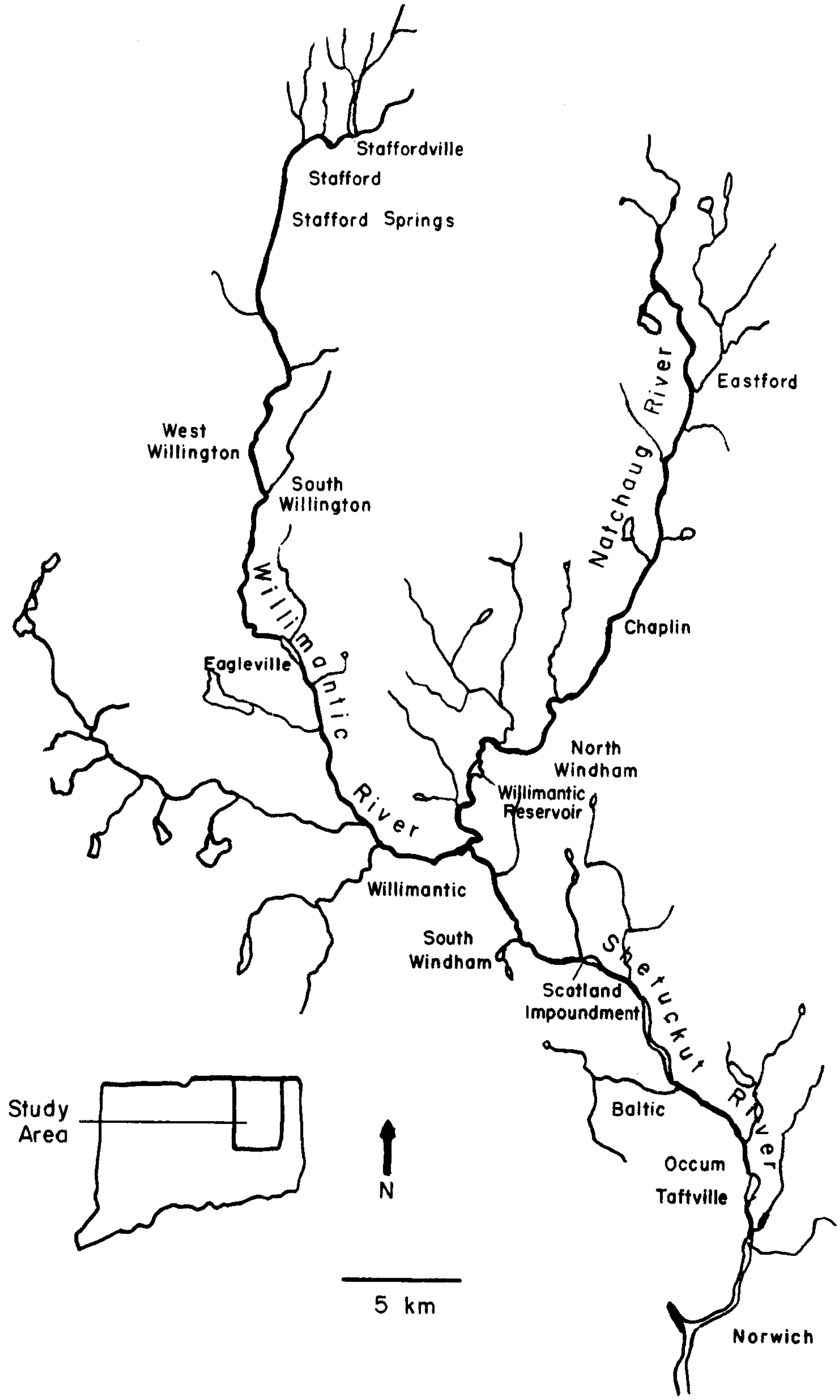


Figure 1. Map of the extended study area, showing the major rivers and many minor tributaries of the Shetucket River system.

