POTENTIAL EUTROPHICATION OF THE RIDEAU RIVER BY AN URBAN DRAINAGE WATERWAY

by

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ABSTRACT

Urban drainage within the City of Ottawa, Ontario, is thought to be a significant contributor of nutrients to the already eutrophic Rideau River. Both chemical characterization and algal bioassay were used to study the nutrient effects of Saw Mill Creek, a major urban drainage waterway to the Rideau River.

Saw Mill Creek was sampled during peak storm flow, when both high concentrations of nutrients and high flow conditions prevailed. Peak flows averaged 9 percent of the flow in the Rideau during the study period.

Although nutrient concentrations were shown to be greater during storm flows, peak flow concentrations for total phosphorus and nitrogen averaged only 0.190 mg-P/l and 2.5 mg-N/l. These concentrations of nutrients did not significantly stimulate algal growth at the 5 percent addition level. However, at the 10 and 20 percent addition level, bioassays produced on the average 0.96 and 1.96 mg/l of algal standing biomass, respectively. These values were significantly different ($P<0.05$) from the average biomass of 0.50 mg/l produced by the Rideau samples.

Alum treatment of Saw Mill Creek, simulated by the jar test, was generally unable to reduce algal growth when compared at any of the addition levels. The treated 5 percent addition produced virtually the same average algal biomass as the untreated, and thus it was concluded that treatment would have no effect on algal growth at low flows of Saw Mill Creek.

It was recommended that a non-structural solution for the reduction of storm flows in Saw Mill Creek be sought, so that the associated decrease of nutrient concentrations would reduce the algal growth potential.

ACKNOWLEDGEMENTS

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NOTATION AND CONVERSIONS

Symbol	Definition
$[ALK]$	Alkalinity concentration, meq/l
α_1, α_2	First and second dissociation constants
C_T	Total Soluble Inorganic Carbon (SIC), meq/l
chl a	Chlorophyll a concentration, μg/l
D_L	Longitudional Diffusion Coefficient
$F_{\alpha;\, m,n}$	Ratio of the larger variance estimate to the smaller at α confidence limits and degrees of freedom, m,n
$[H^+]$	Hydrogen ion concentration, meq/l
K_S, K_N, K_P	Half velocity on saturation coefficient for limiting nutrients, S, N and P, mg/l
MGD	Million Gallons per Day, $[L^3/T]$
1 m^3	220 Imperial gallons, $[L^3]$
1 m^2	10.75 square feet, $[L^2]$
1 m	3.28 feet, $[L]$
1 m^3/s	35.34 cubic feet per second (cfs), $[L^3/T]$
1 mm	0.0394 inches, $[L]$
1 mg/l	1 ppm, $[M/L^3]$
1 μg/l	1 ppb, $[M/L^3]$
meq/l	milliequivalents per litre, $[M/L^3]$
μ, mμ	microns, millimicrons, $[L]$
$[OH^-]$	Hydroxyl ion concentration, meq/l
Q_P	Peak discharge, m^3/s
S	Limiting nutrient concentration, mg/l
X_t	Algal cell concentration after t days, mg/l

CHAPTER 1

INTRODUCTION

Eutrophication is the nutrient enrichment of natural waters, causing algal growth. Nutrients are those substrates considered essential to the growth of algae. The limited supply of carbon, nitrogen and phosphorus in natural waters, combined with the large algal demand for these nutrients (termed macronutrients), make them of particular interest in algal growth control. Under favourable conditions, the addition of these three nutrients will control the extent of algal growth. Until Man's interference with the ecosystem, eutrophication was considered to be only a natural "aging" process for rivers and lakes.

Cultural eutrophication is the nutrient enrichment due to human activities such as industrialization and urbanization. The additional nutrients from these sources are capable of accelerating the natural eutrophication process, causing nuisance blooms of algae, increased turbidity, depletion of dissolved oxygen and changes in the communities of algae, invertebrates and fish.

Awareness of these potential receiving water problems has resulted in stricter effluent quality standards for both municipal and industrial wastewaters. The importance of tertiary treatment for the reduction of phosphorus in controlling cultural eutrophication has been particularly emphasized in Ontario. The control of nutrients at these point sources seems the most logical first step in a eutrophication program. However, as the new effluent standards are achieved at the controllable point sources, the quality of the overlooked point sources and diffuse sources will become the limiting factor in overall water quality improvement. One such source which has received little attention is urban storm drainage. Several authors (5, 6, 22, 26, 53) have shown urban drainage to be a significant source of nutrients that may cause potential damage to the receiving water by eutrophication.

As in the evaluation of the impact of other pollutants, chemical characterization has been used in determining the nutrient loading of urban storm drainage. However, in the analysis of the eutrophication process, chemical characterization bases itself upon the major assumption that the relationship between the chemical analyses and the biological processes is understood. Often the complexities of the relationships and our vague knowledge of them allows chemical characterization only to guide research in the proper direction, not quantifying the impact or pinpointing the exact problems.

Limitations of nutrient analysis for the evaluation of the algal growth process are: (1) Chemical analysis arbitrarily partitions the available and non-available nutrients; (2) It does not directly take into account that certain portions of the unavailable fraction may later become available, nor does it take into account the length of time required to become available; (3) It is not a direct method of quantifying the algal growth potential of the receiving stream. Furthermore, there is no indication of which nutrient is rate-limiting; and (4) Chemical characterization considers the waste stream as a separate system from the receiver.

Algal bioassays represent a viable alternative to chemical characterization for the analysis of the eutrophication process. Bioassays are controlled laboratory procedures which subject the living organisms to different environmental stresses. They have been used by various authors to predict the algal growth potential of receiving waters enriched by nutrients from treatment plant effluents (31), agricultural wastewater (42) and detergent-laden wastewaters (17). Therefore it is presumed that the enriching effects of urban drainage may also be analyzed by algal bioassays.

In the Rideau River, nutrient characterization has been extensive (1, 9). However, little, if any, research has been done using bioassay procedures to attain an understanding of the eutrophication process in this recreational waterway. Dickman (9), who studied the reports by the Ontario Ministry of the Environment, the Rideau Valley Conservation Authority and Pollution Probe, concluded that "the river was nutrient rich (eutrophic) throughout most of its course and consequently supported dense algal and waterweed growth in its slower moving sections". He lists the major sources of nutrients to the river within the Regional Municipality of Ottawa-Carleton to be agricultural land runoff, sewage lagoon runoff, and riparian cottage runoff, but singles out storm sewer flow and combined sewer overflow as the most significant nutrient source within the City of Ottawa.

One major contributor of storm sewer flow to the Rideau River is Saw Mill Creek, an urban drainage waterway. The motivation for this study is the fact that the effects of this waterway as a source of nutrients causing significant algal growth in the river are virtually unknown. Algal bioassay as well as chemical characterization were used to determine the enrichment effects of Saw Mill Creek in the Rideau.

CHAPTER 2

LITERATURE REVIEW

At the 1977 Conference on Modern Concepts for Urban Drainage (47), a major topic of discussion was the quality of urban storm runoff and the problems that it causes in the receiving water. Weatherbe (51) presented quality data collected from 13 urban Ontario catchments from which he estimates that the average urban runoff pollutant load (including combined sewer overflows) during a storm event, is of an order of magnitude larger than a treated wastewater load. Waller (50) outlined the potential receiving water problems associated with the pollutants contained in urban drainage as: (1) Nutrient effects, (2) Oxygen demand effects, (3) Sediment effects, (4) Effects of salt, (5) Bacteriological effects, (6) Toxicity effects.

Since the primary objective of this study is to determine how urban drainage water affects the algal growth of a receiving water, only the nutrient effects will be considered in detail in the literature review. It is recognized however, that many of the other effects of urban drainage water are interconnected with algal growth.

2.1 Urban Drainage Characteristics

The increased production of algae by the addition of nutrients from unnatural or man-made sources has been termed cultural eutrophication (29). Sartor (43) found that urban activities generate such a nutrient source. His study showed that dust and other solids contributed an average of 1.1 lb/curb mile of total phosphorus, 2.2 lb/curb mile of Total Kjeldahl Nitrogen (TKN) and 0.094 lb/curb mile of nitrate-nitrogen in samples collected from the street surfaces of 12 American cities. Kluesener (26) found street litter, which included clippings from gardens, lawns and trees, leaves and other dead vegetation to be a significant source of soluble phosphorus and organic nitrogen. Although not directly studied, it was also suggested that improper use of fertilizers by home owners, and automotive exhausts (lead halophosphates) on heavily travelled roads could also be significant sources of nutrients. Bryan (4) stated that the large volume and high velocity of runoff in an urban area, facilitated the transport of pollutants from the ground surface via a sewer system, to the receiving water.

Characterization of urban storm runoff has been classified by Holbrook (22), Weatherbe (51) and others (10, 16, 52) according to the source of the pollutants: (1) Separate storm drainage water and (2) Combined Sewer Overflows (CSO). The common denominator between the two is storm flow. Storm runoff carries the pollutants generated by urban activities to the catch basin, where it enters a collection system. The characteristics of the resulting pollution depend upon the type of collection system used to transport the wastewater.

In the combined sewer system, storm sewers and sanitary sewers are connected to one conduit. Storm flows cause the system to overflow frequently. Thus, a mixture of raw sewage and storm water, a combined sewer overflow, is released to the nearest natural water course. A prime reason for the decision to separate sewers was recognition that combined sewer overflows were a major contribution to pollution. Marsalek (32) further discusses the advantages and disadvantages of sewer separation.

The separate system generally carries the storm water directly to the receiving water, without any treatment. Treatment, until recently, was deemed unnecessary because the runoff was believed to be "as unpolluted as the rainfall that caused it". Unfortunately, the storm flow from separate sewers systems is not always free from pollution.

As well as several American cities, the Ontario cities of Toronto, Burlington, Windsor, London and Kitchener have reported either combined sewer overflows or separate storm sewers or both as a source of nutrients. For example, concentrations for the nutrient parameters given in Table 2.1 (3, 8, 22, 26, 51) showed that nitrogen and phosphorus concentrations are greater on the average in combined sewer overflows than in separate sewer flows. It is expected that

TABLE 2.1 CHARACTERIZATION OF COMBINED SEWER OVERFLOWS AND SEPARATE SEWERS

SYSTEM	NITROGEN TKN	 NO_2-NO_3 (mg-N/l)	 NH_3	PHOSPHORUS TOTAL	 SOLUBLE (mg-P/l)	CARBON ALK (mg/l $CaCO_3$)
SEPARATE						
AVERAGE CONC.	2.28	0.48	0.29	0.72	0.38	100
RANGE	0.5-20	0.06-6.3	0.05-3.3	0.01-5.4	0-0.69	8-344
REFERENCES	1,2,5-11	all	1,3-11	all	1,5,11	3,4
COMBINED						
AVERAGE CONC.	3.62	0.72	4.06	7.81	5.48	-
RANGE	1.6-46	-	0.1-12	0.8-25	0.1-12	-
REFERENCES	1	2-7	all	all	2-7	-

DRAINAGE BASINS - SEPARATE SYSTEMS

1. Brucewood, Toronto
2. Aldershot, Burlington
3. Windsor 'A', Windsor
4. Windsor 'B', Windsor
5. Carling, London
6. Schneider Ck., Kitchener
7. Montreal Rd., Atlanta
8. Drew Valley, Atlanta
9. Plantation, Atlanta
10. Parkside, Atlanta
11. Manitou Way, Madison

COMBINED SEWER SYSTEMS

1. Conner, Ann Arbor
2. Closes Rd., DesMoines
3. West Prospect, DesMoines
4. Grand, DesMoines
5. Cornell, DesMoines
6. Ingersol,DesMoines
7. 22nd, Desmoines

this is due to the high concentrations of nutrients in raw sewage. Raw sewage is also a source for the micronutrients and other materials required for the growth of algae (20).

Kluesener (26) characterized the urban drainage water of Manitou Way, an input to Lake Wingra, Wisconsin, and found an average concentration of 0.98 mg-P/l of total phosphorus, of which 0.57 mg-P/l on the average was soluble. Organic nitrogen averaged 3.5 mg-N/l, while average ammonia and nitrate nitrogen concentrations were 0.45 and 0.60 mg-N/l, respectively. From the extrapolation of urban runoff data from Manitou Way to the entire Lake Wingra Basin, he concluded that approximately 80 percent of the total phosphorus and about 35 to 40 percent of the total nitrogen influent to the lake arises from urban runoff.

Dugan (11), having done a nutrient inventory for the Lake Tahoe basin concluded that runoff from human occupancy of the land under newly and well developed conditions showed an appreciable excess in algal growth-stimulating nutrients over that from land under natural conditions.

Sartor (43) established a relationship between the solid fractions in urban runoff and nutrients. He reported that from a third to a half of the concentrations of nitrogen and phosphorus were associated with the very fine, silt-like fraction ($<$ 43 microns). Furthermore, he found that this fraction of the solids constituted only 5.9 percent of the total weight of solids.

Consequently, Kluesener (26) found the concentration of organic nitrogen and total phosphorus to vary with the suspended solids and flow of urban drainage water. Concentrations of the nutrients generally increased with increasing flow, reaching their maximum value at or just before peak flow. As runoff progressed, all parameters decreased (Figure 2.1).

Cowen (5) determined that as well as soluble phosphorus, 30 percent of the particulate phosphorus transported with the solids in urban drainage water, was available for algal growth. In similar experiments (6), he found 70 percent of the total nitrogen available for growth. However, he states that his results are specific to Madison, Wisconsin.

In summary, urban drainage water has been demonstrated by the authors cited above to supply a significant proportion of algal growth-stimulating nutrients to receiving water. As well as the soluble nutrients, a large fraction of the available nutrients can be expected to be associated with the suspended solids. Consequently nutrient concentrations may be expected to vary with the flow during storm periods.

None of the above authors have used algal bioassays to determine the significance of the increased algal growth due to the nutrient input of urban stormwater. Qualitatively they conclude that the nutrients in urban stormwater are capable of accelerating eutrophication, leading to increased fertility and biological productivity in a receiving water.

FIG. 2.1 VARIATION OF NUTRIENT CONC. WITH THE FLOW*

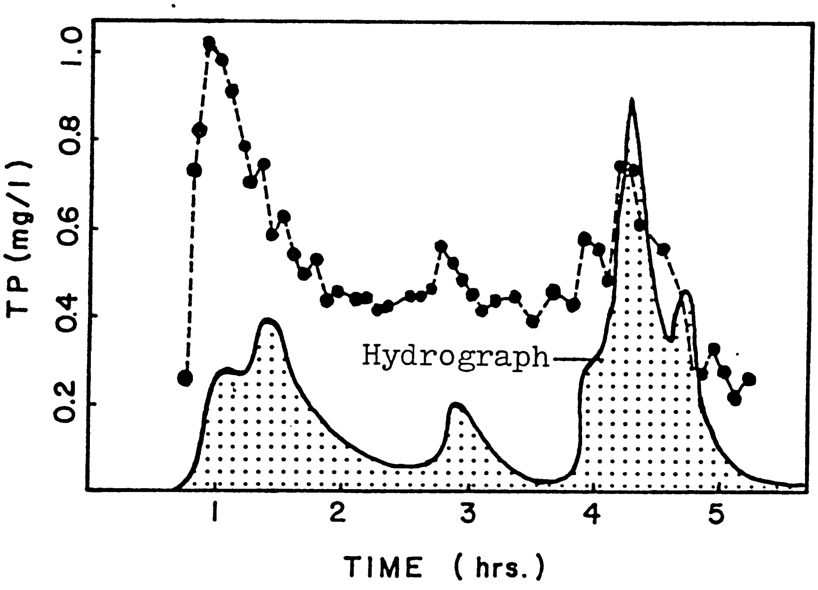


FIG. 2.1(A) VARIATION OF TOTAL PHOSPHORUS WITH THE FLOW

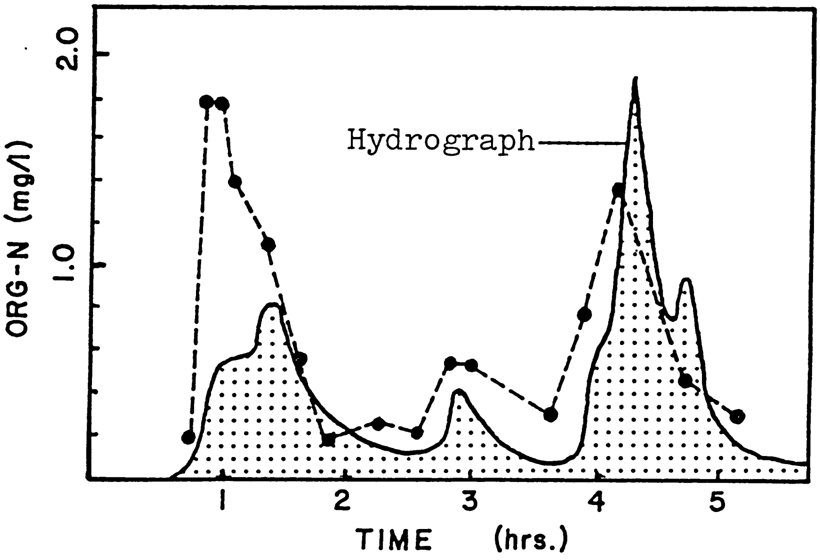


FIG. 2.1(B) VARIATION OF ORGANIC NITROGEN WITH THE FLOW

*sample 9/23 from Kluesener (26)

In the next section algal bioassays are shown to represent a reasonable approach to quantifying the degree and rates of eutrophication.

2.2 Evaluation of the Impact of Nutrients

Realizing that precise nutrient criteria were inappropriate, the Ontario Guidelines and Criteria for Water Quality Management (36) stated that "Nutrients from unnatural sources that will stimulate production of algae...should not be added to water." Then the question arises, "How should the stimulation of the production be evaluated?"

The Environmental Protection Agency (35) developed the Provisional Algal Assay Procedure (PAAP) (now the Algal Assay Procedure) mainly for the evaluation of the potential fertility of various wastewater effluents.

Plumb (40) employed the PAAP to demonstrate that talconite mine tailings did not significantly stimulate the algae of Lake Superior.

Ruckelhaus (42) performed bioassay experiments similar to the PAAP to test the effect of agricultural drainage water on algal growth in the San Joaquin River, California. Instead of using an axenic strain of algae, he used a natural culture and measured the growth response by the chlorophyll a method. Correlation of cell counts with chlorophyll concentrations yielded a statistically significant ($P < 0.01$) correlation coefficient of 0.69.

Middlebrooks (33) compared the growth response indicators of maximum growth rate, μ_b, and cell concentration after time, t, X_t. He found that the cell concentrations after 5 days, the 5 day standing algal biomass, proved to be the most discriminatory measure of algal growth response, from which it was possible to make statistically valid conclusions. He states that the usefulness of an algal assay is limited by the experimental design and interpretation of the results.

Francisco (17) used the PAAP to determine the effects of detergent phosphorus on algal growth in two lakes in North Carolina. The results indicated that enhanced algal growth would proceed regardless of the phosphate content of the detergents contained in the wastewater. He speculated that, unless the receiving water were strongly phosphorus limiting and the wastewater provided a large portion of the phosphorus input, the same results could be expected in other cases.

Emery (12), using algal bioassays, found that urban drainage creeks have negligible effects on algal growth in Lake Sammamish, Washington. It must be noted that this study was done during average flow conditions; the critical periods of storm flow when nutrient concentrations would have been higher not being evaluated.

In summary, algal bioassays have been used by the above authors to evaluate eutrophication potential of wastewaters, including urban drainage water. From the results of such bioassays it is possible to make statistically valid conclusions. Should statistical analysis of bioassay results show significant stimulatory effects for an urban drainage water, a nutrient reduction program, which could also be evaluated through the use of algal bioassays, should be considered. Primary and secondary treatment schemes together with detention facilities have been used with varying degrees of success for nutrient reduction in urban storm runoff.

2.3 Treatment Schemes

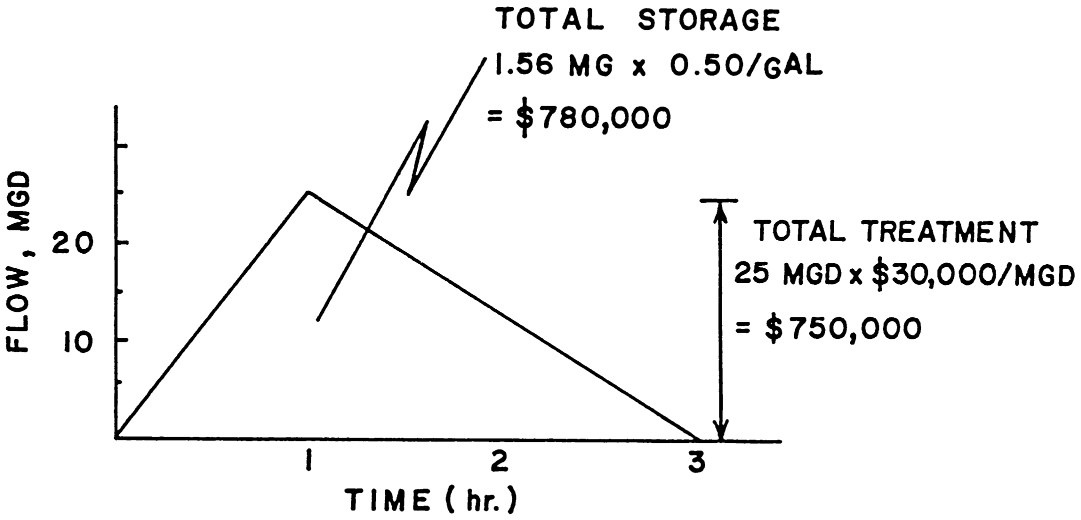
Any form of treatment for urban runoff must be capable of handling shock loads of pollutants and large volumetric loading rates. Ideally, its operation must be automated (or decentralized). Field (16) has shown in the design example illustrated in Figure 2.2 how an integrated system of storage and treatment is cost-superior to the separate approach. Furthermore treatment efficiency is also improved because of the opportunity for the treatment plant to operate at its design capacity for a sustained period of time.

2.3.1 Primary Treatment

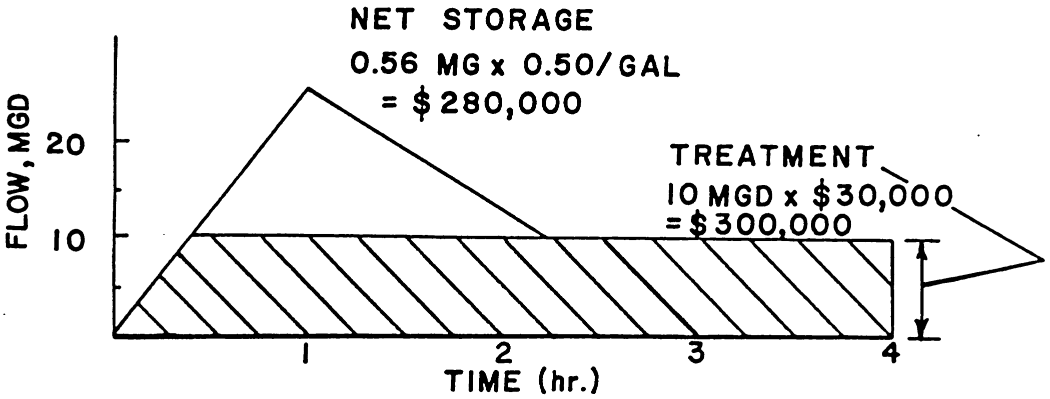
Primary treatment is the term used for the removal of a portion of the suspended solids and settleable solids from any wastewater. Although not specifically intended for the removal of nutrients, it is effective in reducing the nutrient load of urban runoff, especially if a large proportion of the

FIGURE 2.2 SEPARATE AND INTEGRATED APPROACHES TO URBAN STORMWATER TREATMENT – DESIGN EXAMPLE BY FIELD (16).

Design storm with a triangular hydrograph, $Q_P = 25$ MGD and a time base of 3 hours.



(A) SEPARATE APPROACH : MIN. COST – $750,000



(B) INTEGRATED APPROACH : COST — $580,000 nutrients are associated with the settleable solids fraction. In the past primary treatment has been accomplished by physical or mechanical means. At present, it may include the addition of chemicals to aid the removal of solids and other pollutants, particularly if no further treatment is intended.

Examples of primary treatment schemes that have been considered for urban runoff treatment are sedimentation, screening, filtration, dissolved air flotation and regulator concentrators.

Evans (15) carried out settleability studies on Cincinnati urban drainage water and found that the maximum removal of nutrients by sedimentation occurred with a 2.5 hour detention time. Approximately 30 percent of the total phosphorus and 45 percent of the organic nitrogen were removed with 65 percent of the suspended solids.

Table 2.2 shows the results of a treatability study performed on a composite sample of Atlanta drainage water by Holbrook (22). The study included: (1) sedimentation in 3 gallon containers with two different detention times, (2) screening through a 297 micron wire screen, and (3) chemical treatment. The latter involved three separate treatments: (a) the combination of Calgon Coagulant No. 25 with various dosages of a cationic polymer, (b) the combination of lime ($Ca(OH)_2$) and ferric chloride ($FeCl_3$) and (c) aluminum sulphate ($Al_2(SO_4)_3$). Table 2.2 indicates

TABLE 2.2 SUMMARY OF URBAN RUNOFF TREATABILITY STUDIES BY HOLBROOK (22).

	PERCENTAGE REMOVAL OF PARAMETERS				
TREATMENT SCHEME	TSS	TP	TKN	NH_3	NO_3
Sedimentation					
30 min. detention	38	13	20	15	5
60 min. detention	51	13	20	10	3
Screening-297μ sieve.	16	16	17	14	12
Chemical Coagulation	76	57	42	28	12

that chemical coagulation has the highest percentage removal of nitrogen and phosphorus as well as suspended solids.

Screening equipment for wastewater treatment is classified by size of opening into four groups: bar racks, coarse screens, fine screens, and micro-straining. Other than the removal of gross solids, bar racks and coarse screens have little application in the reduction of nutrient concentrations.

Fine screens range from 3360 to 104 microns. Table 2.2 indicates them also to be ineffective in the removal of nutrients.

Although Holbrook (22) estimates from literature a 70 percent removal of both nitrogen and phosphorus for micro-straining, field application of the unit process for the treatment of CSO's in Belleville, Ontario (46) showed an average removal of only 15 percent total phosphorus while removing 79 percent of settleable solids. The removal of suspended solids, and therefore of particulate nutrients, depends greatly on the size of the sieve opening. As the screens become finer, volumetric flux rate and the fragility of the screen become design limiting. Remembering that the greater part of the nutrients can be associated with the solids of 43 microns and less, and that the finest screens reported by the literature to be usable are 24 microns, it is understandable how micro-straining in most applications is incapable of significant reduction of nutrients.

Removal rates of nutrients solely by filtration have not been emphasized in the literature.

Holbrook (22) estimated the nutrient removal percentages for dissolved air flotation as 69 percent total phosphorus and 17 percent total nitrogen removed, while removing 77 percent of suspended solids. Solids separation by flotation is brought about by introducing fine air bubbles into the wastewater. These minute bubbles attach themselves to the suspended materials, giving the particles buoyancy, allowing them to rise. Upon reaching the surface, the floated solids are removed with mechanical skimmers. Since the resulting rise velocity is generally greater than the particles' settling velocity, higher overflow rates and lower detention times can be used as compared to conventional settling tanks. This results in space-saving, making dissolved air flotation an economic alternative expecially when land costs are high. The main disadvantage to flotation is the mechanical equipment such as the pressurizing pumps and skimmers that must be maintained and operated to achieve treatment.

Concentrators, as the name implies, concentrate the solids which are then fed into the nearest sanitary sewer for treatment at a central sewage treatment plant. No overall nutrient removal is achieved unless the treatment plant includes some nutrient removal process.

2.3.2 Secondary Treatment

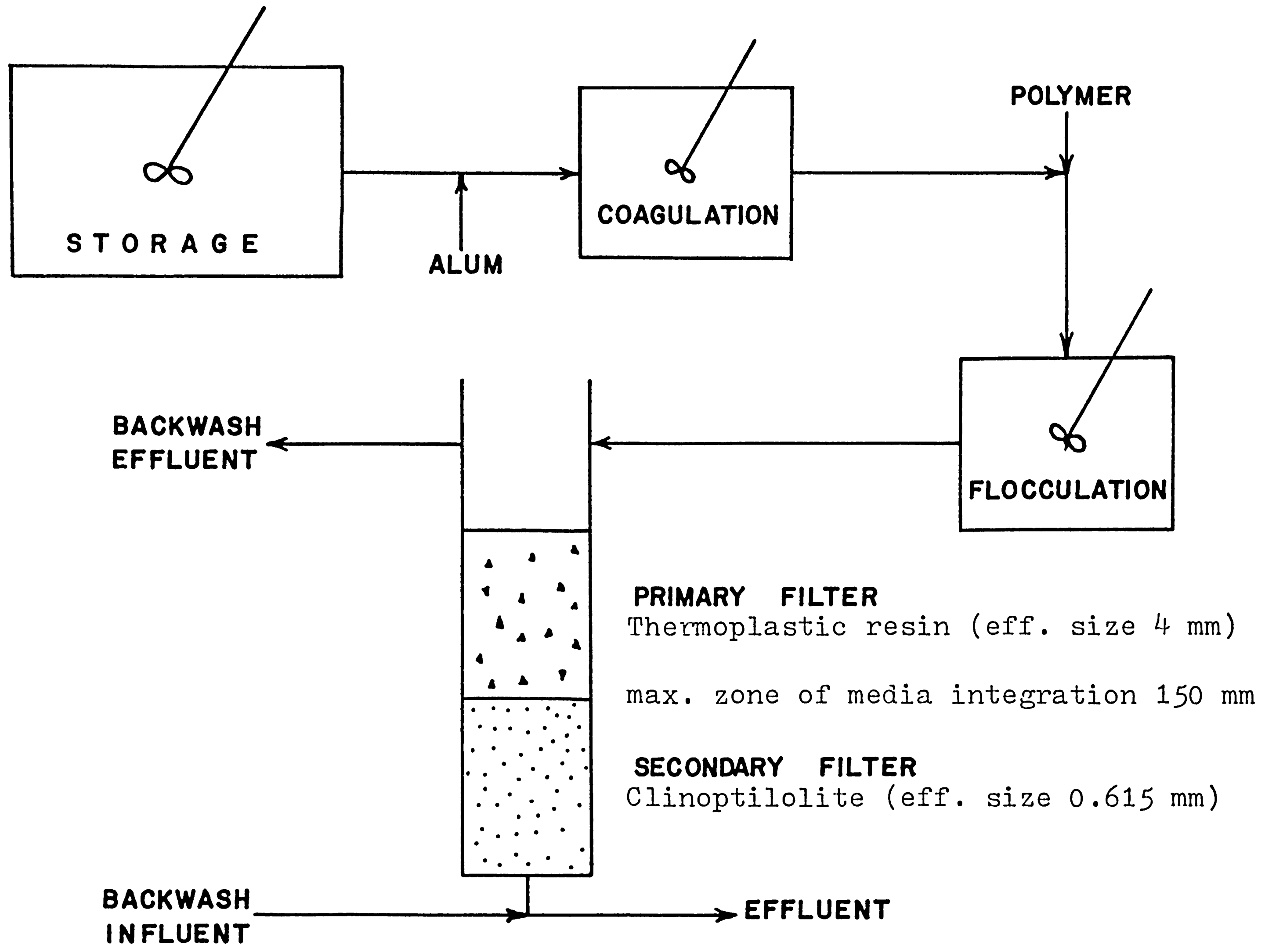
The only treatment process specific to nutrients found in the literature was a single physical-chemical unit described by Murphy (34), primarily intended for removal of phosphorus and nitrogen from combined sewer overflows. The process shown schematically in Figure 2.3 simultaneously removes both NH_3 and P in a single dual media filter under a high rate application. The soluble and particulate phosphates are absorbed and entrained in an alum floc and removed along with the other suspended solids in the primary filter media - a thermoplastic resin. The soluble ammonia and possibly the short chain organic nitrogen species are removed by ion exchange mechanisms in the secondary filter medium - clinoptilolite. Phosphorus concentrations were consistently reduced from 8.0 mg/l to less than 0.3 mg/l, while ammonia nitrogen levels were reduced from 6.0 mg/l to 0.1 mg/l. These removal efficiencies were achieved at application rates of $6.7\ l/m^2 \cdot s (10\ gpm/ft^2)$ and system contact times of approximately 7 minutes. The system was also recommended for stormwater flows where nutrients were found to be a problem.

Biological treatment for the removal of nutrient is not considered suitable for urban stormwater treatment because of intermittent flows and highly variable volumetric and concentration loading rates.

2.4 Algal Densities in the Rideau

One of the problems that has plagued the Rideau is that

FIG. 2.3 P/C NUTRIENT REMOVAL PROCESS FOR COMBINED SEWER OVERFLOWS (34).



of excessive weed and algal growth. Adamowski and Middleton (1) reported data for the algal density indicator, chlorophyll a. Concentrations averaged 15 mg/m^3 for the upstream reach of the Rideau and 21.5 mg/m^3 in the downstream reach, within the Regional Municipality of Ottawa-Carleton. The values for both sections are considerably higher than the average of 2.0 mg/m^3 reported for 9 recreational lakes in Ontario. Robinson (41) considered 6.0 mg/m^3 or greater to indicate high algal densities in lakes, leading to water of deteriorated quality with respect to recreation and aesthetics. Whether or not these criteria should be accepted for the relatively slow moving waters of the Rideau is debatable, however the magnitude of the problem has been indicated. The upstream values have been shown to be significantly different from the downstream values ($P < 0.05$) (see Appendix I). Thus, it may be concluded that the problem of high algal densities is greatest within the Regional Municipality of Ottawa-Carleton.

As an example of the reduction in the aesthetic quality and recreational appeal of the Rideau, Dickman (9) points to the numerous private homes that have swimming pools only a few feet from the river banks, in spite of the bacteriological water quality being within the recommended limits.

Dickman, in his unpublished report, attributed urban drainage water,in particular Saw Mill Creek within the City of Ottawa, as a significant source of nutrients causing excessive algal and weed growth.

2.4.1 Saw Mill Creek

Hauck (21) characterized the nutrient concentrations in Saw Mill Creek for both wet and dry weather flows. His results are summarized in Table 2.3. Provided that sufficient mixing took place at the confluence of Saw Mill Creek and the Rideau, dry weather flows resulted in negligible increase of nutrients. During an average storm period, however, flow in Saw Mill Creek is approximately 10 percent of that in the Rideau, thereby almost doubling the nitrate concentration from 0.06 to 0.11 mg-N/l, and total phosphorus may increase from 0.080 mg-P/l to 0.085 mg-P/l. Because the wet weather samples were taken intermittently, no real indication of the maximum concentration values expected could be found.

2.4.2 Saw Mill Creek Detention and Treatment

In the spring of 1974, the City of Ottawa constructed a dam across both culverts at Heron Road, creating an impoundment that would hold a maximum of 930 m^3, with an estimated surface area of 710 m^2. This would give the flow of 0.21 m^3/s (7.4 cfs), a theoretical detention time of 1.2 hours. Removal of suspended solids and nutrients by sedimentation and alum addition was investigated (21).

Sedimentation showed an average removal efficiency of 30 percent total phosphorus and 21 percent total organic nitrogen, while also removing 35 percent of the suspended solids. With an average alum dosage of 6.7 mg/l, removal increased slightly to 37, 31, and 39 percent respectively.

TABLE 2.3 NUTRIENT CHARACTERIZATION OF SAW MILL CREEK – HAUCK (21)

PARAMETER	SAW MILL CREEK[1]			RIDEAU[2]
	DRY WEATHER FLOW		FLOOD FLOW	AVERAGE
	1974	1975	1974	JULY,1975
Average Flow (cfs)	2.7	4.8	25	249
Total P (mg/l)	0.15	0.10	0.14	0.08
Ortho P (mg/l)	0.03	-	0.27	-
Nitrate (mg/l)	0.18	-	0.60	0.06
Organic N (mg/l)	-	0.28	-	1.85

1. Hauck (21)
2. Adamowski and Middleton (1)

During wet weather flows, a negative removal efficiency of -17 percent was averaged for total phosphorus, while nitrate removal efficiency averaged 0 percent. These results may be explained by the fact that during flood flows, velocities of the drainage water increased to the point where scouring of the reservoir occurred, flushing out the earlier sediment deposits.

2.5 Objectives

Demographic projections for areas as generously endowed with surface waters as the Ottawa Valley, normally show large increases in urban populations. The MacLaren-Richards Report (30) estimates that by the year 2030, one million people will inhabit the Ottawa-Carleton Regional Municipality, which is double the present population. Although the Ontario government has projected a somewhat lesser growth in the Region, the main point of agreement is that population increases will occur. (see Figure 2.4) The urban growth that accompanies the population increase will exert a greater demand on the recreational attributes of the Rideau River, as well as increasing the effects of drainage problems in areas of new development.

The review of the literature has shown that : (1) urban drainage water could be a significant source of nutrients, particularly during storm flows, (2) the effects of nutrients in urban drainage water to the Rideau River are virtually

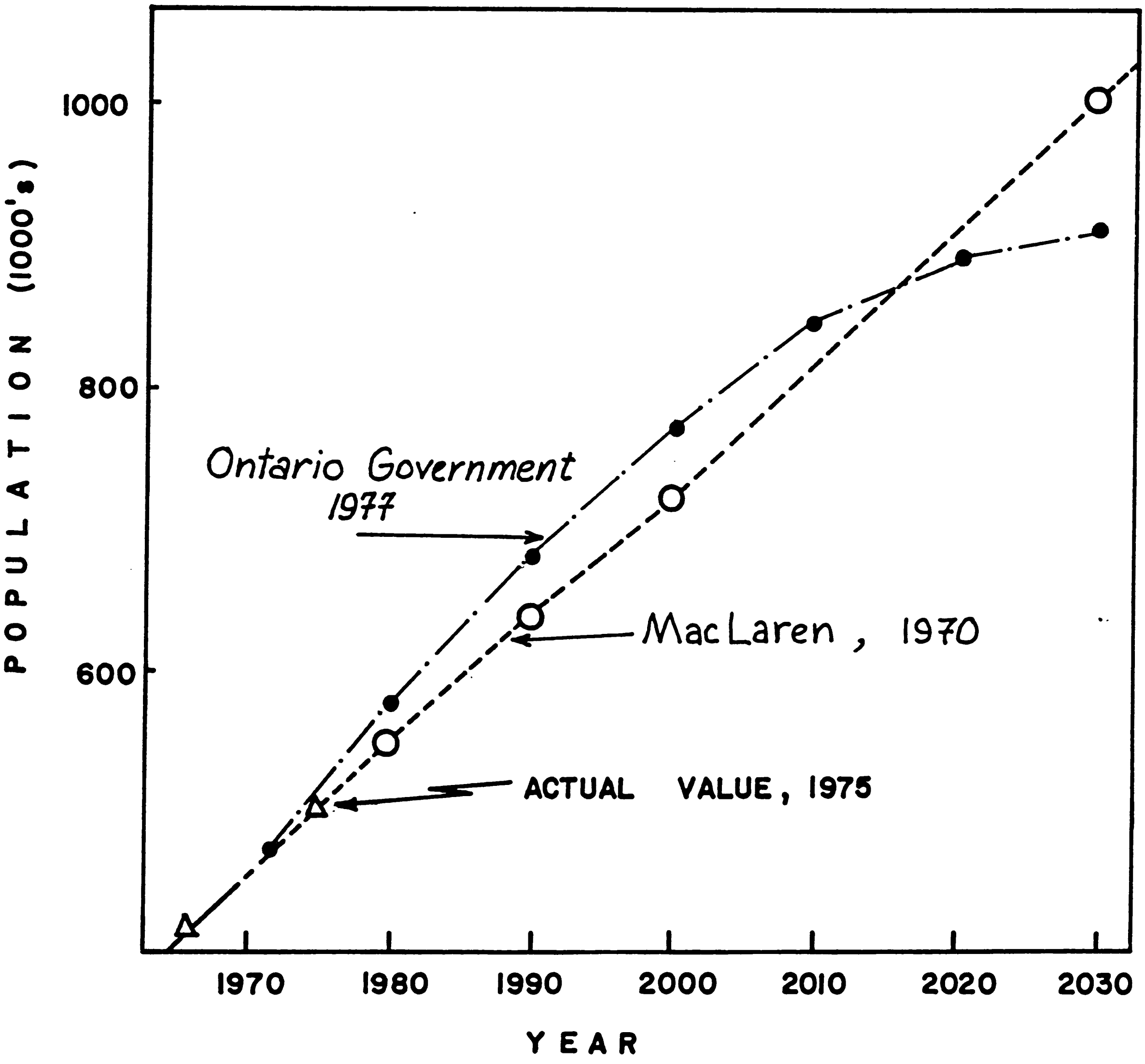


FIG. 2.4 DEMOGRAPHIC PROJECTION FOR THE REGIONAL MUNICIPALITY OF OTTAWA - CARLETON (30)

unkown, (3) algal bioassays may be used to quantify the effects of a nutrient source upon a receiving water, and (4) determination of the effectiveness of a nutrient removal scheme may also be made from algal bioassays.