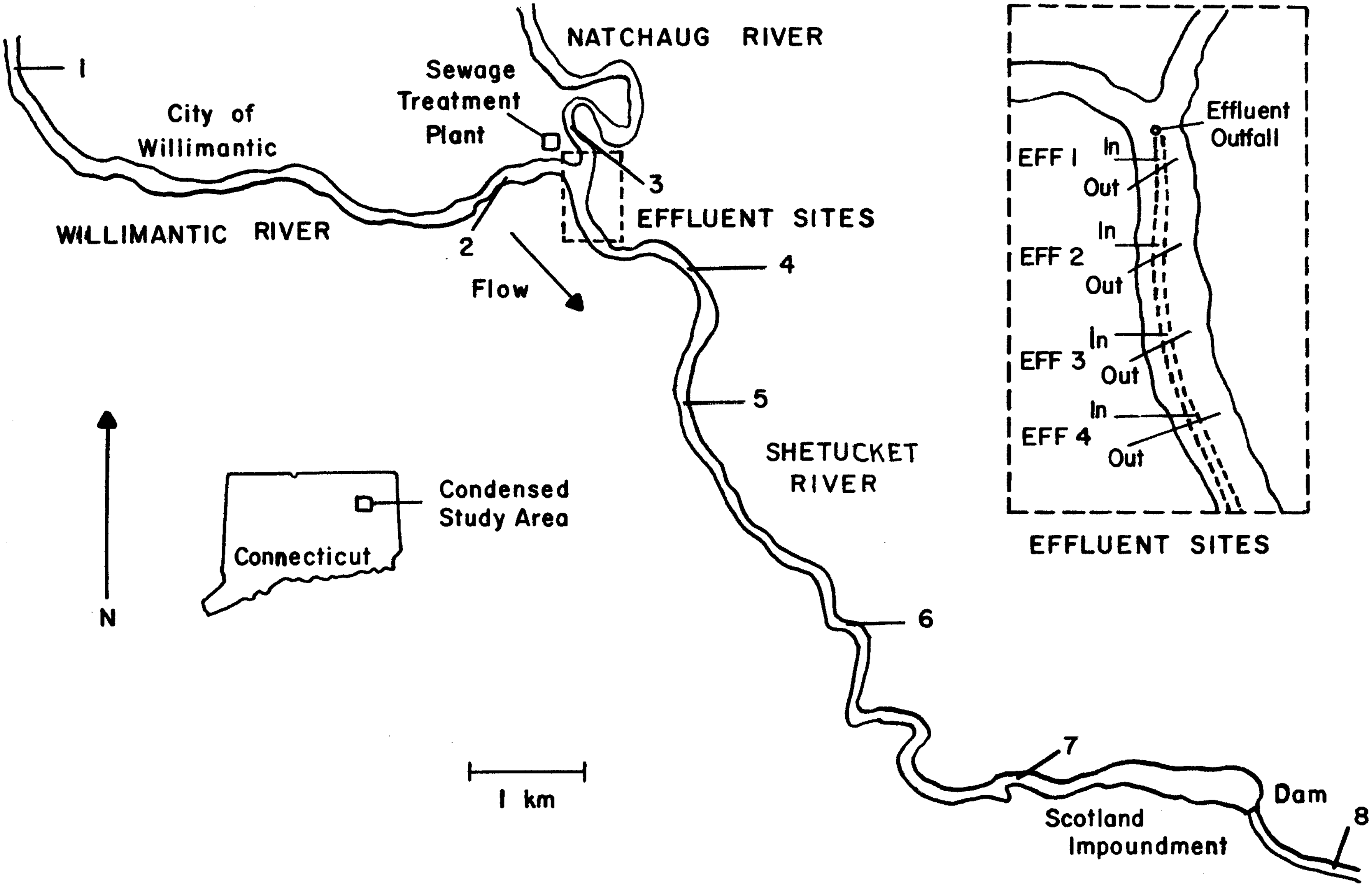


Figure 2. Map of the Condensed Study Area, showing Sites 1 - 6, and the Effluent sites sampled for epilithic algae.

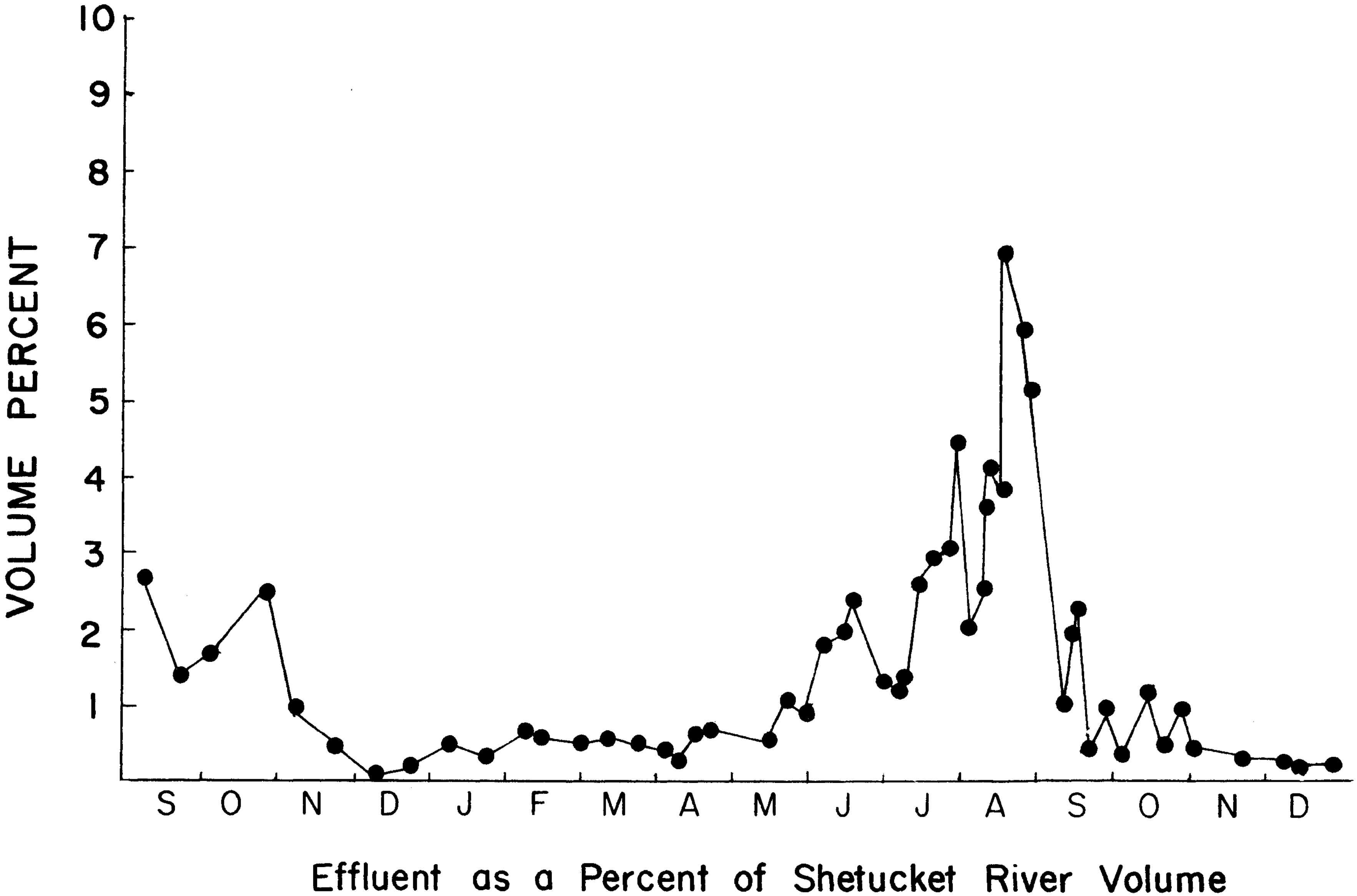


Figure 3. The Sewage Treatment Plant effluent as a percent of the Shetucket River volume in 1974.

Figure 4. Typical effects of primary sewage on river chemistry (after Hynes, 1960).

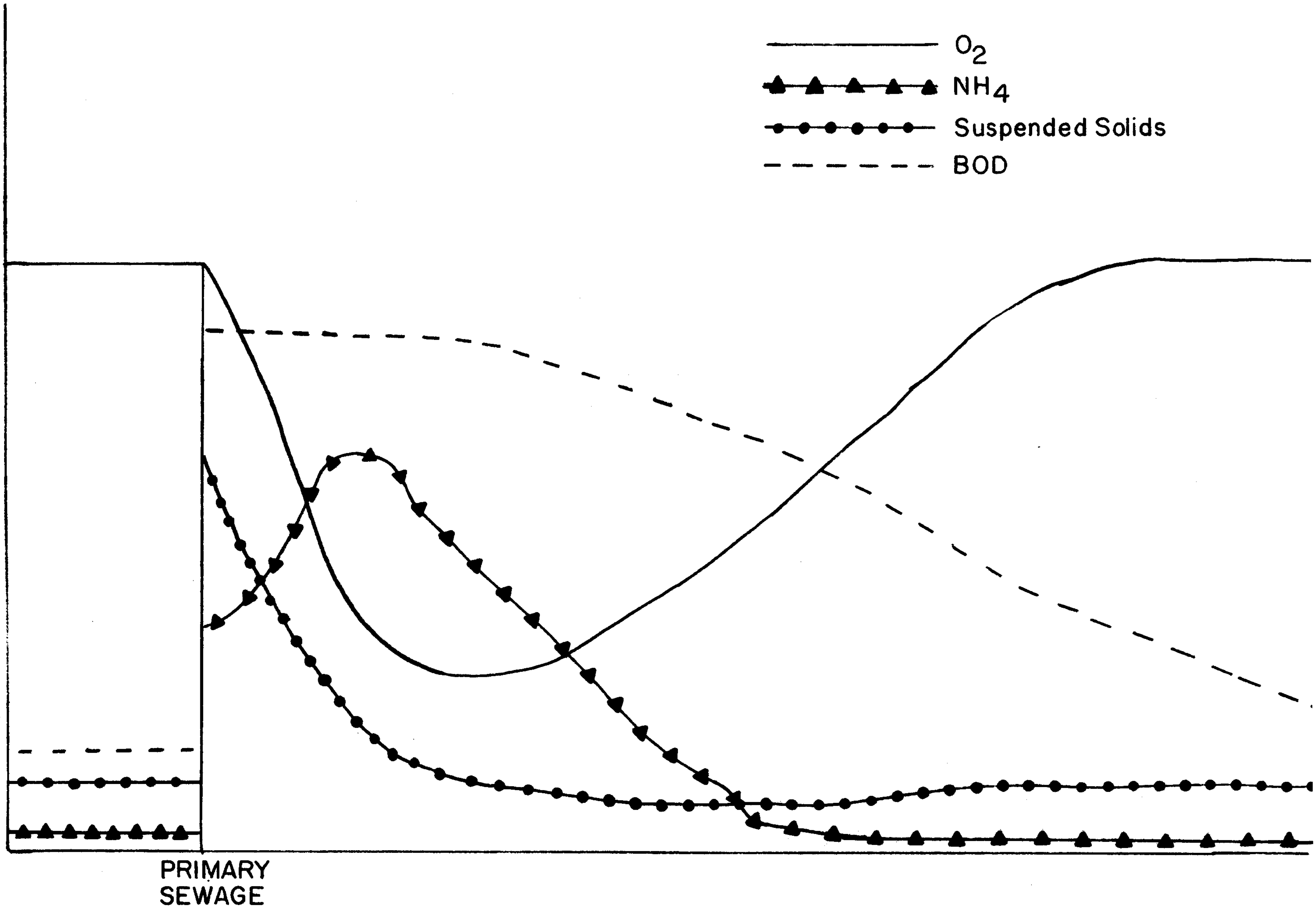
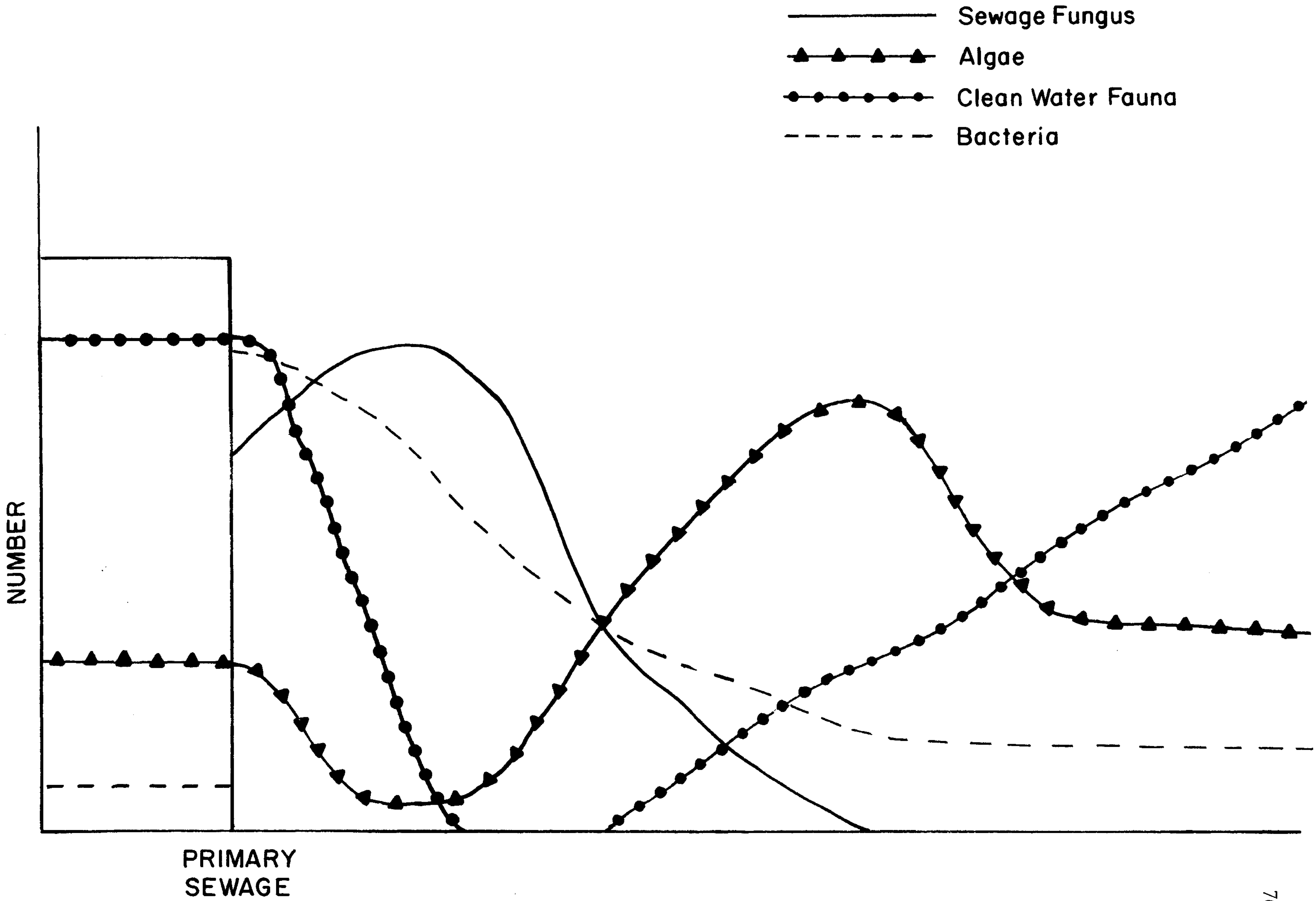


Figure 5. Typical effects of primary sewage on river biota (after Hynes, 1960).