Thus, evaluation of the present effects of urban drainage water is essential, in order that future control plans be both effective and economical.

The objectives of this study are therefore: (1) to chemically characterize the urban drainage storm flow in Saw Mill Creek and its receiving water, the Rideau River, (2) to use bioassays to determine quantitatively the nutrient effects of Saw Mill Creek on algal growth in the Rideau, (3) to determine the effectiveness of phosphorus removal by alum from the drainage water.

CHAPTER 3

THEORETICAL ASPECTS OF ALGAL GROWTH AND ITS CONTROL

3.1 Introduction

The degradation of the water quality along the Rideau has been observed for a number of years. From the recreational and aesthetic point of view, the major cause has been excessive algal and weed growth. Qualitatively the river has been described by Dickman to be highly eutrophic, particularly in the slower moving sections. A quantitative description of the problem however, requires a look at the theoretical aspects of algal growth.

3.2 Algal Growth

The Monod relationship has been shown to be applicable to describe the growth of many different types of microorganisms. Lawrence (28) used it to describe the utilization of degradable organics by a mass culture of bacteria in the activated sludge process. It has also been successfully applied to the description of algal growth in bioassays by Goldman (18) and Middlebrooks (33).

The Monod equation, as it is applied to algal growth, relates the limiting nutrient concentration, S, to the specific growth rate of the algae, μ, (see also Figure 3.1), and is given by:

$$\mu = \mu \left[\frac{S}{K_S + S}\right] \qquad 3.1$$

where μ is the specific growth rate (day^{-1}); û is the maximum specific growth rate (day^{-1}); S is the limiting nutrient concentration (mg/l); and K_s is the half velocity on saturation coefficient (S at $\mu/2$) (mg/l). At low values of S, the Monod equation approximates a first order equation in which the specific growth rate is linearly dependent upon the limiting nutrient concentration, that is:

$$\mu = \mu\left[\frac{S}{K_S}\right] \qquad 3.2$$

When $S \gg K_S$, then the zero order relationship applies

$$\mu = \hat{\mu} \qquad 3.3$$

in which the growth rate is at its maximum and no longer dependent upon the former limiting nutrient concentration, but some other factor such as light or flow conditions.

To allow for nutrient interaction which has been reported by several authors (19a,40a) the growth rate has been made a function of the nutrients involved. An equation of the following form is usually used:

$$\mu = \hat{\mu} \left[\frac{S}{K_S + S}\right] \left[\frac{N}{K_N + N}\right] \left[\frac{P}{K_P + P}\right] \quad \cdots \qquad 3.4$$

where N and P are the available nitrogen and phosphorus concentrations; and K_N and K_P are the respective half velocity coefficients. Thus each nutrient concentration will affect μ.

Determination of the growth rate, μ.

If the growth of algal cells is not limited by any factor, or if these factors may be kept constant during growth, exponential growth of the algal population occurs. Stated mathematically, the rate of growth is proportional to the number of cells at any particular time, as is described by the following equation:

$$\frac{dN}{dt} = \mu N \qquad 3.5$$

where N is the number of algal cells (cells/volume) (or the chlorophyll a concentration (mg/l)); t is time and u is the specific growth rate (t^{-1}) .

Upon rearranging and integrating we obtain:

$$\int_{N_{t=0}}^{N_{t=t}} \frac{dN}{dt} = \mu \int_{t=0}^{t=t} dt \qquad 3.6$$

therefore,

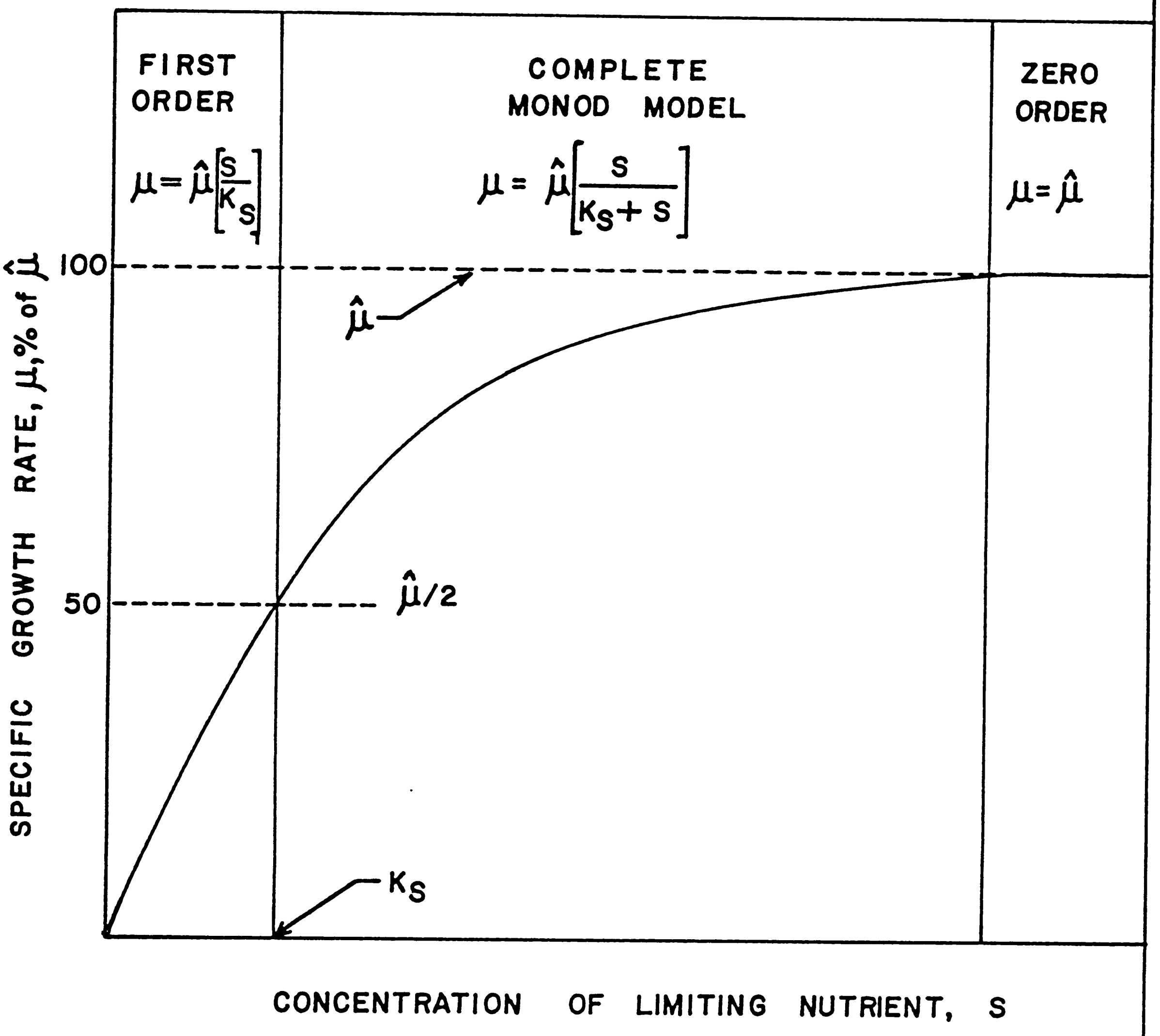
$$\ln \left| N_{t=t} \right| = \mu t + \ln \left| N_{t=0} \right| \qquad 3.7$$

Thus, by comparison to the standard equation of a straight line,

$$y = mx + B$$

where y and x are the dependent and independent variables; m is the slope and B the y intercept, we see that from a semilogrithmic plot of N versus t we may obtain values of μ for various concentrations of nutrients.

FIG. 3.1 MONOD RELATIONSHIP FOR ALGAL GROWTH



Equations 3.1 to 3.4 parallel Liebig's Law of the Minimum which states that the growth of an organism is controlled by the nutrient(s) whose demand is in excess of the supply. Liebig assumed environmental conditions, for example, pH, temperature and light, to be non-limiting.

About 15 to 20 elements are necessary for the growth of freshwater plants. In most natural waters, the micronutrients, manganese, iron, copper, cobalt and others, have been assumed to far exceed their required concentrations for potential maximum algal production. Vallentyne (48) showed the special significance of phosphorus, nitrogen and carbon by preparing a supply/demand table for all essential elements (See Table 3.1). The algal demand estimated the quantities of elements in an average aquatic plant community by weighting the annual production, 7 units of algae to 1 rooted plant. The supply term was approximated from literature data on the chemical composition of mean world river water. Although the supply of nitrogen, phosphorus and carbon may be underestimated, the ratio for those 3 essential elements is by far the highest.

These three algal macronutrients have all taken their turn at being the limiting nutrient, and the only conclusion that can be drawn is that generalizations cannot be made. The three nutrients will be considered individually in the next sections.

TABLE 3.1 DEMAND-SUPPLY RATIO FOR ALGAL NUTRIENTS *

ELEMENT	SYMBOL	PERCENT PLANT DEMAND	PERCENT WATER SUPPLY	DEMAND-SUPPLY RATIO
Oxygen	O	80.5	89	1
Hydrogen	H	9.7	11	1
Carbon	C	6.5	0.0012	5,000
Silicon	Si	1.3	0.00065	2,000
Nitrogen	N	0.7	0.000023	30,000
Calcium	Ca	0.4	0.0015	< 1,000
Potassium	K	0.3	0.00023	< 1,300
Phosphorus	P	0.08	0.000001	80,000
Magnesium	Mg	0.07	0.0004	< 1,000
Sulfur	S	0.06	0.0004	< 1,000
Chlorine	Cl	0.06	0.0008	< 1,000
Sodium	Na	0.04	0.0006	< 1,000
Iron	Fe	0.02	0.00007	< 1,000
Boron	B	0.001	0.00001	< 1,000
Manganese	Mn	0.0007	0.0000015	< 1,000
Zinc	Zn	0.0003	0.000001	< 1,000
Copper	Cu	0.0001	0.000001	< 1,000
Molybdenum	Mo	0.00005	0.0000003	< 1,000
Cobalt	Co	0.000002	0.000000005	< 1,000

*from Vallentyne (48)

3.2.1 Carbon

Most researchers agree that dissolved inorganic carbon in natural waters arise from four sources: (1) dissolution of carbonate minerals to produce alkalinity; (2) carbon dioxide from the atmosphere; (3) carbon dioxide produced by anaerobic fermentation; and (4) carbon dioxide produced by respiration of bacteria and other organisms. The question of which is the major source leads to the carbon limiting controversy. The first two (alkalinity and the atmosphere), have been completely discounted by Kuentzel (27), King (24, 25) and others who believe that carbon dioxide produced by heterotrophic bacteria in degrading organic matter controls the growth of algae. They maintain that reduction of organic carbon discharges into receiving waters would control cultural eutrophication. Goldman, et al. (19) and Maloney (31) argue that the availability of inorganic carbon from bicarbonate alkalinity is sufficient in most natural waters to ensure that some other nutrient is algal-growth limiting.

Typical levels of inorganic carbon in natural waters range from about 10 mg/l (low alkalinity) to 40 mg/l (high alkalinity). Because inorganic carbonate is the major buffering system regulating pH in most natural waters, its consumption by algae leads to an increase in pH. At about pH 10-11 many algae cease to be viable; hence, any carbon left in solution at this pH is in reality unavailable. Commonly such unavailable carbon constitutes half of the inorganic carbon in a water. Thus, it may be generally stated that about half the inorganic carbon is available (18). Since the growth rate of algae appears to be limited by carbon concentrations on the order of 1 to 2 mg/l, carbon should be very rarely the limiting nutrient in natural waters (20).

3.2.2 Phosphorus

In natural waters phosphorus occurs almost always as phosphate and is either associated with mineral matter (inorganic phosphate) or organic matter (organic phosphate). It can be present in solution (dissolved phosphate) or in particulate form (suspended phosphate) (45). Man contributes phosphates through his use of synthetic detergents (pyro- and tripolyphosphates), fertilizers (the so-called superphosphates), his own wastes, and water conditioners for the prevention of scaling and corrosion (hexa- and metaphosphates). The hydrolysis rates of these compounds to orthophosphate is on the order of 5 to 50 days in natural waters, greatly increased from that of a pure system due to the presence of enzymatically-acting bacteria and algae.

Dissolved inorganic orthophosphate is the major source of phosphorus for algae and other photosynthetic plants. In flowing waters the supply of orthophosphate is regulated by the physical processes such as the flow of the river, the mixing and diffusion of phosphate sources and sedimentation.

Chemical and biological processes such as exchange of phosphates with the sediments, regeneration from living and non-living particles and excreta of fish and zooplankton also play a role in the supply of the nutrient.

Sediments usually contain a very large reservoir of phosphate, especially in the slower moving sections of a river where it drops large quantities of the suspended load. The river scours sediment from one section while depositing in another, and in this way concentrates the phosphate sources. Phosphorus is also incorporated into the sediments by sorption and precipitation reactions with the iron, aluminum, clay and calcium minerals present in the sediment. Phosphate is released from the sediments by the dissolution of phosphate-containing minerals and organic matter, which occurs most readily when the sediments are under anaerobic and acidic conditions. As the water becomes shallower, the effect of the sediment sources increases.

As could be expected, concentrations of phosphate limiting growth vary considerably from one alga to the next. Vollenweider (49) states that for flowing waters a value between 2 and 230 µg/l could be limiting. The Environmental Protection Agency (14) considers from approximately 5 to 100 µg/l to provide sufficient nutrient for algal blooms. A widely quoted value in textbooks, etc. (20), is 10 µg/l, with the qualification that for significant algal growth considerably more than this concentration may be required.

As well as problems in determining a "limiting concentration", there are difficulties in establishing a relationship between the analytically measured concentration of phosphate to that concentration which is actually available to the algae for growth. Differentiation, however, can be made using the algal bioassay method. Perhaps it is for this reason that the Ontario Ministry of the Environment in its Guidelines (36) has not specified nutrient criteria.

3.2.3 Nitrogen

Naturally occurring forms of nitrogen, ammonia, nitrate, nitrite, elemental nitrogen gas and a variety of organic nitrogen compounds are found dissolved in natural waters. Biological conversion from one form to another is possible. Ammonia is the preferred nutrient form for plankton, since it is already at the lowest reduction level of organic nitrogen. Nitrate, the predominant inorganic nitrogen form, can also be used by most organisms, however they must have a reduction system, containing the enzyme nitrogen reductase. Several genera of blue-green algae _Anabaena_, _Gloeotricha_, _Nostoc_, and others are able to "fix" nitrogen directly from the atmosphere (20). Consequently, dissolved nitrogen concentrations do not limit the growth of these algae.

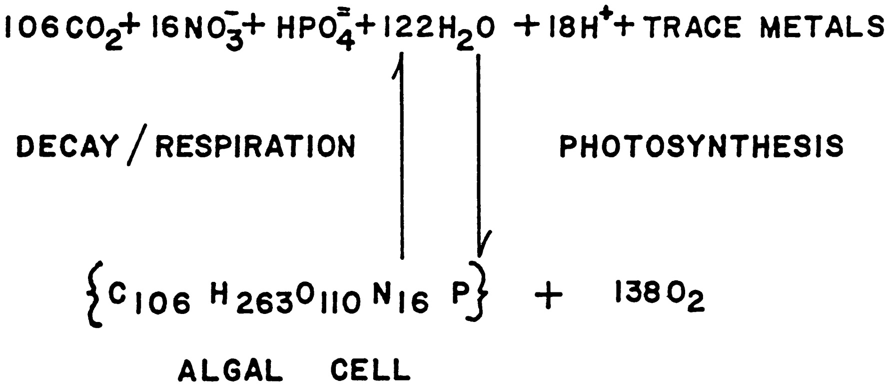
Organic nitrogen compounds are frequently associated with sediments, and are subject to recycling similar to phosphates. Ammonia and soluble organic nitrogen are released to the water during the decomposition of organic benthic matter. Biological conversion of organic nitrogen to ammonia and its subsequent nitrification-dentrification under anoxic and acidic conditions to the relatively insoluble nitrogen gas can actually lead to the loss of nitrogen directly to the atmosphere.

Like phosphorus, nitrogen concentrations which limit algal growth are dependent upon the species. The "residence time" and reaction rates of nitrogen compounds are variable. Concentrations of nitrogen less than 0.1 mg/l can cause sufficient nitrogen-stress in certain algal species such that they are eliminated and replaced by other species better able to grow in low nitrogen conditions. As well, some blue-green algae are able to "fix" nitrogen directly from the atmosphere. Therefore the use of a rate-limiting concentration for nitrogen is somewhat questionable. Vollenweider (49), in spite of these complications, quotes values in the range of 0.5 to 1.2 mg/l to be limiting in some flowing waters.

3.2.4 Mechanisms of Growth

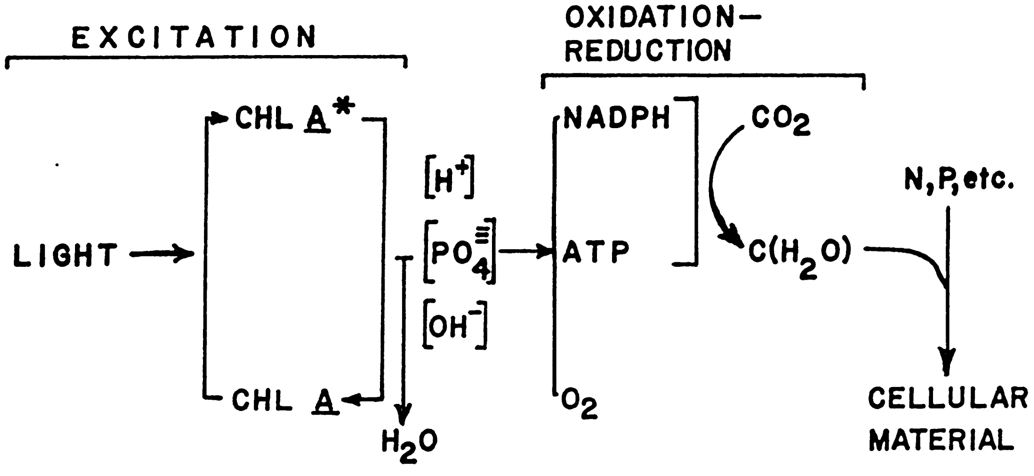
Figure 3.2 shows the average overall photosynthesis reaction and the average proportional demands of algae for carbon, nitrogen and phosphorus. Those nutrients, as well as many other biochemical materials shown in Table 3.1 are

FIG. 3.2 OVERALL PHOTOSYNTHESIS REACTION



$$106CO_2 + 16NO_3^- + HPO_4^{=} + 122H_2O + 18H^+ + \text{TRACE METALS} \underset{\text{DECAY / RESPIRATION}}{\overset{\text{PHOTOSYNTHESIS}}{\rightleftharpoons}} \underbrace{\{C_{106}H_{263}O_{110}N_{16}P\}}_{\text{ALGAL CELL}} + 138O_2$$

FIG. 3.3 TRANSFORMATION OF ENERGY



required to complete the photosynthesis reaction which produces algal cells. Although shown as a chemical equation, photosynthesis is a biological process involving the trapping of the biochemical components and light energy by the algal cells and subsequent conversion to the cellular components. The intermediate reaction is described by Figure 3.3. The photo-activated pigments, primarily chlorophylls,are able to transform physical light energy into chemical energy. Light energy excites the chlorophyll molecules to a higher energy state. Upon returning to the ground state an equivalent amount of energy is released and is used by the cell to reduce CO_2. The first products of photosynthesis are phosphorolated sugars which are rapidly converted to the metabolites such as carbohydrates, proteins and nucleic acids, provided that the proper biochemical materials are available.

The respiration process, in which carbon compounds within the algal cell are oxidized to CO_2, operates continuously. During the light hours, photosynthesis is the predominant process equaling and exceeding the oxygen demand of respiration. The excess oxygen produced during this period is defined as net photosynthesis. At night however, light conditions limit photosynthesis, while respiration continues and represents an oxygen demand.

The photosynthesis-respiration cycle is superimposed upon the growth and decay cycle. Algae, upon completion of their life cycle, die and the dead cellular materials settle out. Mineralization, the oxidative breakdown of the carbonaceous material which follows, also creates a significant oxygen demand.