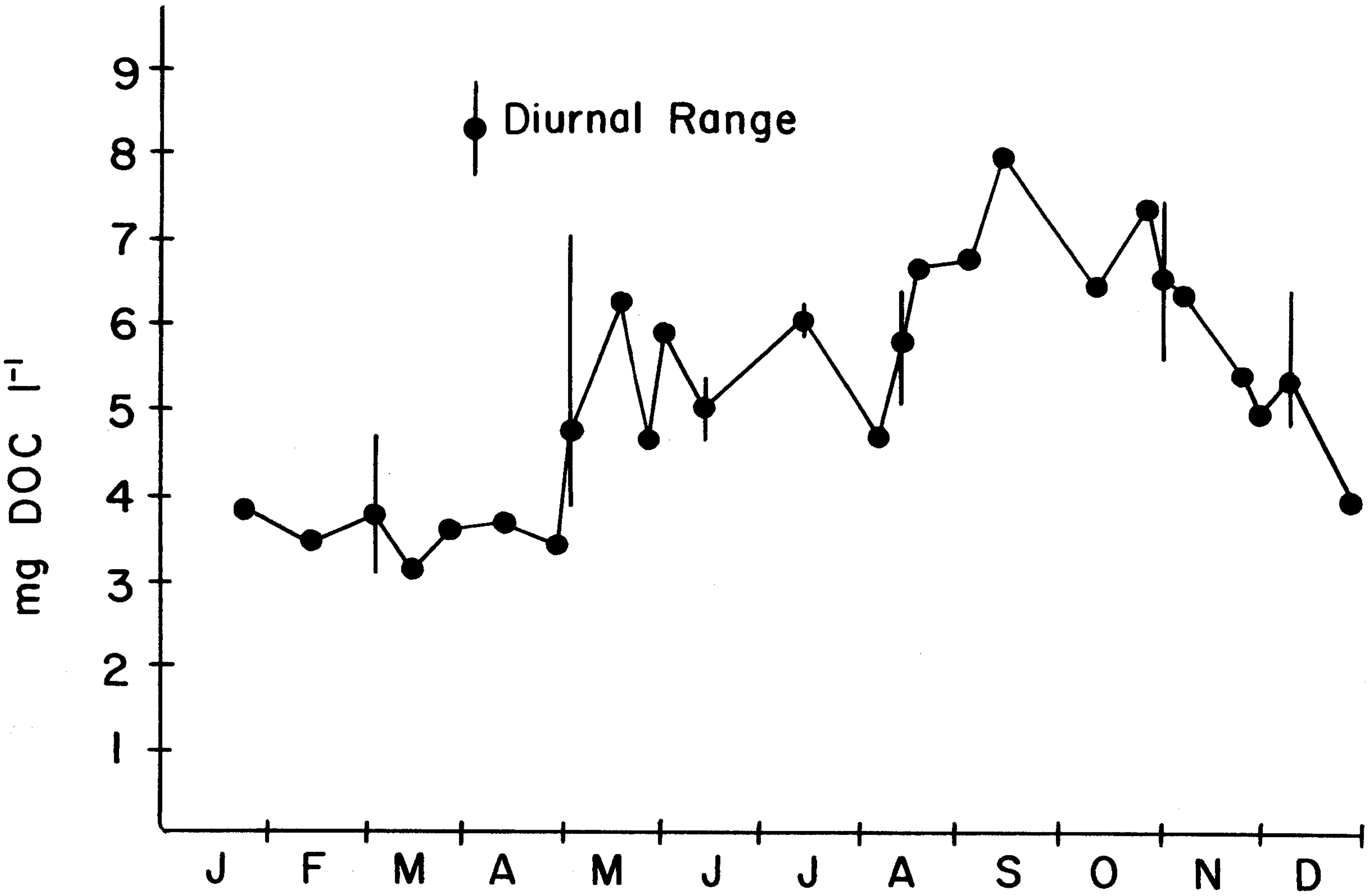


Figure 6. The concentration of dissolved organic carbon in the water column at Site 5 during 1974. Vertical lines represent the diurnal range. Values for Site 3 on the control Natchaug River form a parallel line of a similar seasonal pattern.