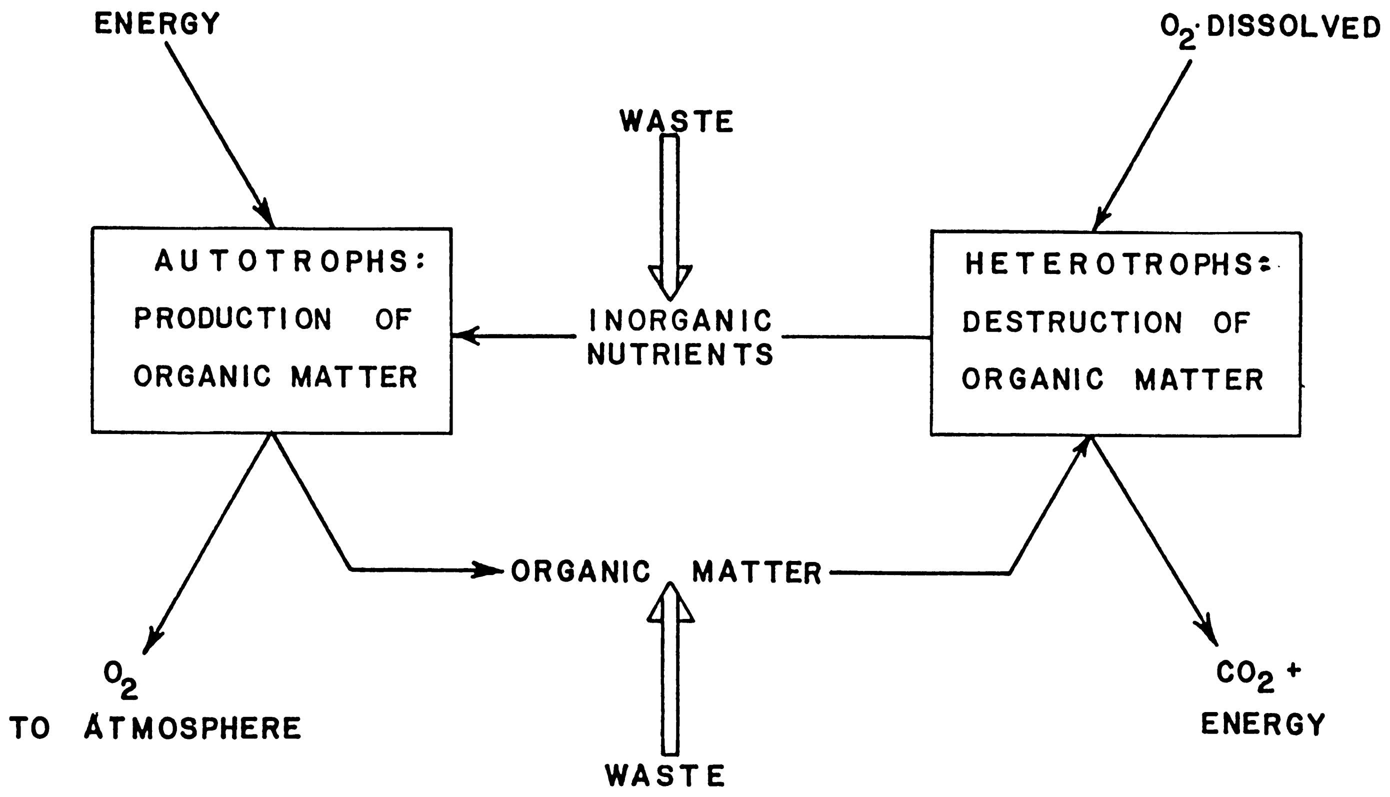
Jewell (23) states that if the aquatic weeds were completely oxidized, the potential oxygen usage is 1.3 mg O_2/mg Ignitable Suspended Solids (ISS). In his experiments he found that only 76 percent of the aquatic weeds were readily available for decomposition, the other 24 percent had a rate too slow to measure within the experimental period of 3 to 4 months. The algae decomposed at an average rate of 9 percent per day depending on the species tested. He points out that because this rate is approximately half the uptake rate of untreated domestic sewage, it could have an adverse effect on dissolved oxygen after the algal growing season. Furthermore, he found that regeneration of the nutrients, nitrogen and phosphorus varied from 0 to 100 percent depending on the refractory fraction of the weeds.

The overall production-decay cycle is shown for flowing waters in Figure 3.4. Net primary productivity is defined as the net photosynthesis minus losses due to respiration and mineralization over 24 hours.

3.2.5 Algal Bioassays

The theoretical basis for algal bioassays, discussed in the next section, will concern the applicability of the laboratory bioassay model to the natural conditions. Two

FIGURE 3.4 PHOTOSYNTHESIS – RESPIRATION/ DECAY RELATIONSHIP FOR FLOWING WATERS.[†]



[†] Adapted from Stumm and Morgan

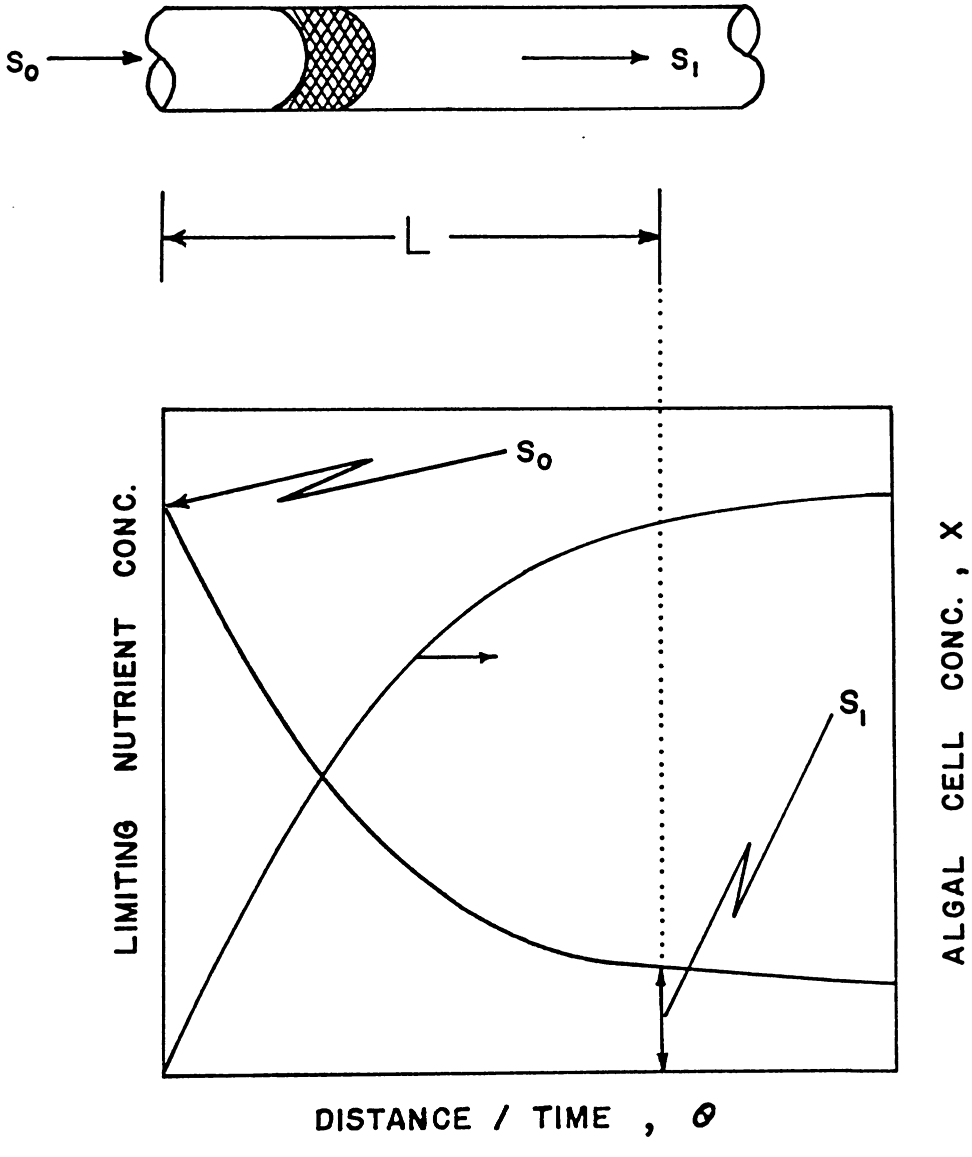
forms of bioassays are available: (1) continuous flow, and (2) batch growth (39). The continuous flow system was deemed unnecessarily complex both theoretically and practically. The batch algal bioassay was accepted as sufficient to obtain the results required.

Four basic steps are required for the use of batch algal bioassays as an indicator of the growth potential of an effluent-receiving water system. These are: (1) inoculation of the growth medium with nutrients and algal seed; (2) incubation of samples; (3) determination of the growth response; and (4) statistical evaluation. For the results of the bioassay to be properly interpreted, the analogies of the theoretical batch bioassays to the natural conditions must be well understood. Inoculation is considered analogous to an influent wastewater stream meeting its receiving water, at a point where complete mixing has taken place.

A plug flow type model is applicable to algal growth during the incubation period of the batch bioassay. Algal growth is indicated by the increase of cell concentration and the decrease in the rate limiting nutrient over time, within the reactor. This relationship is shown diagrammatically in Figure 3.5. Similarly, the same curve applies to the growth of the organisms within the plug of the receiving water, their growth and nutrient uptake varying with distance from the initial source.

The conditions required for the application of this

FIGURE 3.5 CHARACTERISTICS OF THE ALGAL BATCH CULTURE – PLUG FLOW MODEL.



plug-flow model to a nutrient source such as urban drainage water to a receiving water are that: (1) there are no sources, other than the initial source for nutrients; (2) there are no sinks for nutrients; (3) complete mixing of the waste stream with the receiving water occurs; (4) there is no longitudinal mixing of water, i.e., plug flow conditions exist.

Sediments may act as either a source or a sink for nutrients, depending upon the oxidative state and exchange equilibrium of the solid-water interface. Because the chemical and biological reactions which control the nutrient concentrations are dependent upon the size of the solid-water interface, the effectiveness of the sediments as a source or sink for nutrients varies with the quantity of water overlying the sediment. In shallow reaches, the sediments play a much larger part in the recycling of nutrients than in deep waters, where the sediments have a more localized effect.

Sedimentation acts as a sink "agent", removing a portion of the particulate nutrient fraction from the influent, thus reducing the quantity immediately available for algal growth.

Lateral complete mixing of the influent with the receiving water rarely occurs at the immediate vicinity of the outlet, but this assumption improves as the plug of receiving water moves further downstream.

Provided that longitudinal dispersion is small when compared to other convective transport mechanisms, longitudinal mixing of one plug with another may be considered negligible.

The validity of these assumptions is essential in the proper interpretation of batch algal bioassay results to the real world situation.

3.3 Phosphorus Removal with Alum

Alum acts in two ways to remove phosphorus from wastewaters: (1) precipitation of aluminum phosphates, and (2) entrainment of both the precipitate formed in (1) and particulate phosphorus in an alum floc. The first removes soluble phosphorus, basically in the ortho- form (PO_4^{-3}). The second removes phosphorus associated with the suspended solids - particulate phosphorus, which could be of any chemical form.

Alum, a hydrated aluminum sulphate having the formula $Al_2(SO_4)_3 \cdot 14\ H_2O$ (molecular weight of 594) averages about 9.1 percent Al^{+3}. The overall precipitation reaction with the PO_4^{-3} ion may be written as follows:

$$Al_2(SO_4)_3 \cdot 14\ H_2O + 2PO_4^{-3}(aq) \longrightarrow 2AlPO_4 + 3SO_4^{-2} + 14\ H_2O \qquad 3.8$$

The above reaction indicates that 1 mole (594 gm) of alum is required to react with 2 moles (62 gm) of P to form 2 moles (244 gm) of relatively insoluble precipitate, $AlPO_4$. The stoichiometric requirement of alum per gram of P is easily calculated to be 9.58 mg alum/mg P. If sufficient aluminum ion is present, the reaction goes to completion.

The solubility of $AlPO_4$ then determines the concentration of phosphorus remaining in solution. Stumm (45) calculated the solubility of $AlPO_4$ and found the insoluble P concentrations to be 8 μg-P/l at pH 5, 2.5 μg-P/l at pH 6 (minimum solubility), and 80 μg-P/l at pH 7 in a pure system.

It can be seen from equation 3.8 that 3 moles (288 gm) sulphate are brought into solution. This increased sulphate ion concentration must not exceed harmful proportions. For example, the Ontario Ministry of the Environment (36) recommends that for potable waters the sulphate concentration be kept below 100 mg/l. This limits the alum dosage to 206 mg/l provided that sulphate concentration initially present is negligible and no reduction of sulphate is experienced in the treatment process.

Carbonates, as well as phosphates also compete for alum in the reaction:

$$Al_2(SO_4)_3 \cdot 14\ H_2O + 6\ HCO_3^- \longrightarrow 2Al(OH)_3 + 6\ CO_2 + 14\ H_2O + 3\ SO_4^{-2} \qquad 3.9$$

The release of CO_2 and the neutralization of alkalinity brought about by this reaction, results in the reduction of pH of the water being treated. In low alkalinity wastewaters, such as stormwater, pH reduction may be significant, so that the addition of lime or other pH adjuster may be required to raise the pH to an acceptable level.

The competition of the carbonate ion increases the stoichiometric requirement of alum from 9.58 mg-alum/mg-P depending on the alkalinity of the wastewater and the percentage phosphorus removal desired.

Aluminum hydroxide, $Al(OH)_3$ is also insoluble and acts as a flocculant precipitate which carries with it the particulate phosphorus, as well as the insoluble $AlPO_4$, when it settles.

3.3.1 Jar Test

Theoretically, it is very difficult to predict the quantities of phosphorus removed by a certain dosage of alum. The jar test has been used to provide preliminary design and operational information such as the optimum alum dosage required for a given removal rate and estimating the quantity of sludge for disposal. This standard procedure parallels that used by potable water treatment plant operators in that a standard arbitrary timing sequence is used to ensure adequate mixing, reaction and flocculation. The details for the use of this procedure as it was used to simulate the treatment of Saw Mill Creek water are given in Section 4.6.

CHAPTER 4

EXPERIMENTAL DESIGN AND METHODS

4.1 Description of the Rideau River-Saw Mill Creek System

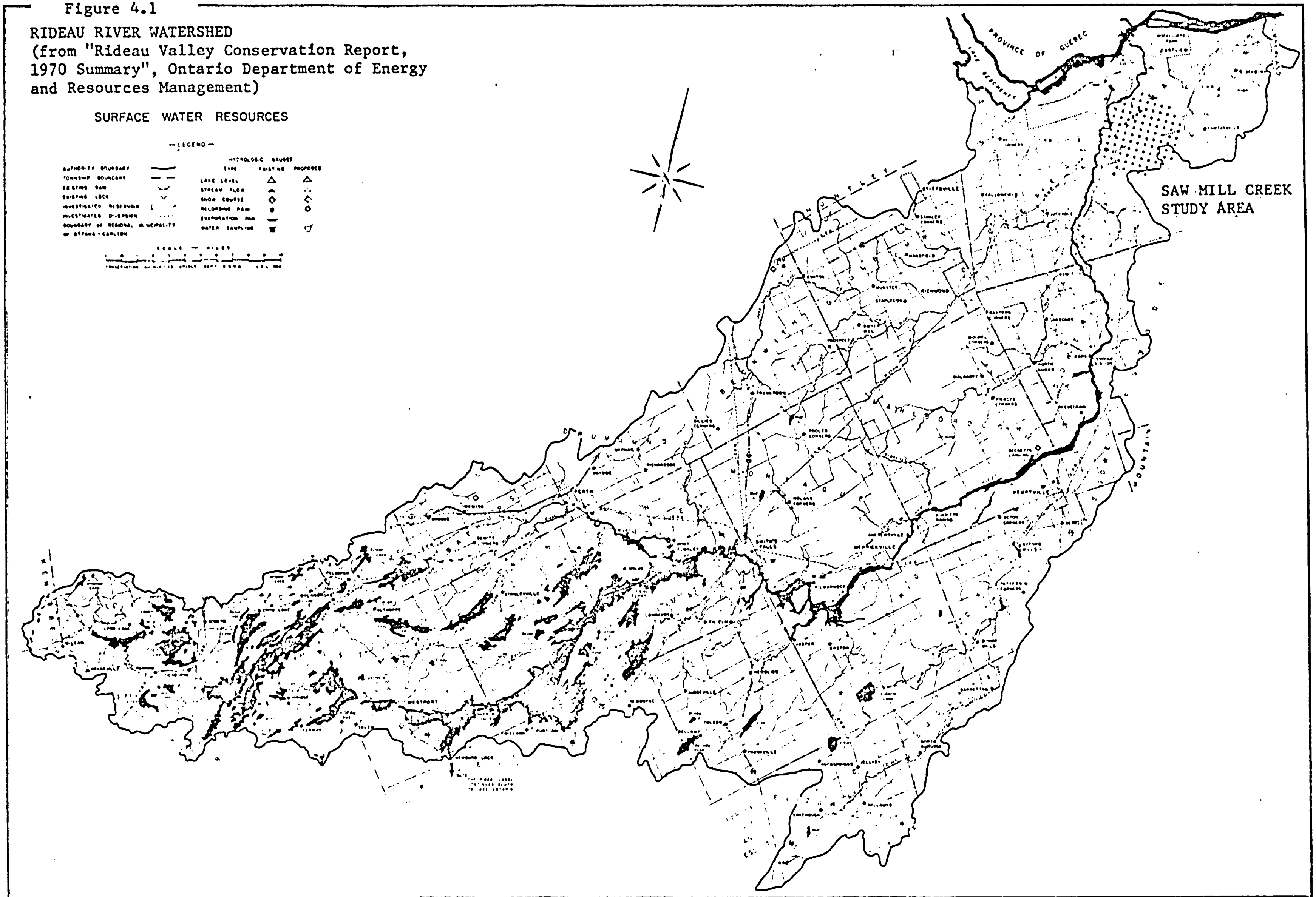
The Rideau River is 126 km in length and drains an area of 4100 km^2. The flow during the summer months ranges from 5.7 to 11.3 m^3/s (200 to 400 cfs) and is fairly constant because it is controlled by the Department of Transport for navigational purposes. The Rideau is part of a canal-river network connecting the Ottawa River with Lake Ontario. At present it is used primarily as a recreational waterway for contact and non-contact sports.

The headwaters of the Rideau are the Rideau Lakes. From the lakes, the river flows in a northeasterly direction through the small communities of Merrickville, Burritts Rapids, Kars and Manotick. To this point, the Rideau has been joined by Kemptville, Cranberry, Steven and Mud Creeks, all of which are minor tributaries draining primarily agricultural land, open fields and woodlots . In Manotick, the Rideau turns northward, heading towards the City of Ottawa (Figure 4.1).

Eight kilometers downstream from Manotick, the Jock River flows into the Rideau. Although it is the largest

Figure 4.1

RIDEAU RIVER WATERSHED
(from "Rideau Valley Conservation Report, 1970 Summary", Ontario Department of Energy and Resources Management)



tributary to the Rideau, it has been known to have intermittent flow during the summer. The Jock, as well as draining agricultural land, also drains the rapidly expanding suburban community of Richmond, within the Regional Municipality of Ottawa-Carleton.

Flowing through the urban areas of Ottawa, the Rideau has a great number of man-made outlets. All outlets to the Rideau within the Regional Municipality of Ottawa-Carleton have been classified according to type and are shown in Table 4.1 .

The Rideau flows into the Ottawa River within the city, 140 km from the mouth of the Ottawa.

4.1.1 Saw Mill Creek

Saw Mill Creek, the largest of five urban drainage basins emptying into the Rideau within the Regional Municipality, has an area of approximately 20 km^2. The basin is comprised of the percentages of the land uses listed in Table 4.2. As the table indicates, the relatively small developed area (23 percent) is estimated to contribute nearly 60 percent of the runoff to Saw Mill Creek. Large portions of these subdivisions are impervious and therefore convert almost all rainfall to runoff.

Figure 4.2 shows the Saw Mill Creek Drainage basin. The creek begins just outside city limits, with two drainage ditches running together, one from the Blossom Park development, and

Table 4.1 Outlets to the Rideau River *

Type of Outlet	Number
Storm sewers (<48")	41
Storm sewers (≥48")	12
Urban waterways (includes 3 outside The Regional Municipality of Ottawa-Carleton)	8
Sewage treatment plant outlets	2
Sanitary sewer overflows	6
Minor urban drainage ditches	9
Total	78

*source: Pollution Control Div.,
R.M.O.C.

Table 4.2 Percentage Runoff Contribution from Various Sources to Saw Mill Creek

Land Use	% of Drainage Basin[1]	C-Value[2]	% Contribution to Runoff
Woodland	14	0.15	6
Open field	63	0.20	36
Suburban area	4	0.70	9
Urban area	19	0.90	49

[1] from Hauck (21)

[2] Rational method runoff coefficient

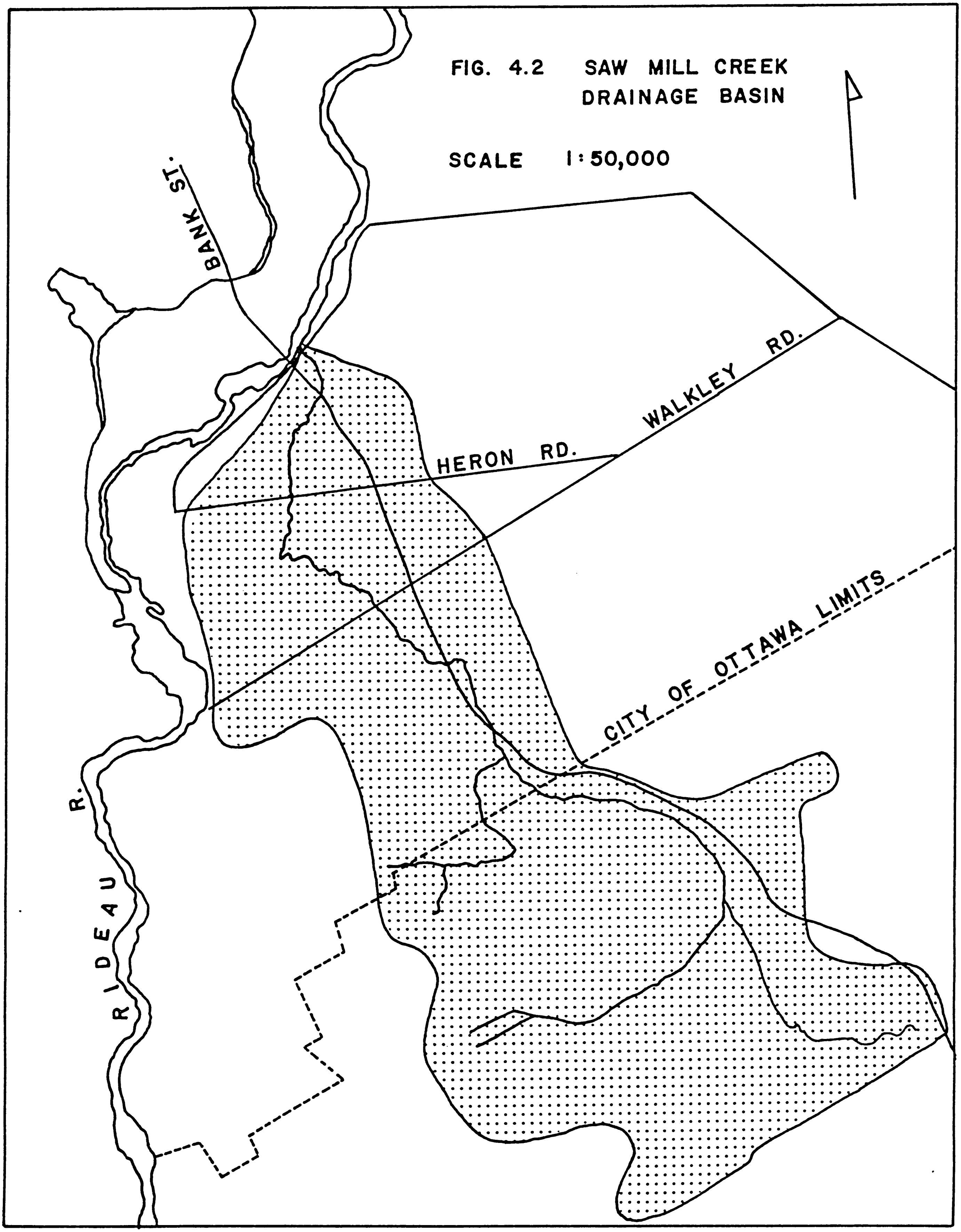


FIG. 4.2 SAW MILL CREEK DRAINAGE BASIN

SCALE 1:50,000

the other from CFB Ottawa South. From there it meanders through the NCC greenbelt in a northwesterly direction. At Bronson Avenue it turns due north, eventually emptying into the Rideau a few hundred metres north of the Bank Street Bridge.

Saw Mill Creek, over its 11.2 km course, has 75 drainage outlets contributing to its flow, which are listed according to source in Table 4.3.

4.1.2 Flow Regime

Saw Mill Creek enters the Rideau River on its south bank just north of Billings Bridge. The flow distance required for material released from Saw Mill Creek to become completely mixed with the Rideau River flow is estimated from an equation given by Holley and Rood (22a) to be 89 km. (See Appendix VII for calculations). Thus, lateral mixing of Saw Mill Creek is not completed within the Rideau River.

Longitudinal mixing is also minimal. Based on two dye studies, one in a reach just below Black Rapids Dam and the other near Kars, Curran (7) estimated the longitudinal dispersion coefficient to be negligible, i.e., $D_L \simeq 0$. Therefore, a plug-flow type model is acceptable for the present study.

4.2 Experimental Rationale and Design

The experiments were designed to determine the nutrient concentrations, loadings and effects on algal growth of urban stormwater during the most critical period of summer flow in

Table 4.3 Outlets to Saw Mill Creek*

Type of Outlet	Number
Established Storm Sewers	17
Recently Installed Storm Sewers	4
Catch Basin Outlets (roadways, parking lots)	24
Ditches and culverts	28
Tributaries	2
Total	75

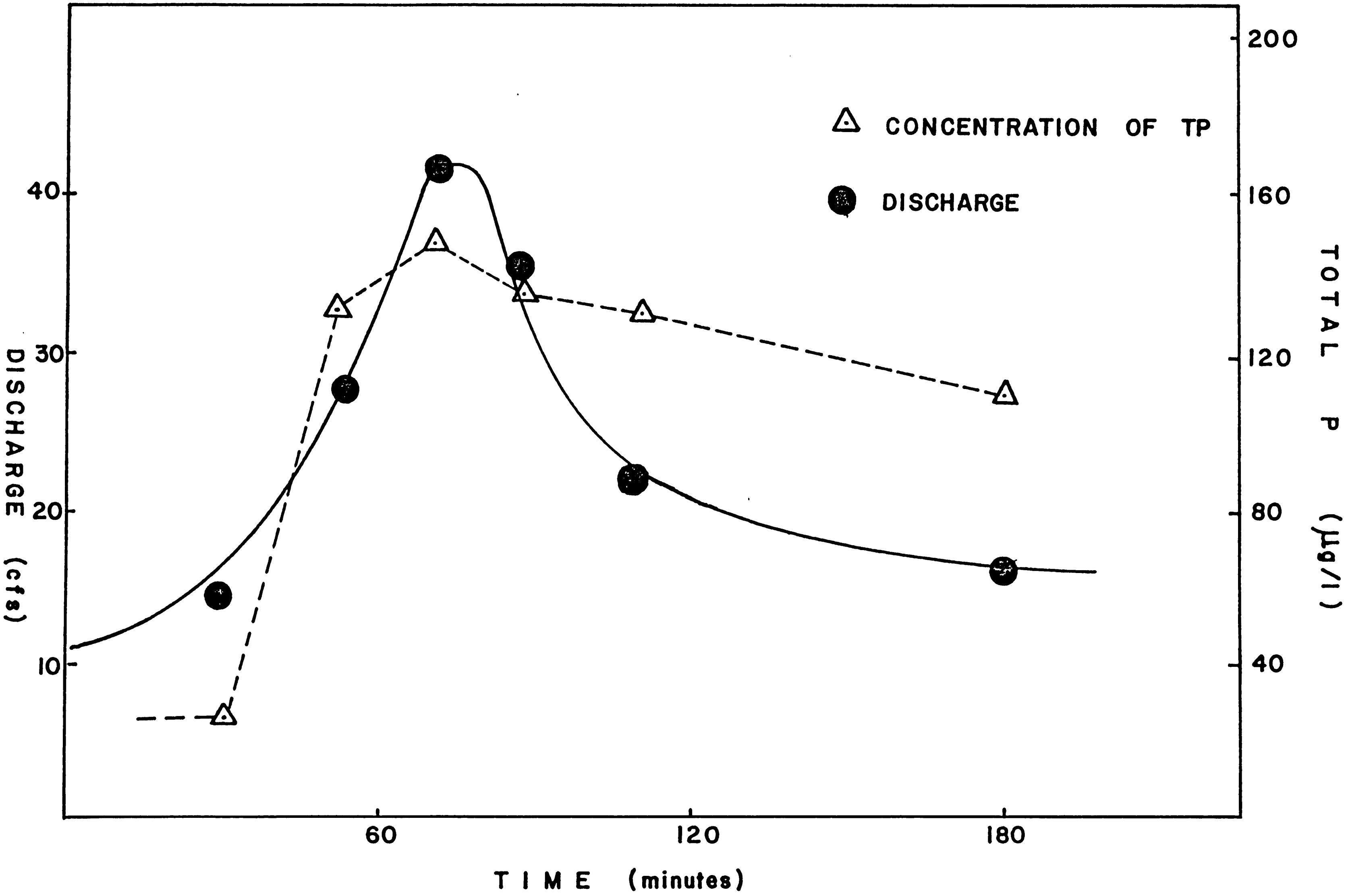
*Hauck (21)

the Rideau. The critical period was defined as the occurrence of a storm which created a significantly greater flow than the base flow of 0.14 m^3/s in Saw Mill Creek. It was assumed that the peak flow of the urban drainage water would occur near the peak nutrient concentrations, as was shown by Kluesener (26) in Figure 2.1. This was verified for Saw Mill Creek as is indicated by Figure 4.3. The increased flow during a storm increases the concentration of total phosphorus with the maximum concentration occurring at, or just prior to the peak discharge, Q_p. The low summer flows of the Rideau provide the least dilution water for the storm flow, during a time when algal growth conditions are optimum. Maximum light conditions and high water temperatures combine with the low flow conditions to produce ideal algal growth conditions. Assessment of these conditions would indicate the severity of the algal growth problem caused by urban drainage water.

To evaluate these conditions, Saw Mill Creek was grab-sampled at Q_p, and the Rideau was sampled shortly thereafter. These samples were subjected to chemical analysis, as well as bioassay procedures. For the algal bioassay, the peak flow samples of Saw Mill Creek were added in various proportions to the Rideau samples.

Recently, the Regional Municipality of Ottawa-Carleton has attempted the removal of phosphorus and suspended solids with alum, as outlined in Section 2.4.2. Evaluation of an improved version of this scheme, with an average of 85 percent removal of total phosphorus from the Q_p samples, was

FIG. 4.3 VARIATION OF TOTAL P CONCENTRATION WITH FLOW IN SAW MILL CK.



made using the jar test to simulate the removal process. The treated samples were added to the Rideau River samples and bioassayed, just as the untreated samples had been.

A statistical test, the F-ratio, was used to determine homogeneity between the various bioassay results. The F-ratio test does this by comparing the sample means and variances to establish a significant difference between them. The Rideau River bioassay results were used as a basis for comparison of untreated sample additions, while the appropriate untreated addition was used as a basis for the comparison of treated addition samples.

Once a significant difference had been shown to exist, regression analysis was used to indicate the degree of association between dependent and independent variables. The correlation coefficient, r, that was calculated for each regression varies from +1 to -1, depending on the agreement of the variables. Close to 1 there is a high degree of correlation, while at 0 no correlation may be observed.

On the basis of these statistical results, some course of action could be decided upon.

4.3 Sampling Techniques

Samples were taken from both the Rideau River and Saw Mill Creek in the maximum algal growth period of the late summer and early fall of 1976. Bioassay procedures were commenced within 24 hours of collection, while chemical analysis was completed within a few days. Nitrate analysis was the only exception, for which the samples were preserved and the analyses performed in November, 1976.

4.3.1 Saw Mill Creek

Samples from Saw Mill Creek were taken at the peak stage of flood flow during storms of the algal growing season. It was anticipated that the maximum mass loading on the Rideau River would occur at that time. Figure 4.3 shows this assumption to be sufficiently accurate for the purpose of this study.

The sampling point location was approximately 200 metres upstream from the mouth of the creek, just above the culvert underneath the eastbound lane of Riverside Drive. For the exact location, see Figure 4.4.

Samples were taken at six-tenths of the total depth from the surface, which in Saw Mill Creek, depending on the stage, is from 0.25 to 0.50 m.

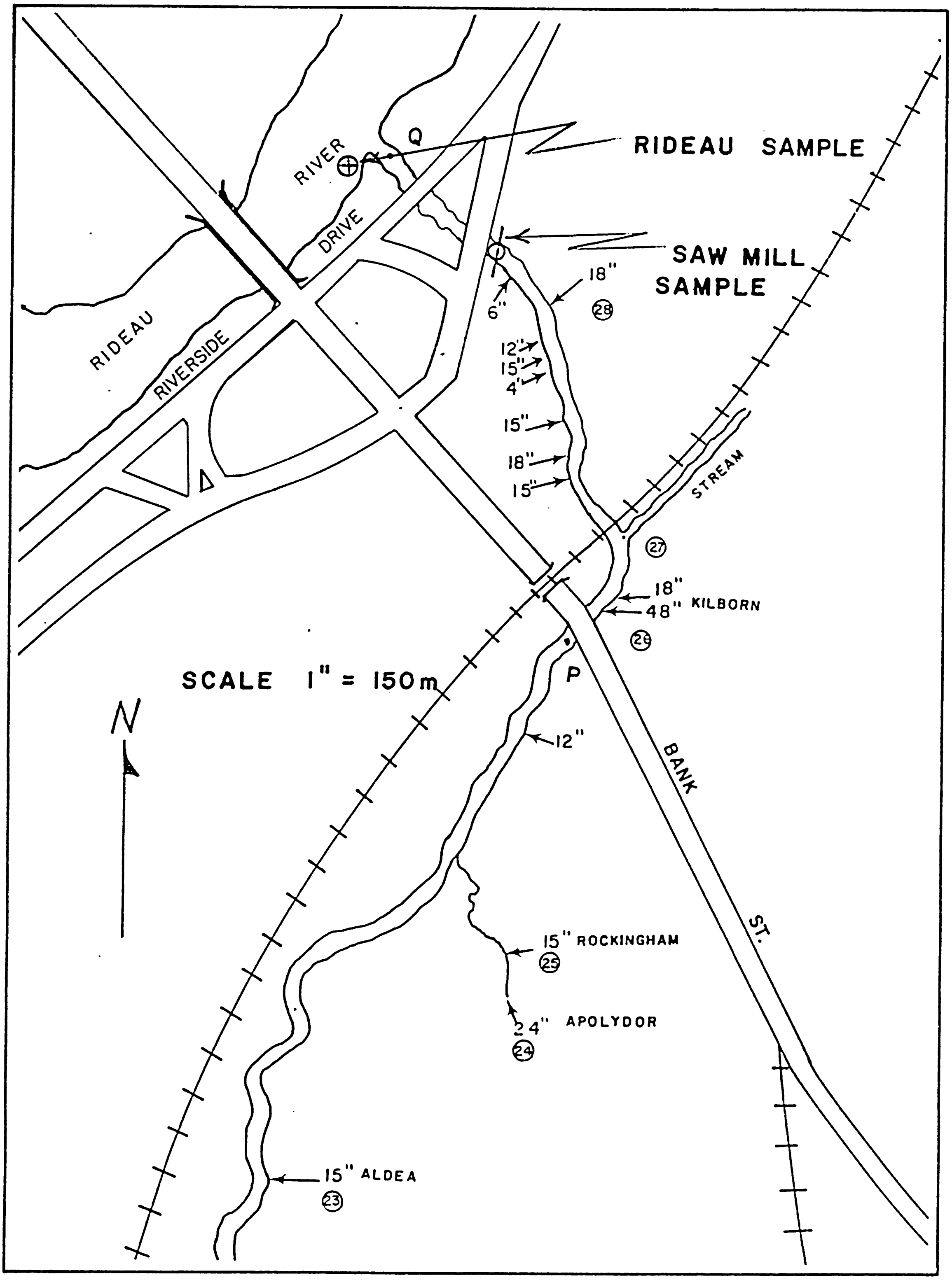
4.3.2 Rideau River

Rideau River samples were taken immediately following the Saw Mill Creek samples, the time element not being as critical.

Samples were taken just upstream from the Saw Mill Creek mouth. See Figure 4.4 for the exact location.

Depth of the samples varied between 1.00 and 1.25 m depending on the overall depth.

FIG. 4.4 SAMPLING LOCATIONS



4.4 Chemical Analysis

All chemical parameters measured are listed in Table 4.4.

Analyses were conducted according to procedures given in either Standard Methods for the Examination of Water and Wastewater, 14th Edition (1976) (2) or the Analytical Methods Manual (1974) (13) published by Environment Canada with the modifications and exceptions as noted in the following sections.

To reduce methodological error, nitrogen and phosphorus analyses were done in triplicate with only the average value being reported.

4.4.1 Total Phosphorus

Total phosphorus analysis was done by the persulphate digestion of the samples followed by the stannous chloride-molybdenum blue colourimetric determination outlined in Sections 425 C.III and 425 E. of Standard Methods (2). Filtration, done prior to addition of stannous chloride, was used to remove turbidity from samples when required. Triplicate samples were always run. A 50 mm cell was used with the Bausch & Lomb Spectronic 70 spectrophotometer to measure the light absorbances. Standards were analyzed identically to the samples and the resulting calibration curve is shown in Appendix II.

The relative error for the method is 9.2 percent at a concentration of 0.210 mg-P/l.

Table 4.4 List of Parameters Measured.

Chemical	Phosphorus	Total
	Nitrogen	Total Kjeldahl
		Nitrate
		Ammonia
	Carbon	Soluble Inorganic
		Alkalinity
		pH
Biological	Algal Biomass	Chlorophyll a
Physical	Flow	Stage-Discharge Relation
	Temperature	Hg thermometer

4.4.2 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen was measured by acid digestion of 250 ml of sample followed by distillation and back titration of the distillate, as presented in Section 421 of Standard Methods (2). The titrant was 0.0200 N sulfuric acid. The relative error for the method is 3.7 percent at a concentration of 0.80 mg-N/l.

4.4.3 Nitrate

Since these analyses could not be completed following collection, samples were first filtered through a 0.45 micron millipore filter and then acidified with 0.8 ml concentrated sulfuric acid and stored at 2°C for preservation. Once the required chemicals had been obtained, the Brucine colourimetric method outlined in Section 419 of Standard Methods (2) was followed. The Bausch & Lomb Spectronic 70 spectrophotometer was used with a 10 mm cell, at a wavelength of 410 mμ to measure the light absorbance. The calibration curve for the method is shown in Appendix III. The optimum range for the method is 0.1 to 1.0 mg-N/l. The relative error for the method is 6.0 percent at a nitrate concentration of 1.0 mg-N/l.

4.4.4 Ammonia

Ammonia concentration was determined using an Orion Model 95-10, Specific Ion Electrode, with the Orion Model 801 Digital pH/millivolt Meter read-out system. Suggestions for low concentration analysis given in the instruction manual, Orion Publication (38), were followed. The limit of detection is 0.1 mg/l NH_3; below the limit a "mud level read-out" is given.

4.4.5 Alkalinity, pH and Total Soluble Inorganic Carbon

A conductimetric titration (Section 403 of Standard Methods (2)) gives the values for both the pH and alkalinity. A 100 ml sample was titrated with 0.0200 N sulfuric acid to pH 4.2. The pH and alkalinity values were used to calculate the total soluble inorganic carbon from equations given by the definition of alkalinity (45):

$$[ALK] = C_T\ (\alpha_1 + 2\alpha_2) + [OH^-] - [H^+] \qquad 4.1$$

where $[ALK]$ is alkalinity concentration; C_T is the total carbonate carbon concentration; $[OH^-]$ and $[H^+]$ are the hydroxyl and hydrogen ion concentration, respectively; and α_1 and α_2 are the first and second acid dissociation of the carbon dioxide system. All concentrations are in equivalents per litre. Details of soluble inorganic carbon calculation may be found in Appendix IV.

The standard deviation for alkalinity measurements is estimated at 0.02 meq/l for concentration between 0.2 and 10 meq/l. Accuracy of the pH electrode is reported to be $\pm$ 0.1 standard units.

4.5 Bioassay Procedures

Growth of the algae was started immediately on the day of sample collection. Rideau River water was used as the basic medium for growth. Saw Mill Creek water, treated and untreated, was added in proportions of 0, 5, 10, and 20 percent, but keeping the total volume constant at 400 ml. These samples were incubated in one litre Erlenmeyer flasks in a constant temperature room at 22°C illuminated by 400 ft-cd of fluorescent light for six days. Samples were agitated once a day for twenty minutes. At the end of six days chlorophyll a determination was done using the entire 400 ml sample.