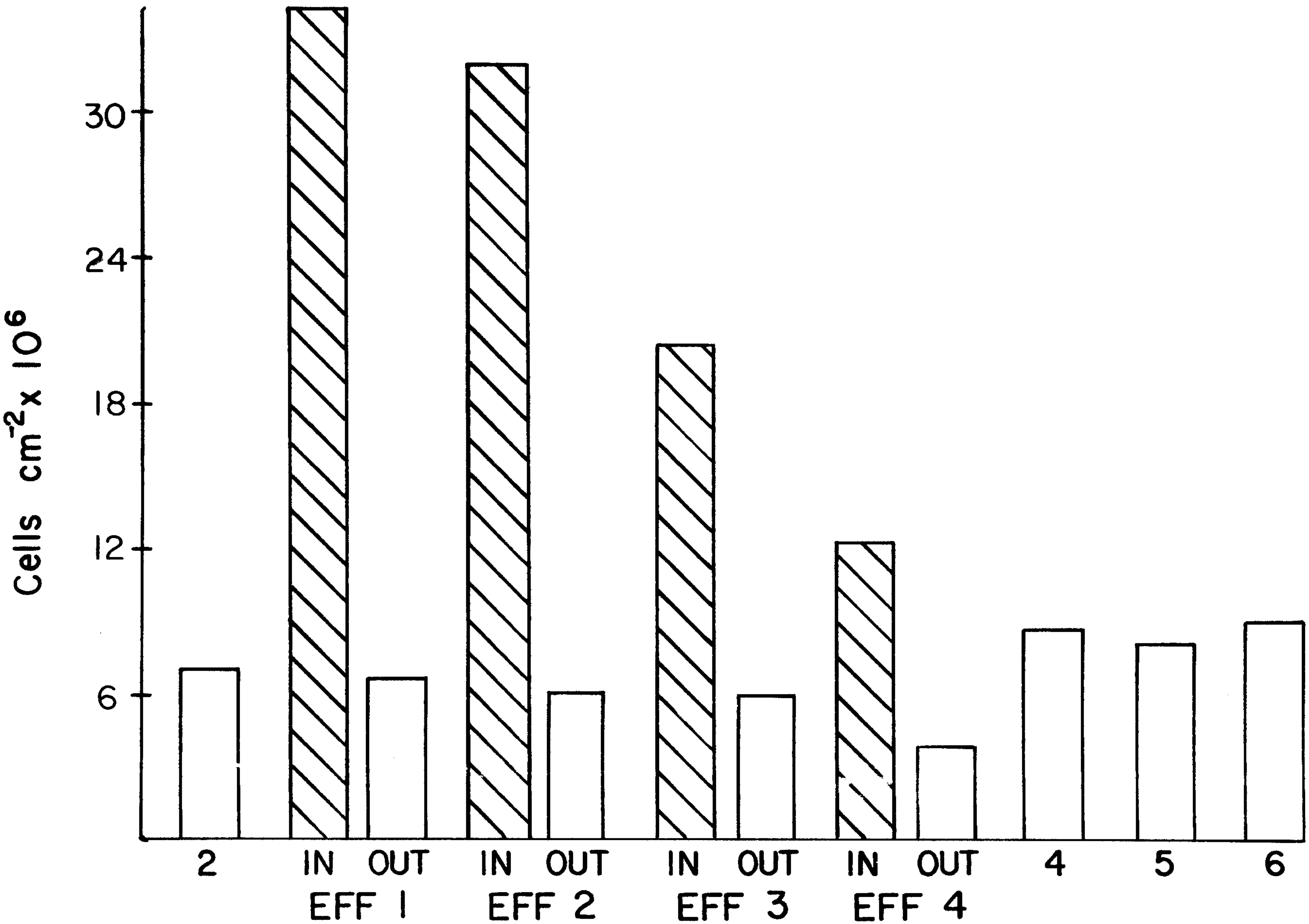


Figure 7. The algal biomass (cells cm^{-2}) attached to the rocks in the condensed study area.

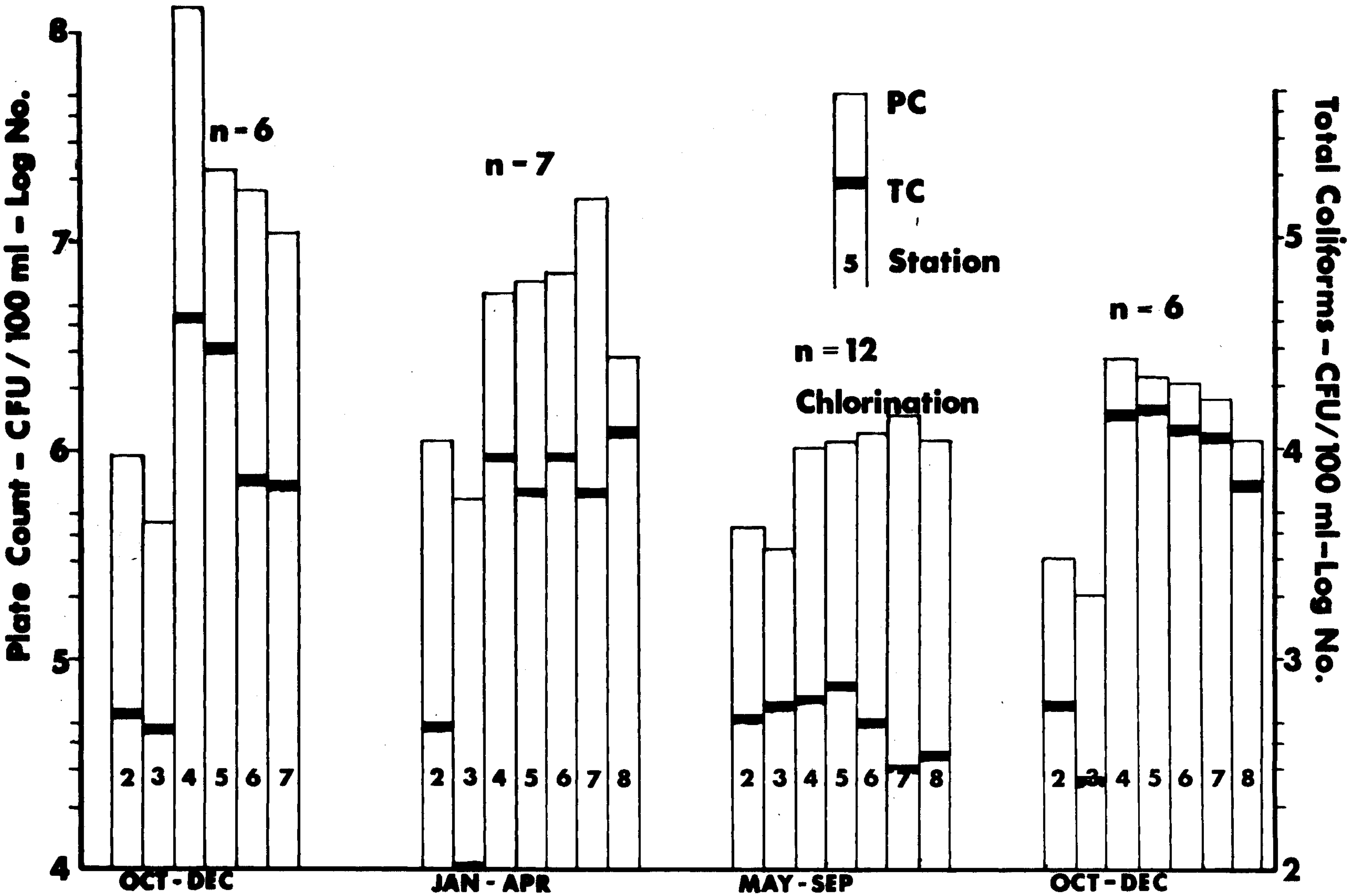


Fig. 8 SEASONAL AVERAGES: Total Coliform and Plate Count Bacteria

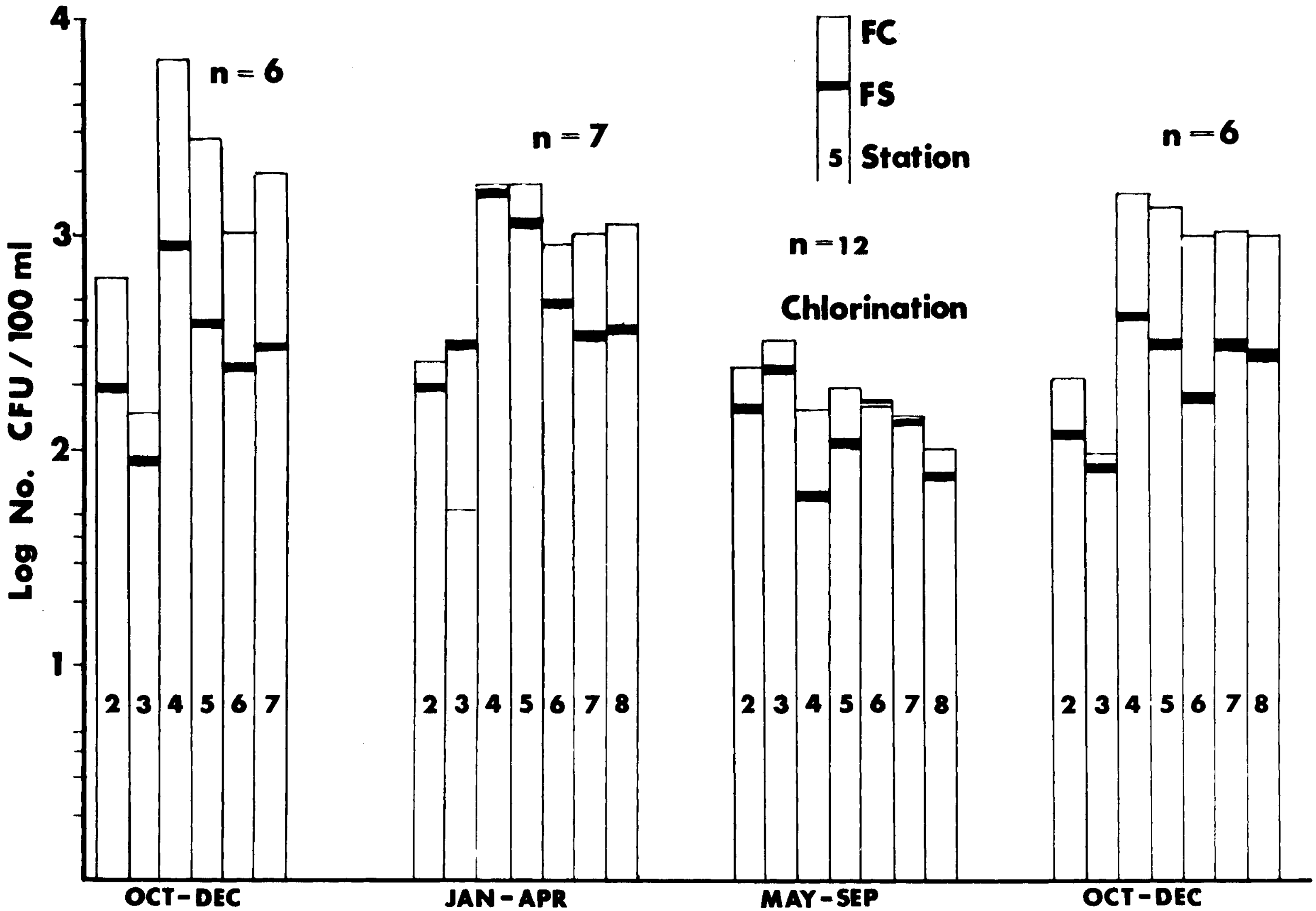


Fig. 9 SEASONAL AVERAGES: Fecal Coliforms and Fecal Streptococci

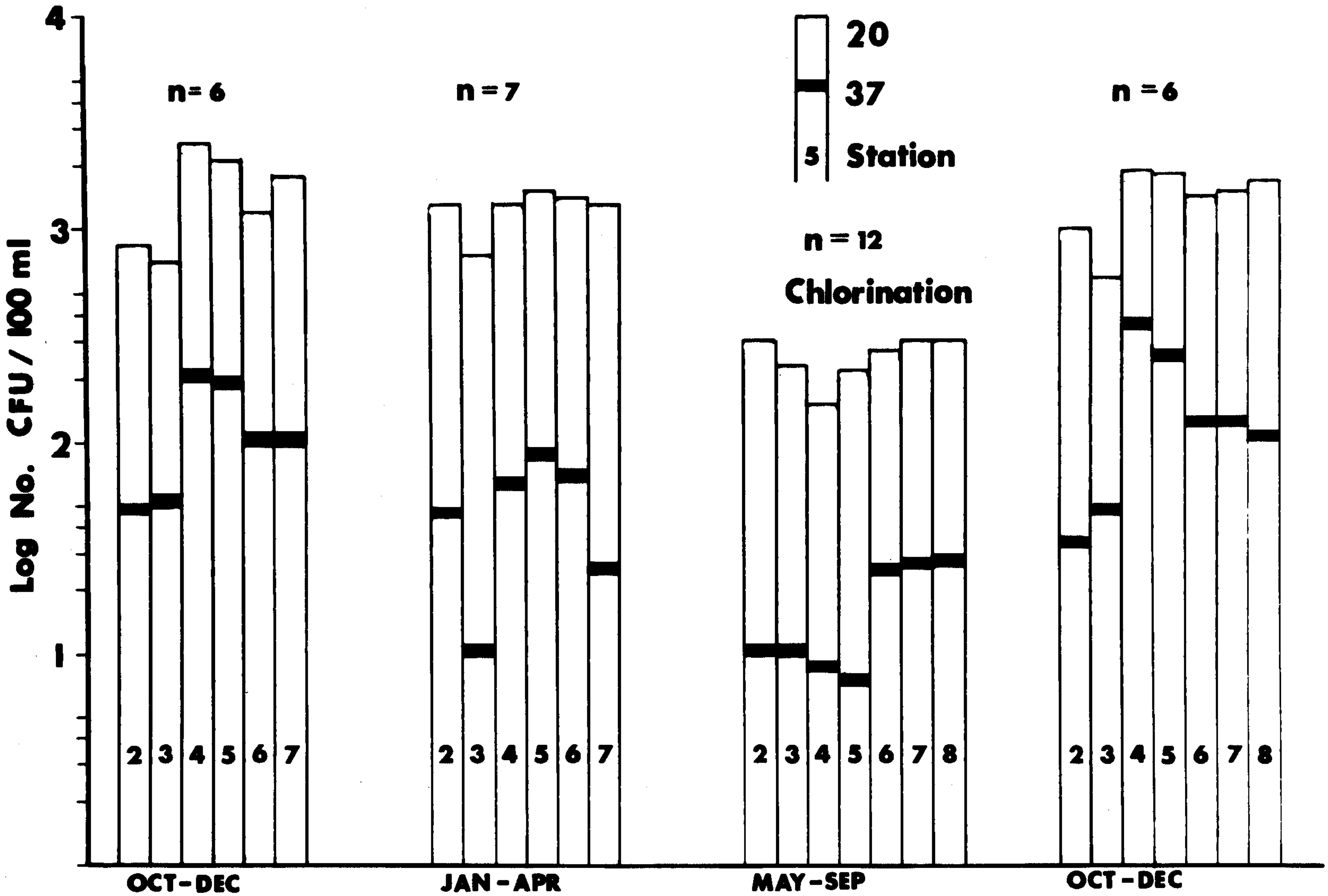