4.5.1 Chlorophyll a Determination

The sample was filtered through a Millipore 0.45 µ membrane filter, type HA. This filter was then placed in a minimum of 15.0 ml of aqueous acetone in screw-cap centrifuge tube and stored at 4°C in darkness for a minimum of twenty-four hours. Following twenty minutes of centrifugation, the optical densities of the centrate were measured at 750, 663, 645, and 630 mµ using a Bausch & Lomb Spectronic 70 spectrophotometer. The light path length was fifty millimetres. Recorded optical densities were converted to equivalent optical densities of a ten millimetre light path, and used in the following formula to calculate the chlorophyll a concentration in the centrate.

$$C_a = 11.6\ (D_{663} - D_{750}) - 6.14\ (D_{645} - D_{750}) + 0.10\ (D_{630} - D_{750}) \qquad 4.2$$

where C_a is the chlorophyll a concentration in the centrate in milligrams per litre, and D_{750}, D_{663}, D_{645}, and D_{630} are the optical densities at 750, 663, 645 and 630 mμ, respectively. The chlorophyll a concentration in the original sample was found by multiplying C_a by a concentration factor equal to the ratio of acetone volume to the filtered sample volume.

By assuming that chlorophyll a constitutes, on the average, 1.5 percent of the dry weight organic matter (ash free weight) of the algae, one can estimate the algal biomass (mg/l) by multiplying the chlorophyll a content (mg/m^3) by a factor of 0.067 mg-VSS/μg-chl a.

The precision of the chlorophyll a trichromatic technique has been estimated to be ±0.5 μg/l in the optimum range of 1 to 8 μg/l (37).

4.6 Sample Treatment - Jar Test

All Saw Mill Creek samples were treated with a range of ten to one hundred milligrams per litre of aluminum sulphate (alum) to determine the "optimum" dosage. The sample was stirred at 80 RPM when alum was added to ensure complete mixing. This was followed by a 20 minute period of stirring at 20 RPM to allow flocculation. Finally the floc was allowed to settle for twenty minutes after which the supernatant was drawn off. Analysis for phosphorus was done for each supernatant and the "optimum" dosage was determined by the dosage giving a minimum of 65 percent removal of total phosphorus. That supernatant was used in the bioassay to simulate the alum treatment of Saw Mill Creek water done at the Heron Road culvert-dam. Figure 4.5 shows a typical total phosphorus removal versus alum dosage curve.

4.7 Hydrometeorological Measurements

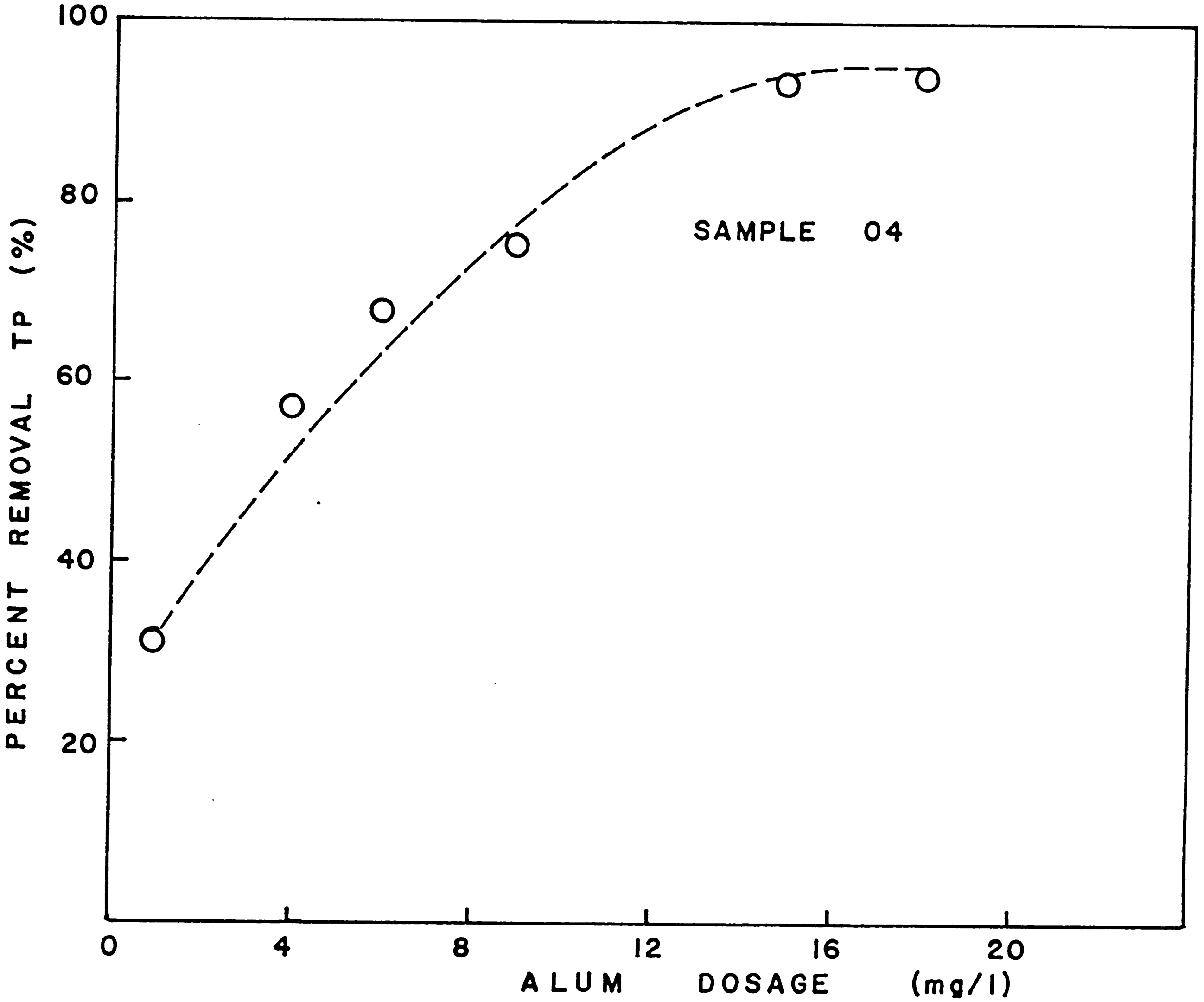
The peak stage measurement made on Saw Mill Creek during each storm was converted to discharge by the use of a stage-discharge curve determined in June, 1976, shown in Appendix V. It was assumed that this relationship remained constant throughout the period of investigation. The estimated relative error for the curve is ± 10 percent.

The Rideau instantaneous discharge was determined at the Carleton University gauging site (Environment Canada Station No. 02LA004) by the use of a "telemetering" system. The relative error was estimated by the Inland Water Branch of Environment Canada to be ± 4 percent.

Temperatures of both the Rideau River and Saw Mill Creek were taken at the time of sampling. Error is approximately ± 0.5°C.

Rainfall data for the Ottawa region (Uplands Airport Station) was obtained from the monthly report of the Atmospheric Environment Service (Environment Canada).

FIG. 4.5 TYPICAL PHOSPHORUS REMOVAL vs. ALUM DOSAGE CURVE



4.8 Statistical Methods

A one-way classification for the analysis of variance was used to test the null hypotheses of no significant difference between the biomasses produced by the 20, 10 and 5 percentage additions, biomasses produced by the Rideau, and the control biomasses. The hypotheses tested are listed in Table 4.5. Details of the F value calculation may be found in Appendix VI. All hypotheses were tested at the 95 percent confidence limits. Thus, the probability of type I error, rejecting the null hypothesis, if in fact there was no significant difference, was less than 5 percent. The critical F values at the 95 percent confidence limits and at the appropriate degrees of freedom were:

$F_{0.95;\ 1,10} = 4.96$, and $F_{0.95;\ 10,1} = 242$

The probability of type II error, accepting the null hypothesis if there was a real significant difference, was estimated from charts by Pearson and Hartley in Scheffe (44) to be less than 5 percent. A significant difference of 2 standard deviations (0.067 mg/l of algal biomass) was detectable 95 percent of the time.

Regression analysis was used to establish a cause of significant difference and was performed by the standard method of least squares. Regression coefficients (r) were tested for significance by the Student's T-test at the 99 percent confidence limits.

Table 4.5 Hypotheses Tested

The 6-day Algal Biomasses of the	were compared with the Biomasses of the
Control (100% Saw Mill)	Rideau Untreated 20% Untreated 10% Untreated 5 % Treated 20% Treated 10% Treated 5%
Rideau	Untreated 20% Untreated 10% Untreated 5% Treated 20% Treated 10% Treated 5%
Treated 20%	Untreated 20%
Treated 10%	Untreated 10%
Treated 5%	Untreated 5%

All hypotheses were tested at the 95 percent confidence level.

CHAPTER 5

RESULTS

5.1.1 Rideau River Data

The results of the chemical analysis for the Rideau River grab samples are presented in Table 5.1. The sample numbers correspond to the dates indicated and to the Saw Mill Creek samples. The river samples were also used as the basic growth medium in the corresponding bioassay experiment number. It may be noticed that ranges of all parameters are moderate.

Total phosphorus (TP) ranged from 0.015 to 0.094 mg-P/l, with an average of 0.040 ± 0.019 mg-P/l. Considering the error, a relatively small change in the concentrations is detectable within the sampling period.

Nitrate (NO_3) concentrations ranged from 0.01 to 0.26 mg-N/l, with an average of 0.10 ± 0.06 mg-N/l. Values greater than 0.1 mg-N/l were reported twice (sample 07 and sample 08). It is expected that although the samples were filtered and preserved according to <u>Standard Methods</u> (2), some denitrification did occur, leading to lower results. Thus, caution must be used in the interpretation of these values. As categorized by the Ontario Water Resources Commission (37a), the nitrate values lie between the low to moderate ranged, i.e., 0.1 mg-N/l being

Table 5.1 Chemical Characterization of the Rideau River

Code	Date	Total PO_4 (mg-P/l)	TKN	NH_3 (mg-N/l)	NO_3	SIC (mg-C/l)	ALK (meq/l)	pH
RR01	July 7	0.034	0.26	0.2	-	27.9	2.32	8.3
02	July 15	0.054	1.10	<0.1	-	31.1	2.56	8.1
03	Aug. 5	0.015	1.30	<0.1	-	30.5	2.56	8.5
04	Aug. 13	0.046	0.70	<0.1	0.01	29.8	2.48	8.3
05	Aug. 25	0.032	0.80	<0.1	0.02	27.5	2.30	8.4
06	Aug. 28	0.016	1.33	<0.1	0.04	24.7	2.06	8.3
07	Sept. 1	0.026	0.94	<0.1	0.20	28.4	2.38	8.4
08	Sept.10	0.040	0.88	<0.1	0.26	25.7	2.10	8.0
09	Sept.23	0.094	-	<0.1	0.06	29.0	2.34	7.8
average		0.040	0.91	<0.1	0.10	28.6	2.34	8.2
std. deviation		0.024	0.35	-	0.10	2.2	0.18	0.2
std. error		0.008	0.12	-	0.04	0.8	0.06	0.1

low, and 0.1 to 1.0 mg-N/l being moderate.

Ammonia (NH_3) concentrations exceeded the limit of detection for the electrode method, 0.1 mg-N/l only once (sample 01). Total Kjeldahl Nitrogen (TKN) ranged from 0.26 to 1.33 mg-N/l with an average of 0.91 ± 0.03 mg-N/l. TKN is comprised of both organic and ammonia nitrogen, which includes fecal and proteinaceous matter.

The Total Nitrogen (TN) concentration was found by the addition of all measured nitrogen parameters. It averaged 1.1 ± 0.1 mg-N/l. Although nitrites were not included, values greater than 0.1 mg-N/l are seldom recorded for nitrites in natural waters because they readily oxidize to the nitrate form.

Soluble Inorganic Carbon (SIC) varied from 25.7 to 31.1 mg-C/l with an average value of 28.6 ± 0.3 mg-C/l. These values were calculated from the pH and alkalinity using Equation 4.1.

Alkalinity values fluctuated between 2.06 and 2.56 meq/l with an error of ± 0.02 meq/l. In this low alkalinity water, pH remained fairly constant at 8.2.

The summary of observed data, along with two other sample summaries of the Rideau River are presented in Table 5.2. It may be observed that the results of the present study are between those values reported by Middleton and Adamowski, and Dickman. The comparison was necessary to position the present data relative to past observations.

Table 5.2 Data Summary and Comparison for the Rideau River

Parameter	Dickman[1] (1970-73)	Adamowski & Middleton[1] (1975)	Habicht[2] (1976)
Total PO_4 (mg-P/l)	0.056 (12)[3]	0.080 (4)	0.040 (9)
TKN (mg-N/l)	0.72 (12)	1.6 (6)	0.91 (9)
NH_3 (mg-N/l)	0.046 (12)	0.26 (2)	<0.1 (9)
NO_3 (mg-N/l)	0.13 (12)	0.06 (6)	0.10 (6)
Total N (mg-N/l)	0.9 (12)	-	1.0 (6)
SIC (mg-N/l)	-	22.9 (14)	28.6 (9)
ALK (meq/l)	-	2.30 (8)	2.34 (9)
pH (std. units)	-	8.5 (12)	8.2 (9)

Note:

[1] Samples collected at Hog's Back above the dam.

[2] Samples collected just upstream of Saw Mill Creek

[3] Number of samples in parenthesis

Since both past samples were taken above Hog's Back Dam, longitudinal as well as temporal variation must be allowed.

5.1.2 Saw Mill Creek Data

Results of the chemical analysis of grab samples taken during peak storm flow in Saw Mill Creek are presented in Table 5.3. These concentrations can be considered to be the highest values expected during storm flow conditions in Saw Mill Creek. The possibility of fugitative discharges, slugs of pollutants which people intentionally or inadvertently flush down the storm sewer, still exist.

It may be noticed that the parameter values are highly variable. This may be explained quantitatively by the following observations. Initially, contaminants accumulate upon the land surface as a function of dustfall, street sweeping frequency and efficiency, antecedant rainfall conditions, etc. When a rain event occurs, the energy of the dissipating raindrops dislodges contaminants from street surfaces, roof tops and other urban sources, causing some contaminant particles to become suspended in the runoff. The soluble fraction of the material will be dissolved by the runoff. Subsequently, runoff transports contaminants across urban land, into gutters and storm sewers, to be eventually disposed of by discharge to a receiving water. Dependence on the large number of variables listed above, creates highly variable parameter concentrations in the runoff.

Table 5.3 Chemical Characterization of Peak Storm Flows in Saw Mill Creek

Code	Date	Total PO_4 (mg-P/l)	TKN	NH_3 (mg-N/l)	NO_3	SIC (mg-C/l)	ALK (meq/l)	pH
SM01	July 7	0.108	0.84	<0.1	-	-	-	7.6
02	July 15	0.151	2.06	<0.1	-	38.8	3.11	7.7
03	Aug. 5	0.061	2.60	<0.1	-	21.4	1.71	7.7
04	Aug. 13	0.233	1.40	<0.1	0.23	30.2	2.44	7.8
05*	Aug. 20-5	0.015	0.10	<0.1	1.73	42.0	3.48	8.2
06	Aug. 28	0.091	2.97	<0.1	0.35	16.3	1.34	8.0
07	Sept. 1	0.108	0.80	0.1	1.01	25.6	2.08	7.9
08	Sept. 10	0.565	3.56	0.4	0.01	22.0	1.74	7.6
09	Sept. 23	0.180	-	0.1	0.84	38.6	3.08	7.7
average		0.187	2.03	<0.1	0.70	29.4	2.21	7.8
std. deviation		0.162	1.07	-	0.63	9.5	0.70	0.1
std. error		0.057	0.40	-	0.26	3.4	0.26	0.1

*Average values of 5 samples taken during the dry weather period of August 20-25, 1976.

Total Phosphorus (TP) ranged from 0.061 mg-P/l to a hgih 0.565 mg-P/l, with an average value of 0.190 ± 0.019 mg-P/l. This value is somewhat higher than 0.14 mg-P/l recorded by Hauck (21) during wet weather flows of 1974. It is possible that because his samples were not taken during peak flow, lower total phosphorus concentration were recorded.

Nitrate (NO_3) ranged from 0.01 to 1.73 mg-N/l, with an average of 0.70 mg-N/l. Again, caution must be used in the interpretation of these nitrate values for reasons outlined earlier. Hauck (21) recorded an average 1974 wet weather flow concentration of 0.60 mg-N/l which compares reasonably well with present values.

Ammonia (NH_3) concentrations remained at or below the limit of detection of 0.1 mg-N/l for all samples except sample 08 for which the value 0.4 mg-N/l was recorded.

Total Kjeldahl Nitrogen (TKN) ranged from 0.80 to 3.56 mg-N/l, with an average value of 2.03 ± 0.03 mg-N/l.

Total Nitrogen (TN) averaged 2.5 ± 0.1 mg-N/l which includes NH_3, NO_3 and TKN nitrogen.

Soluble Inorganic Carbon (SIC) ranged from 16.3 to 38.8 mg-C/l with an average of 29.4 ± 0.3 mg-C/l. This average value is within experimental error of the average reported for the Rideau River (28.6 mg-C/l).

Alkalinity values varied from 1.34 to 3.48 meq/l with an average of 2.37 ± 0.02 meq/l. The pH averaged 7.8.

5.2 Hydrometeorological and Physical Data

The hydrometeorological data for the study period is shown in Table 5.5. Six rainfalls which averaged 12.7 mm at the Ottawa airport rain gauge, produced the six flood events during which peak flow samples were collected from Saw Mill Creek. The peak discharge values were highly variable, ranging from 0.34 to 1.44 m^3/s, with a mean value of 0.90 m^3/s. Flow in the Rideau during these six occasions averaged 10.96 m^3/s. The flow ratio calculated was the percentage of peak flow in Saw Mill to the flow in the Rideau. Temperature in the Rideau averaged $21^o \pm 0.5^oC$, while Saw Mill Creek averaged $17^o \pm 0.5^oC$.

The number of rainfree days prior to a storm event are shown in Column 6 of Table 5.5. Probably due to the lack of data, no relation of the rainfree period to the chemical characteristics was apparent.

Figure 5.1 shows the Saw Mill-Rideau confluence just north of Billing's Bridge. The degree of mixing is clearly visible, as the browner, more turbid water of Saw Mill Creek enters the clearer water of the Rideau.

5.3 Alum Treatment Data

The jar test was used in the laboratory to simulate phosphorus removal from Saw Mill Creek water. The maximum phosphorus removal efficiency of alum for each sample is reported in Figure 5.3. On the average, 85 percent removal of total phosphorus was achieved with an average dosage of

Table 5.4 Physical Data Summary

Sample No.	Flow			Rainfall	No. of Dry Days Prior to Event	Temperature	
	Rideau (m^3/s)	Saw Mill (m^3/s)	Ratio (%)	(mm)		Rideau °C	Saw Mill °C
03	10.19	0.34	3	11.4	4	20	15
04	9.49	0.96	10	10.4	0	21	17
05	9.82	0.28	3	0.0	9	19	16
06	10.90	1.44	13	29.2	12	22	18
07	8.35	1.08	13	12.7	3	24	18
08	8.07	0.85	11	8.6	4	23	19
09	18.77	0.71	4	4.1	0	21	18
Average	10.96	0.90	9	12.7	-	21	17

12.5 mg/l alum. This was considerably better than the 35 percent achieved in the field by Hauck (21) (Section 3.2). Since all the conclusions from this study are based upon higher treatment efficiencies, this level must be achieved in the field as a prerequisite to obtaining the results predicted by this study.

Figure 5.2 shows the impoundment facility at the Heron Road culvert used by the Regional Municipality of Ottawa-Carleton for treatment of Saw Mill Creek.

Figure 5.1 Rideau-Saw Mill Confluence

Figure 5.2 Impoundment Facility at Heron Rd.

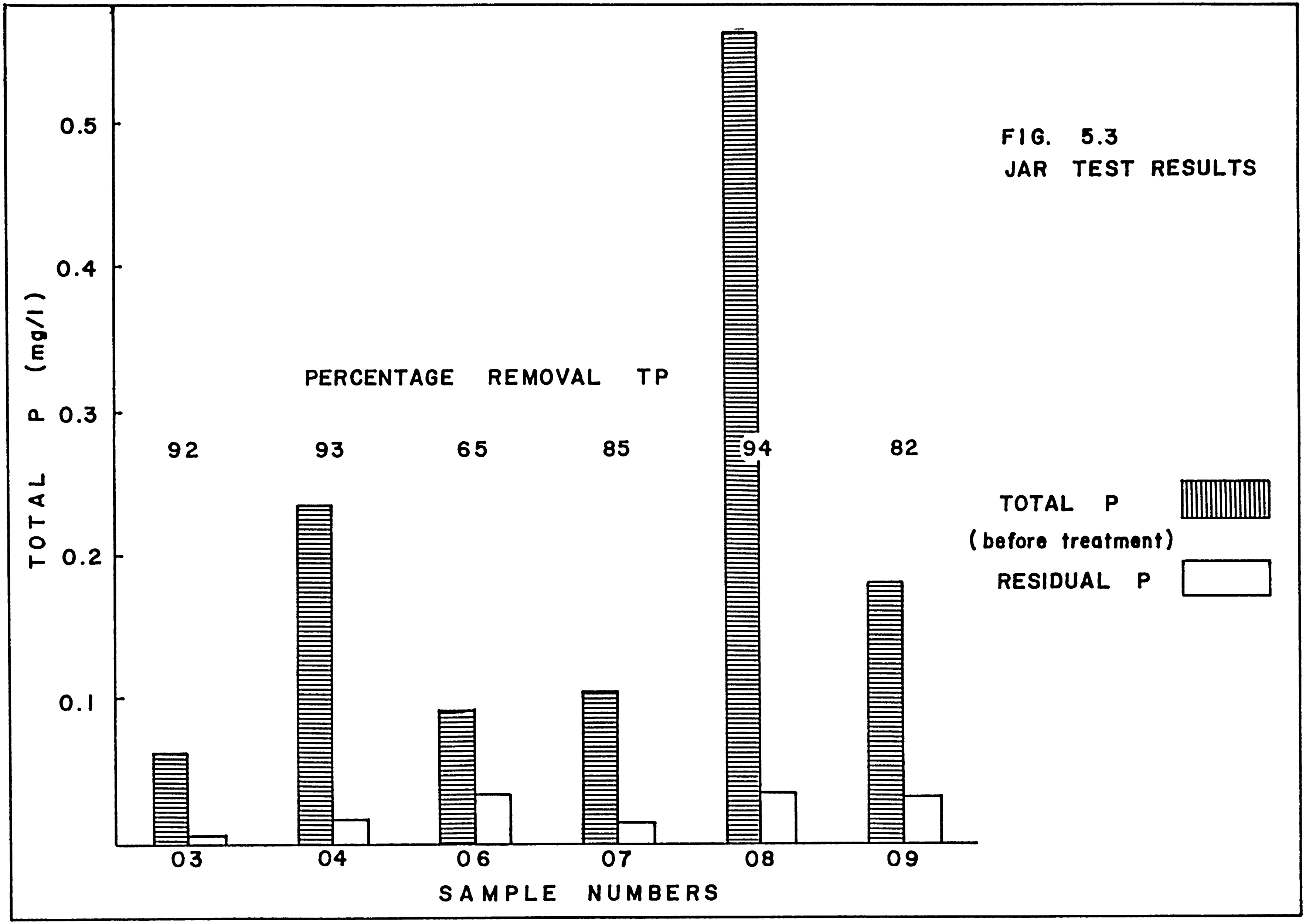


FIG. 5.3
JAR TEST RESULTS

5.4 Bioassay Results

Each peak flow sample of Saw Mill Creek water, treated and untreated, was added to Rideau water in proportions of 0, 5, 10 and 20 percent. These mixtures were incubated under constant conditions for six days, as was a control to ensure that growth was possible. Chlorophyll a measurements were made after six days, and to obtain the standing algal biomass, the final chlorophyll a concentration was multiplied by 0.067 mg-VSS/µg chlorophyll a. Results for the various samples for each dilution are given in Figures 5.4, 5.5 and 5.6.

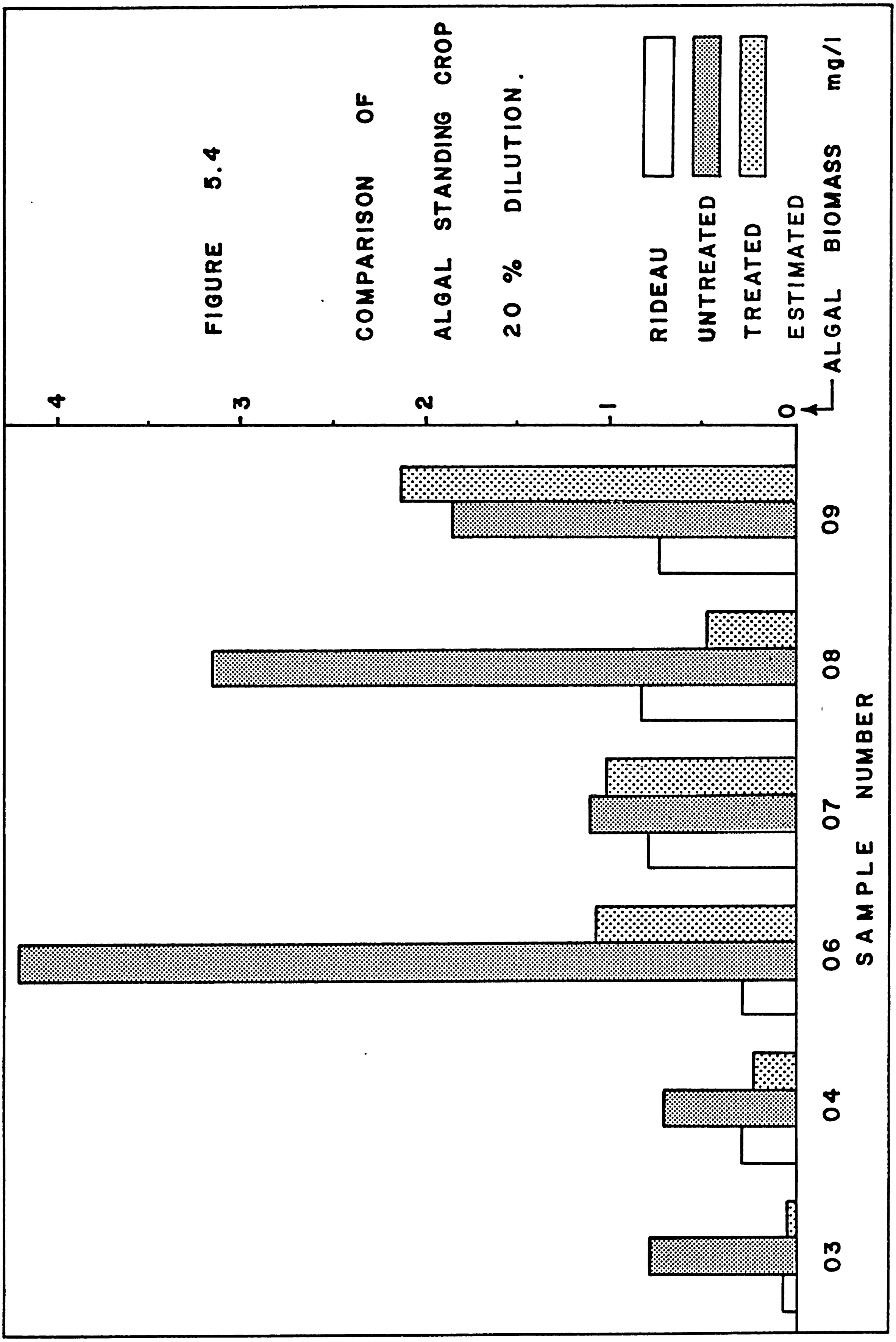


FIGURE 5.4

COMPARISON OF ALGAL STANDING CROP 20 % DILUTION.

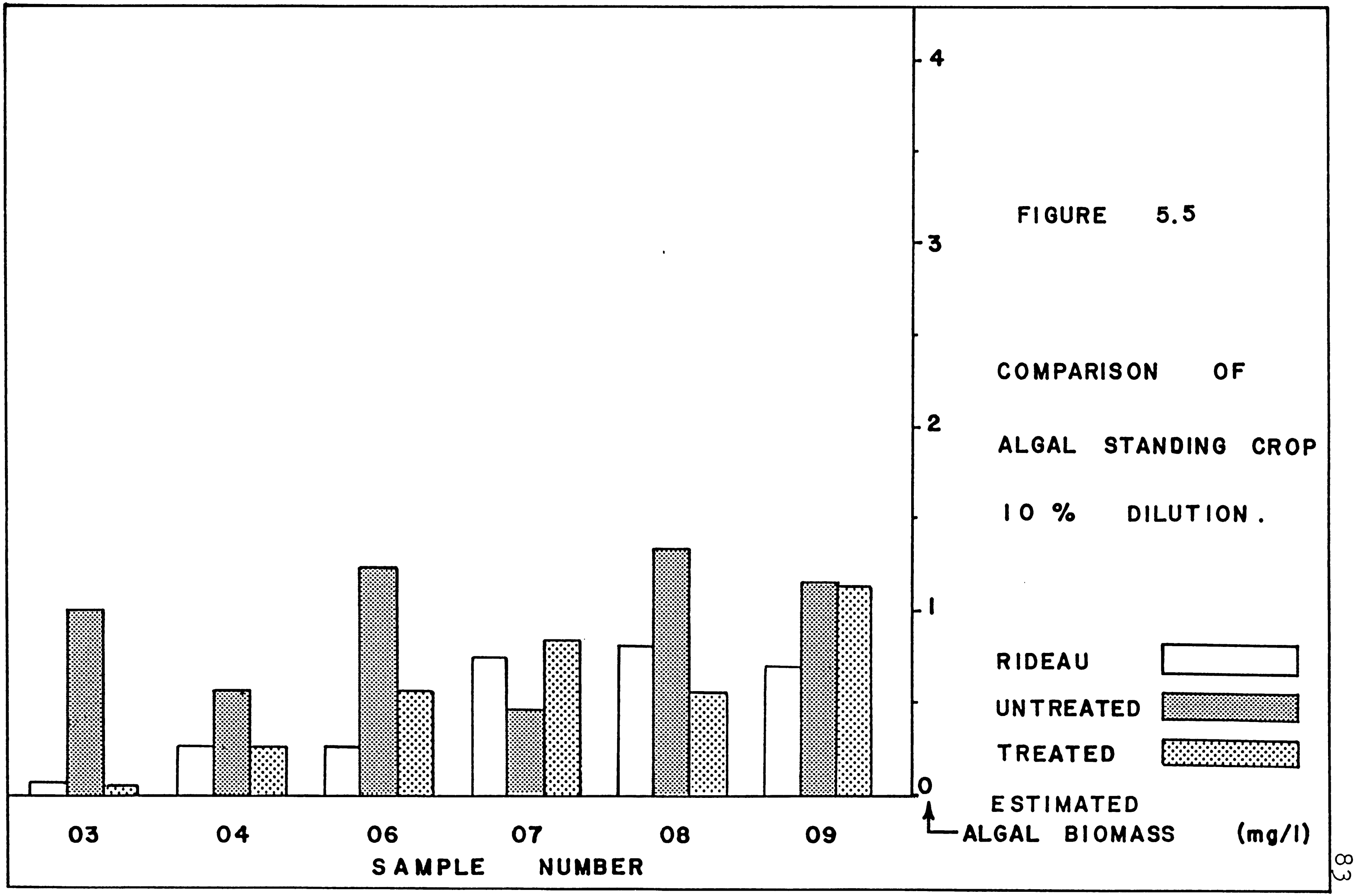


FIGURE 5.5

COMPARISON OF ALGAL STANDING CROP 10 % DILUTION.

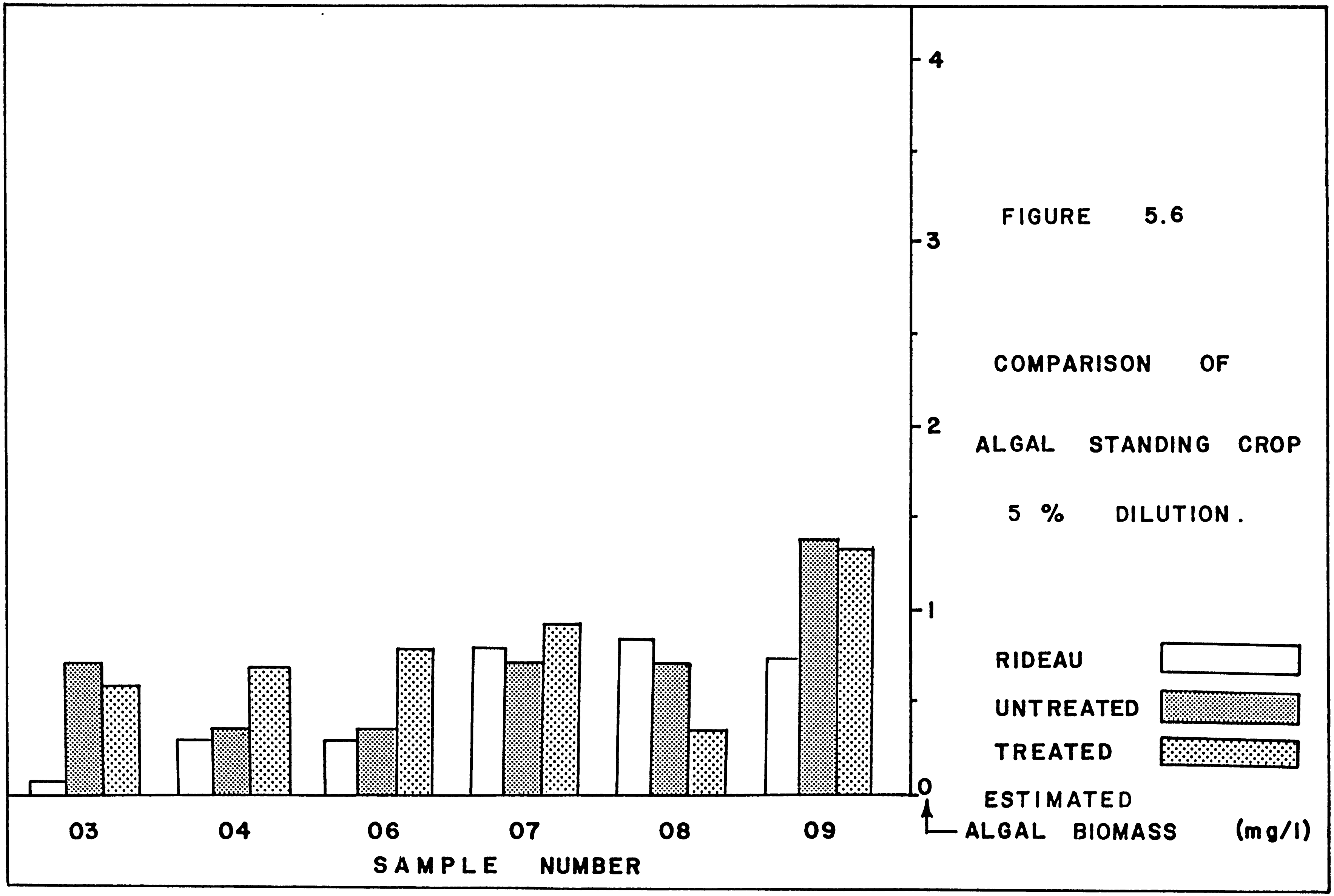


FIGURE 5.6

COMPARISON OF ALGAL STANDING CROP 5 % DILUTION.

CHAPTER 6

DISCUSSION

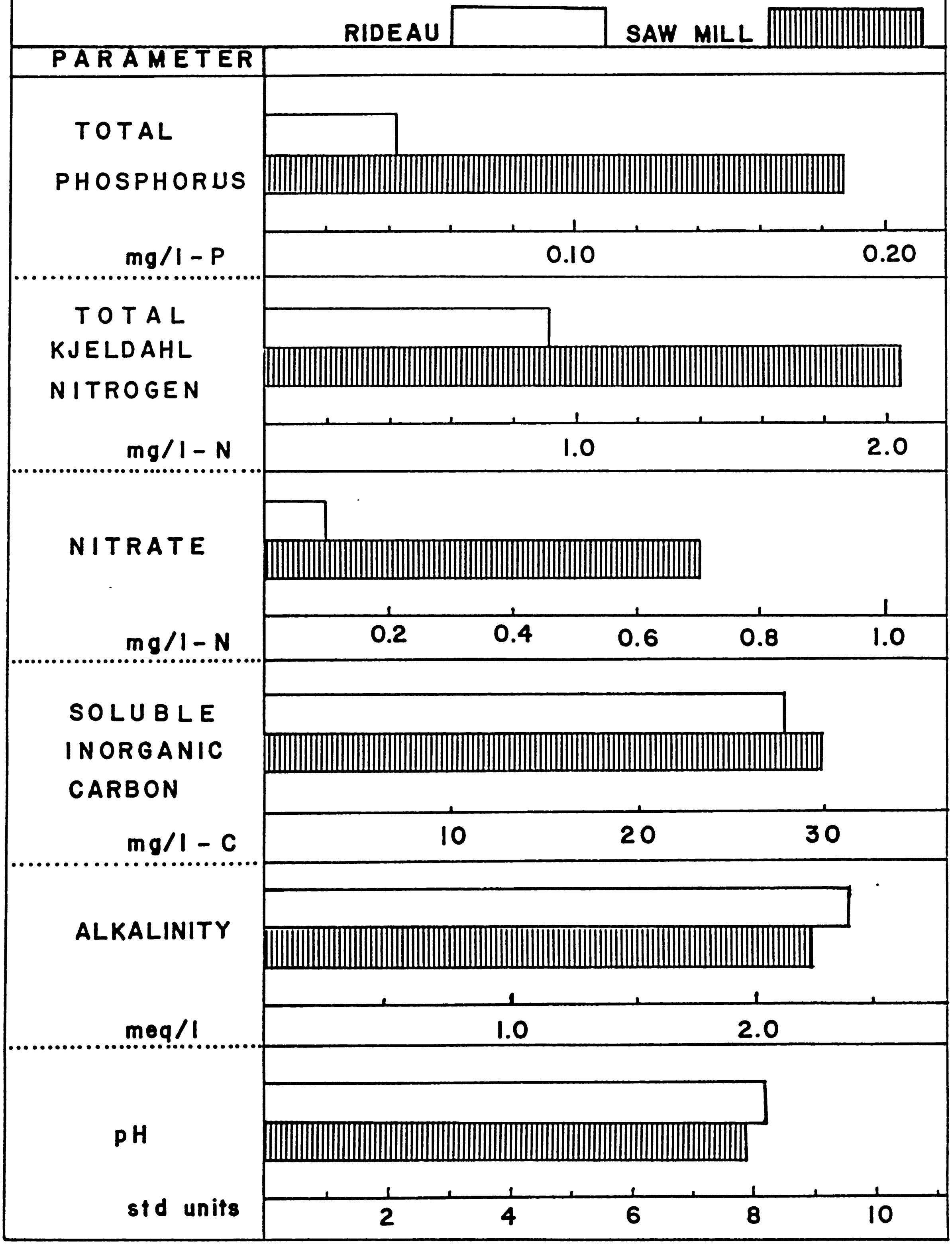
6.1 Chemical Characterization

Figure 6.1 compares the average parameter concentrations found at peak flow in Saw Mill Creek with the average Rideau River parameter concentrations. The Rideau River values for Total Phosphorus (TP) and Total Nitrogen (TN) have been considered within the growth limiting range given by Vollenweider (49). Therefore, any addition of either or both TP and TN to the Rideau could cause an increase of algal productivity. Soluble Inorganic Carbon (SIC) far exceeds the requirements of algae, and could therefore be considered non-limiting. From Figure 6.1 it becomes obvious that the two parameters which could cause increased algal growth due to Saw Mill Creek are TP and TN, while SIC is nearly of the same concentration in both the Rideau and Saw Mill.

The influent TN is approximately twice that of the Rideau, while TP is over four times greater. While these concentrations appear to have shock loading capabilities under high flow rate conditions, it must be remembered that these conditions rarely exist for long periods during summer storms.

Furthermore, as Saw Mill Creek mixes with the Rideau, the

FIGURE 6.1 COMPARISON OF AVERAGE CHEMICAL CONCENTRATIONS DURING PEAK FLOW IN SAW MILL CK. AND RIDEAU RIVER.