Fig.10 SEASONAL AVERAGES: 20 and 37 C YEASTS

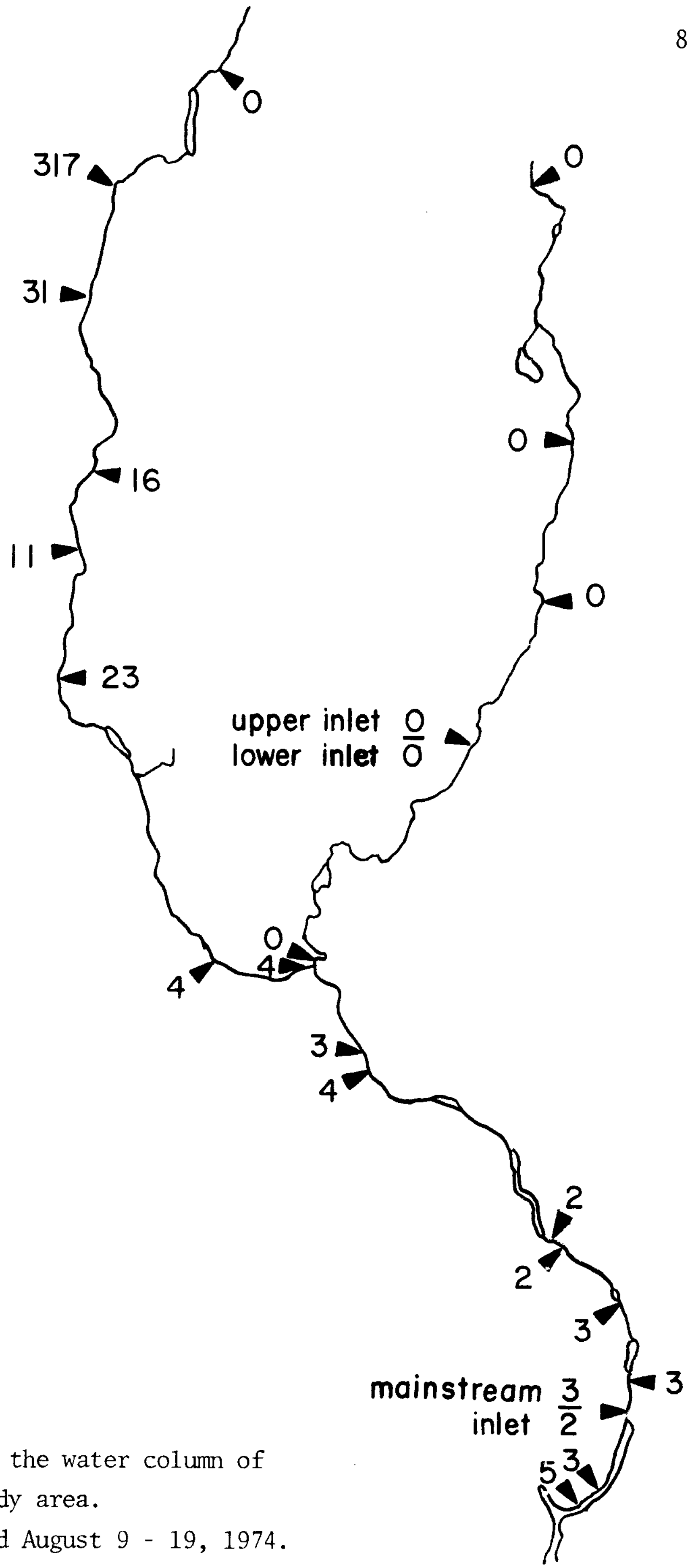


Figure 11. Copper levels in the water column of the extended study area. Samples collected August 9 - 19, 1974.

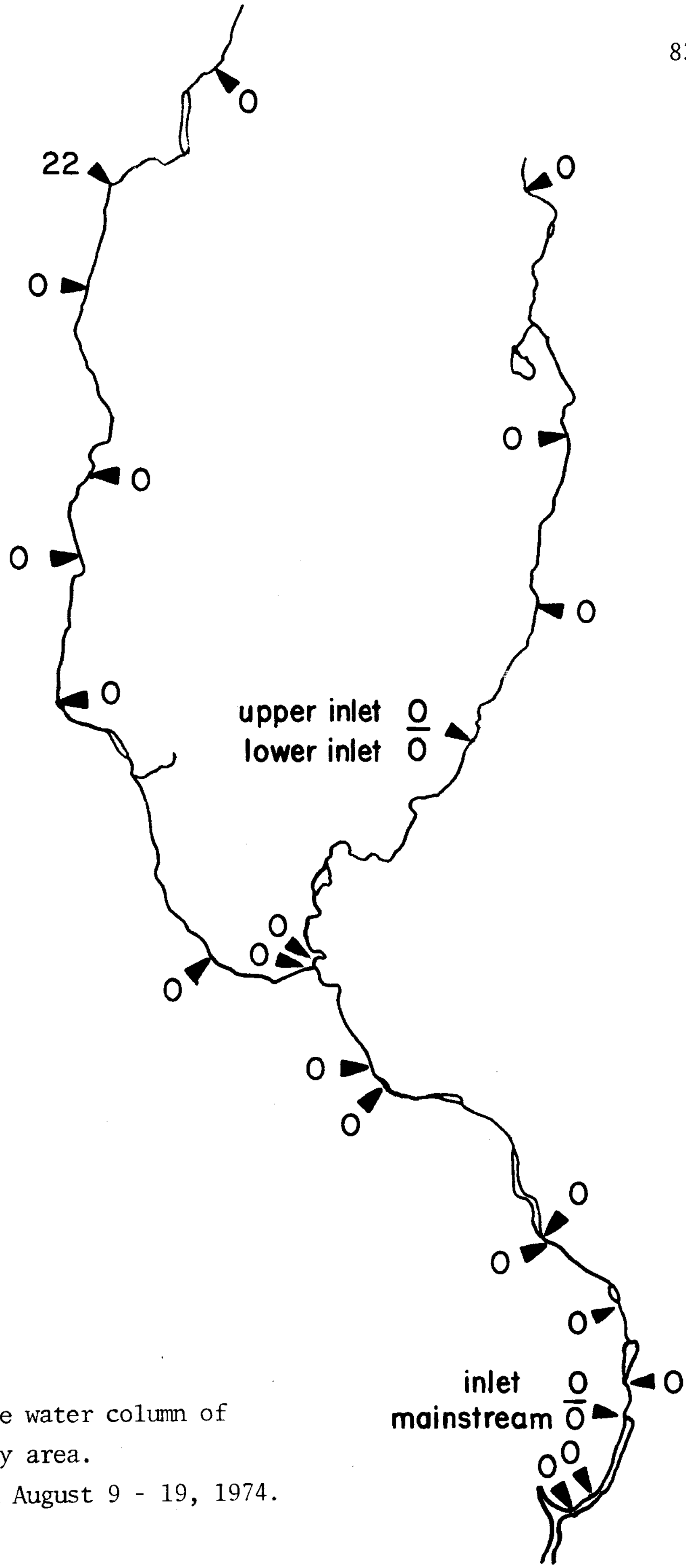
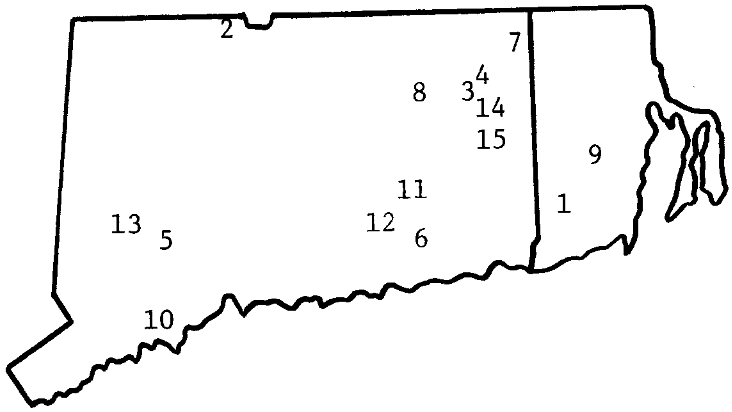


Figure 12. Lead levels in the water column of the extended study area. Samples collected August 9 - 19, 1974.



Rivers Sampled

	No.	Watershed Size (km^2)	Date Sampled (1974)	Distance Sampled (km)
Ashaway River	1	74.1	7/8	1.5
East Branch of Salmon Brook	2	87.5	9/16	5.5
Fenton River	3	91.9	5/16	3.2*
			7/31	5.5*
Mt. Hope River	4	94.8	5/16	3.7*
			7/31	3.8*
Aspetuck River	5	131.0	9/19	8.3
Eightmile River	6	138.8	8/6	5.8
Fivemile River	7	198.4	7/11	6.5
Hop River	8	207.7	5/15	7.5
			5/17	7.5
Wood River	9	221.9	7/8	3.2
Saugatuck River	10	241.4	7/16	8.5
Yantic River	11	254.8	8/8	9.5
Salmon River	12	388.5	7/10	5.6
Shepaug River	13	404.0	7/23	11.0
Natchaug River	14	455.8	5/7	6.0*
			5/8	5.0
			5/21	6.6
			5/22	3.0
			6/4	6.0*
Shetucket River	15	1160.5	6/19	5.0*
			7/17	7.0
			7/22	5.0*

*Partial or entire section repeated

Figure 13. Rivers in southern New England sampled for fish populations by snorkeling.

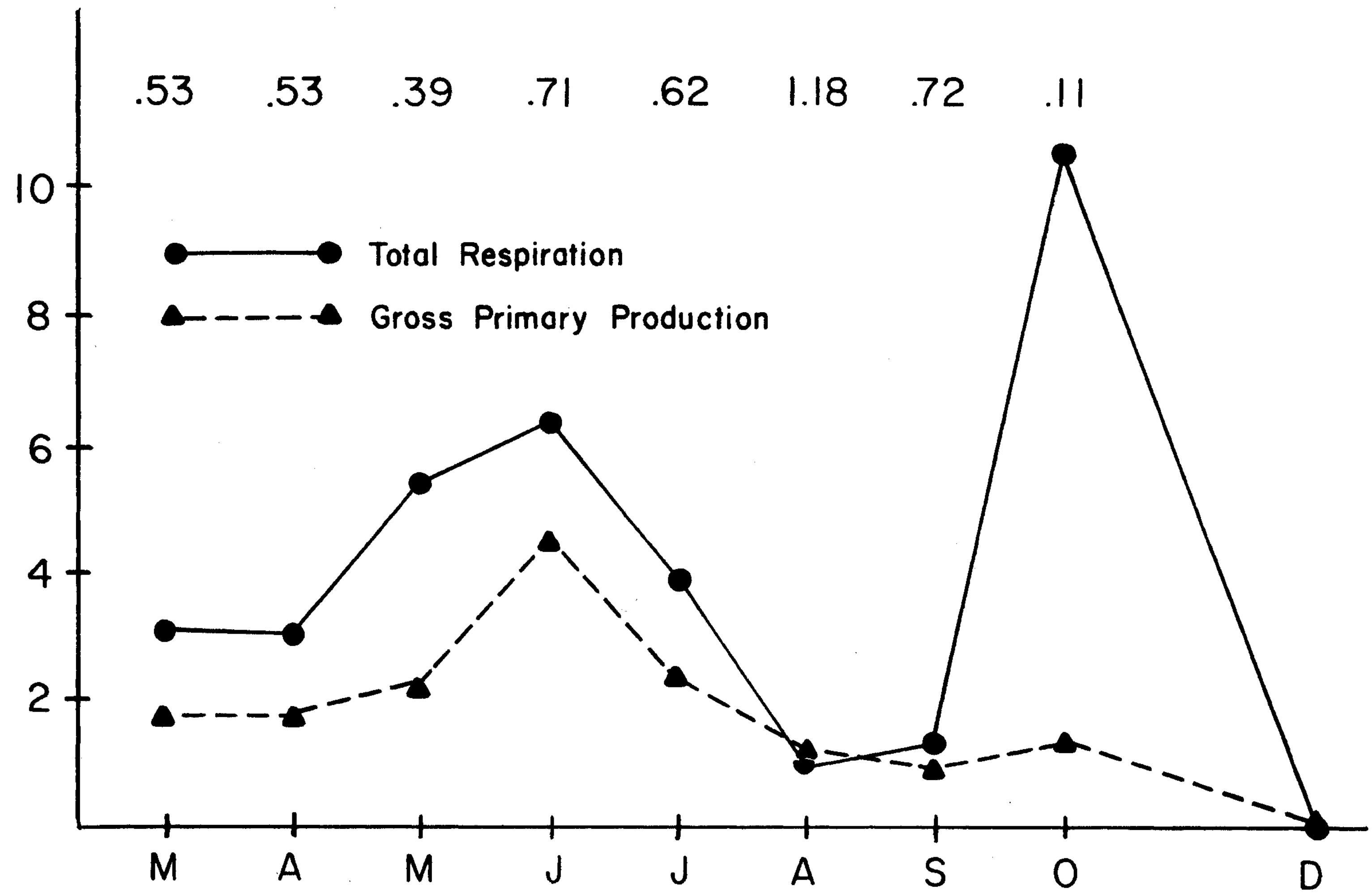


Figure 14. Monthly Shetucket River metabolism, March - December 1974.