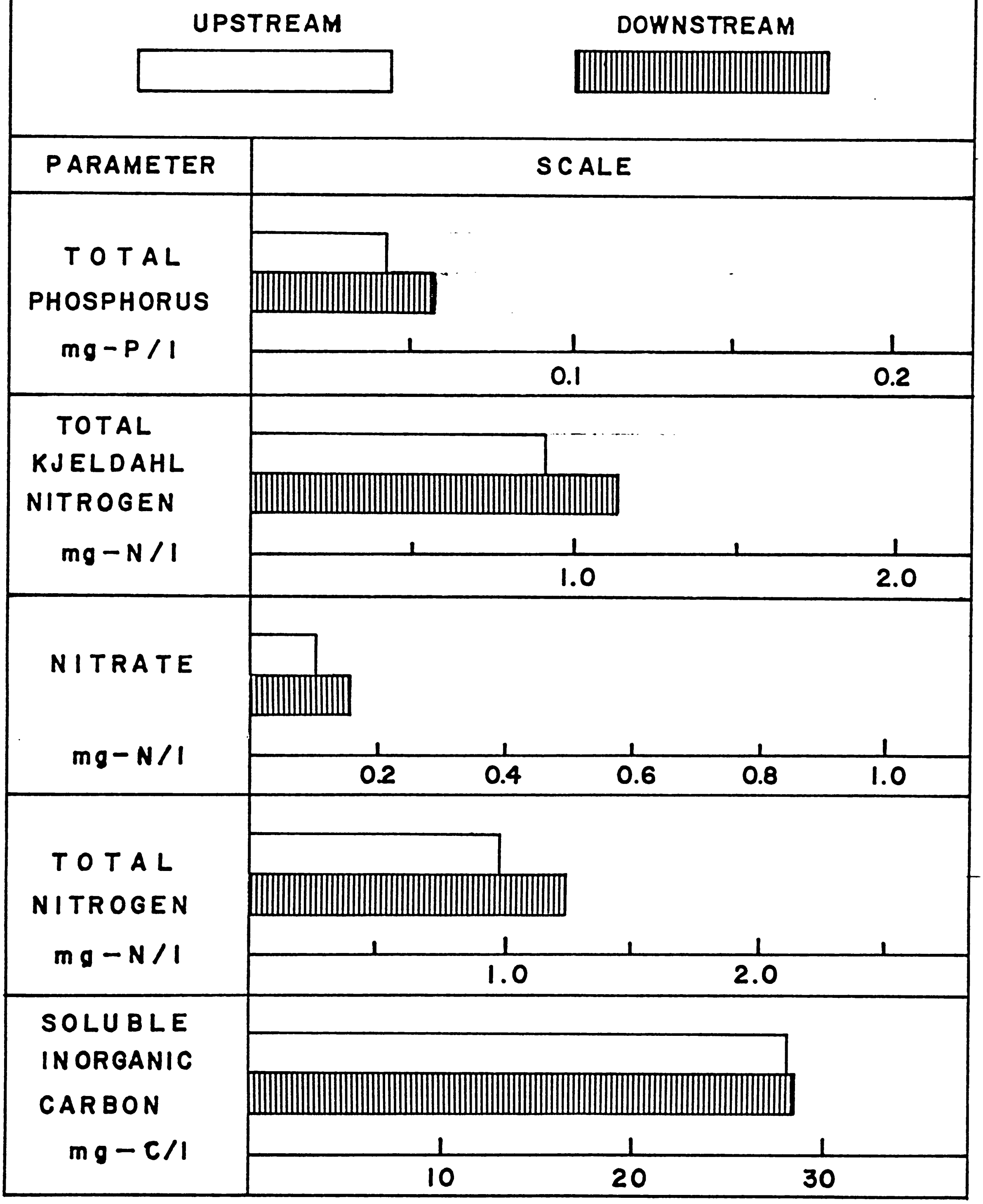
increased concentrations of nutrients become diluted. Figure 6.2 compares the Rideau River nutrient concentrations upstream of Saw Mill Creek with the completely mixed concentrations after being joined by Saw Mill Creek.

Under the complete mix assumptions, the increase in concentration of all parameters is small. The increased values of TP, TN and NO_3 due to the influent Saw Mill Creek are all within experimental error of the corresponding average parameter measured in the Rideau upstream of the Saw Mill Creek entrance. Although the assumption of complete mixing of Saw Mill Creek with the Rideau has been made, its only purpose is to serve as a basis for making comparisons. Transverse mixing is never fully attained within the Rideau system.

For any given flow, it is expected that near the bank outfall, concentrations will be greater than those expected under complete mix conditions. Moving further to the centre of the channel, nutrient concentrations would decrease when compared to those of the complete mix assumption. Once the mixing characteristics of the outfall have been defined, a more complete analysis of the problem is possible.

Upon entering the slow moving waters of the Rideau, Saw Mill Creek must reduce its suspended load. Sedimentation of the particulate nutrients, occurring simultaneously with the mixing process, could be considered a lowering of the nutrient concentrations in the deep sections of the channel, while increasing the nutrient concentrations of the shallower

FIG. 6.2 COMPARISON OF UPSTREAM AND DOWNSTREAM NUTRIENT CONCENTRATIONS (ASSUMING COMPLETE MIXING OF SAW MILL)



sections. Sedimentation, particularly where a large proportion of the nutrients are associated with the suspended solids, can concentrate nutrients in the confluence region of an inlet such as Saw Mill Creek. As well as the sediment and associated particulate nutrients supplied by Saw Mill Creek, the sediments of the Rideau River may play an important role in the depletion and supply of nutrients for algal growth.

In this experiment, the suspended solids were not removed prior to the bioassay analysis. Thus the effect of the particulate nutrients is included with the bioassay results. However, no attempt was made to account for the source-sink phenomenon of the already present Rideau sediments. As a result the algal growth recorded represented the maximum expected for that particular addition ratio, assuming the sediments of the Rideau to have no effect.

6.2 Bioassay Response Analysis

From the preceding section, it may be concluded that nutrient enrichment of the Rideau River occurs during storm flow periods, when both flow and concentrations of nutrients in Saw Mill Creek are high. Discussion of the nutrient enrichment leads to the question of how the increased nutrient concentrations affect algal growth. In this respect, algal bioassays have been an invaluable tool for estimating the resultant increased algal growth.

The 6-day standing algal biomasses for the various additions and treatments were analyzed for significant differences using the F-ratio test. Results of the comparisons are shown in Figure 6.3 where the calculated F-values are tested against the critical values at the 95 percent confidence limits. A significant difference is considered to exist, i.e., the null hypothesis must be rejected if the calculated value exceeds the critical. The calculated F-value has less than a 5 percent random chance of being greater than the critical, and no significant difference existing ($\alpha < 0.05$). Also, the calculated F-value has less than a 5 percent random chance of being less than the critical value, and a significant difference existing ($\beta < 0.05$) (see section 4.8).

To ensure that a significant difference could be detected, all samples were compared with the control growth sample (100 percent Saw Mill Creek). The shaded areas in Figure 6.3 indicate the comparisons where a significant difference was found, while the non-shaded area indicates no significant difference had been detected.

Figure 6.3 shows a significant difference to exist for all comparisons with the control samples, thus the experimental design was successful. Significant differences were also found between the comparisons of the Rideau biomasses with the biomasses of the 10 and 20 percent additions. The Rideau samples had an average 6-day biomass of 0.50 mg/l, while the 10 and 20 percent additions produced an average 6-day biomass of 0.96 mg/l and 1.96 mg/l, respectively. All other comparisons had no significant difference detectable.

FIGURE 6.3 RESULTS OF THE ANALYSIS OF VARIANCE.

COMPARISON OF CALCULATED F-VALUES WITH THOSE CRITICAL AT A PROBABILITY P = 0.95

H_0: THERE IS NO SIGNIFICANT DIFFERENCE BETWEEN

VARIABLE "A" → WHEN COMPARED TO VARIABLE "B". ↓	CONTROL	RIDEAU	UNTREATED 20 %	UNTREATED 10 %	UNTREATED 5 %
RIDEAU	4.96 28.0 ▨				
UNTREATED 20 %	4.96 8.15 ▨	4.96 6.18 ▨			
UNTREATED 10 %	4.96 11.3 ▨	4.96 5.85 ▨			
UNTREATED 5 %	4.96 12.1 ▨	4.96 1.17			
TREATED 20 %	4.96 11.5 ▨	4.96 1.03	4.96 3.41		
TREATED 10 %	4.96 11.6 ▨	4.96 1.10		4.96 1.99	
TREATED 5 %	4.96 11.8 ▨	242 198			242 178

H_0 ~ ACCEPTED ☐ ~REJECTED ▨

Because significant differences were indicated for the biomasses of the 10 and 20 percent additions, correlation analysis was considered appropriate. In Figure 6.4, the percent addition is correlated with the corresponding average 6-day biomass. The relationship is extremely strong, as is indicated by the correlation coefficient (r) of 0.99, which is significant at $P < 0.01$. It was presumed that the increase in biomass was due to the increased concentrations of nutrients in the larger additions of Saw Mill Creek water.

To test this assumption, the nutrient concentrations were correlated with the corresponding 6-day algal biomasses. The least squares analyses of the correlations are shown in Figures 6.5, 6.6, 6.7 and 6.8. Statistics are summarized in Table 6.1.

Nitrogen and phosphorus parameters demonstrate a significant positive relationship with the 6-day algal biomass. Soluble Inorganic Carbon, on the other hand, showed a weak negative correlation, suggesting that it is non-limiting in both the Saw Mill and the Rideau. The addition of nitrogen and/or phosphorus from Saw Mill Creek could increase the algal growth in the Rideau. The resulting increase was significant in storm water additions of 10 percent or greater to the Rideau flow. Because the design of the experiments was not intended for determining the limiting nutrient, further discussion could not be warranted.

Since phosphorus has been considered limiting, its removal with alum, and subsequent reduction of other nutrients associated

FIG. 6.4 EFFECT OF DILUTION ON ALGAL BIOMASS

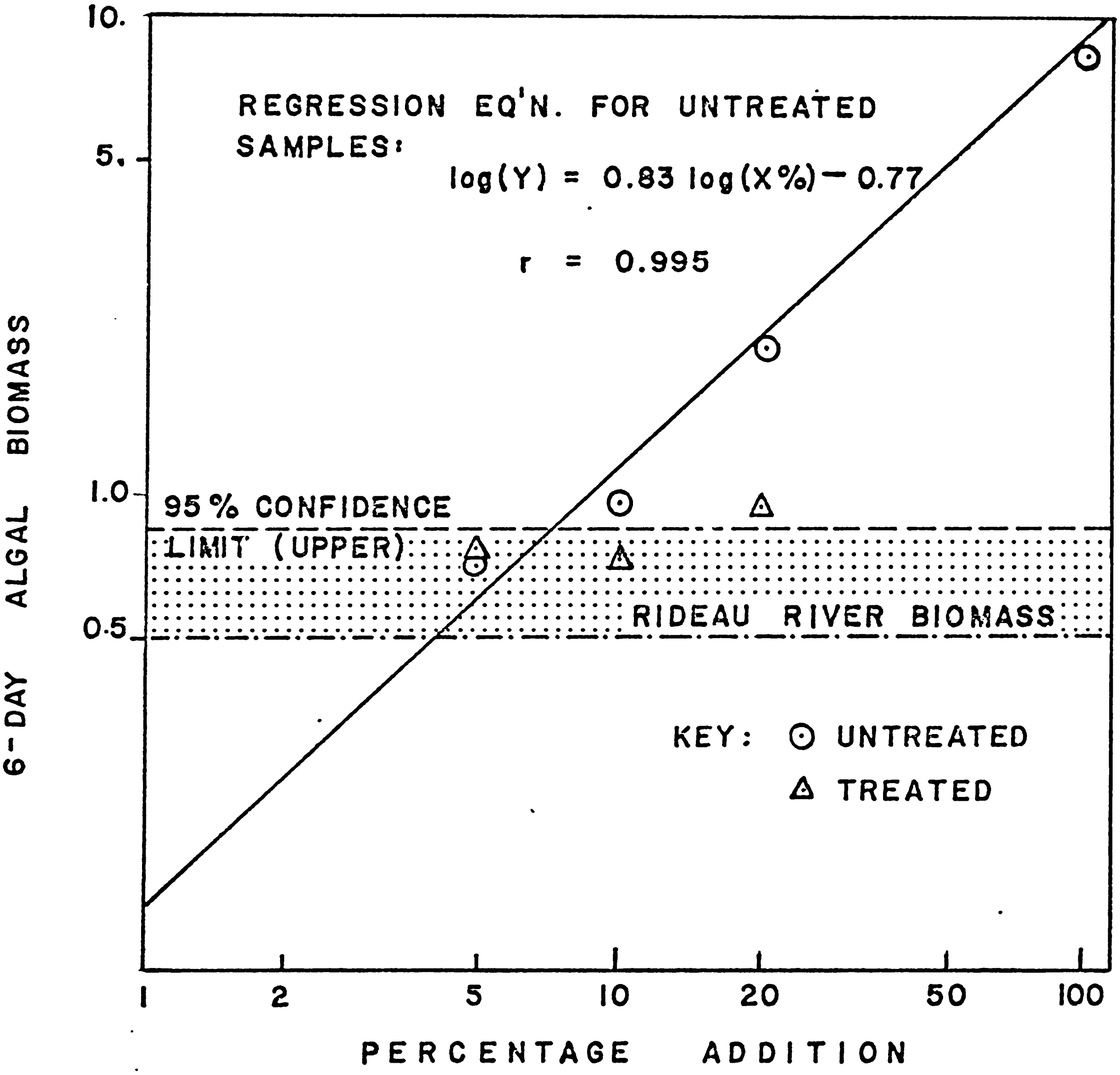
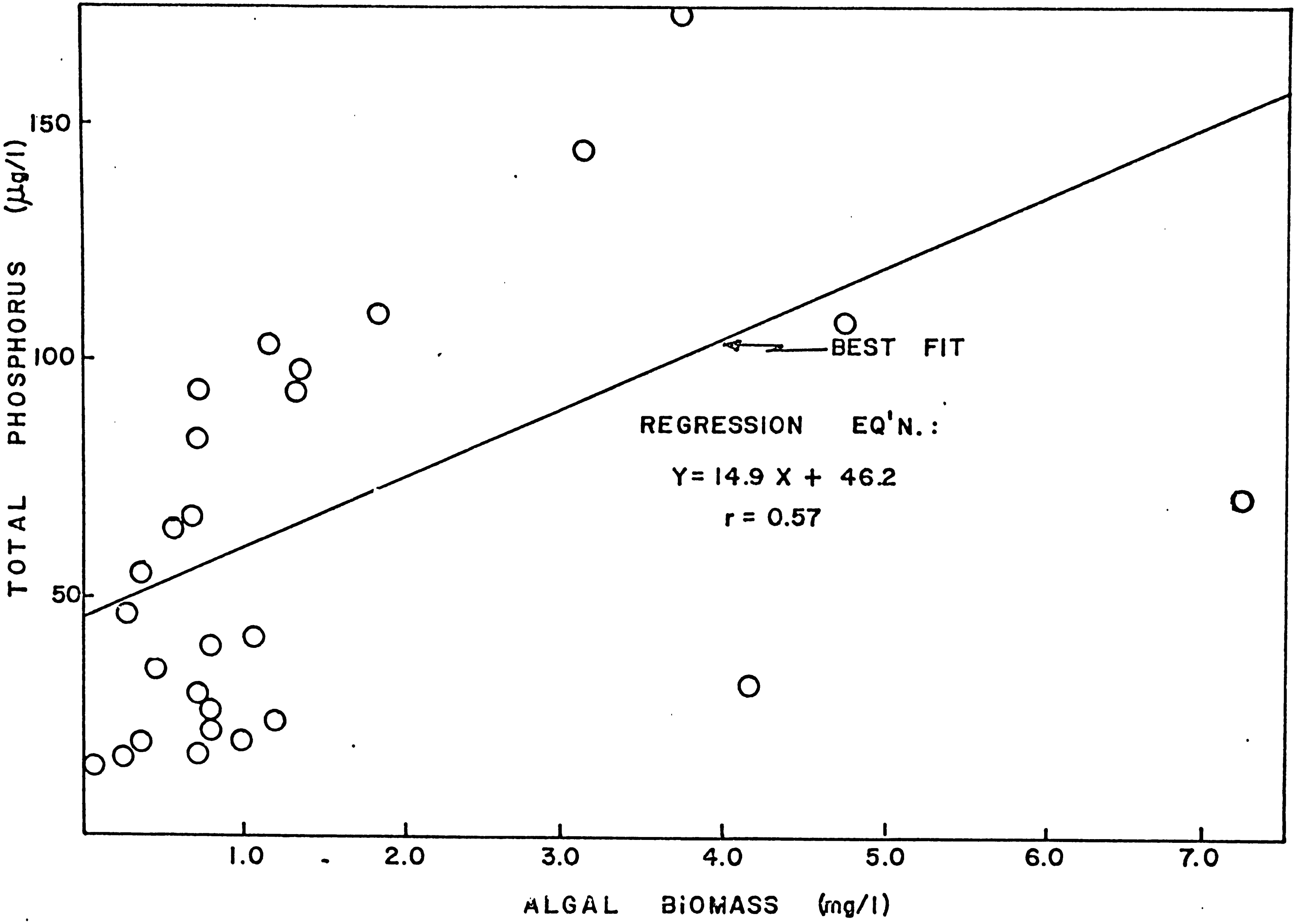


FIG. 6.5 TOTAL PHOSPHORUS VS 6-DAY ALGAL BIOMASS



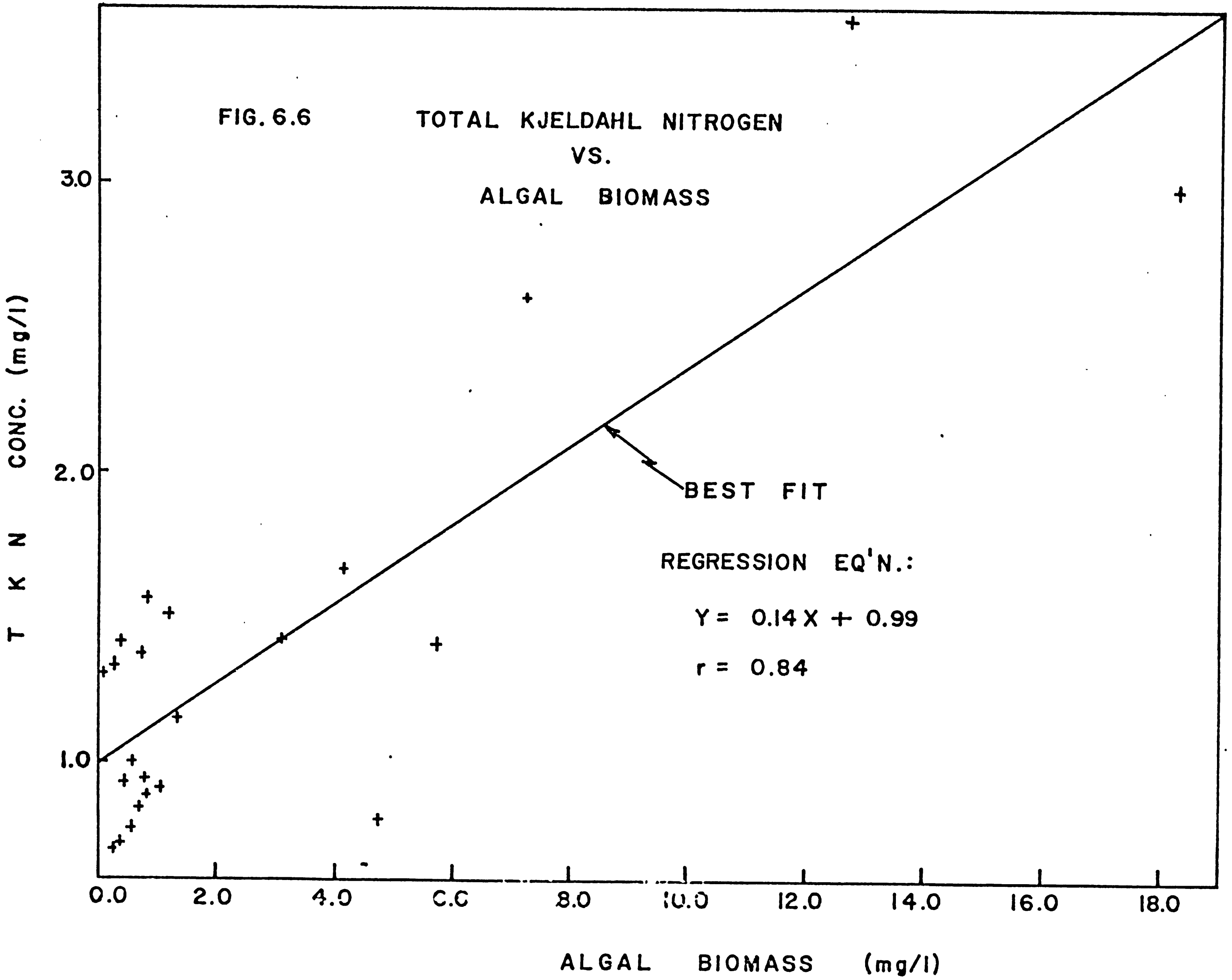


FIG. 6.6 TOTAL KJELDAHL NITROGEN VS. ALGAL BIOMASS

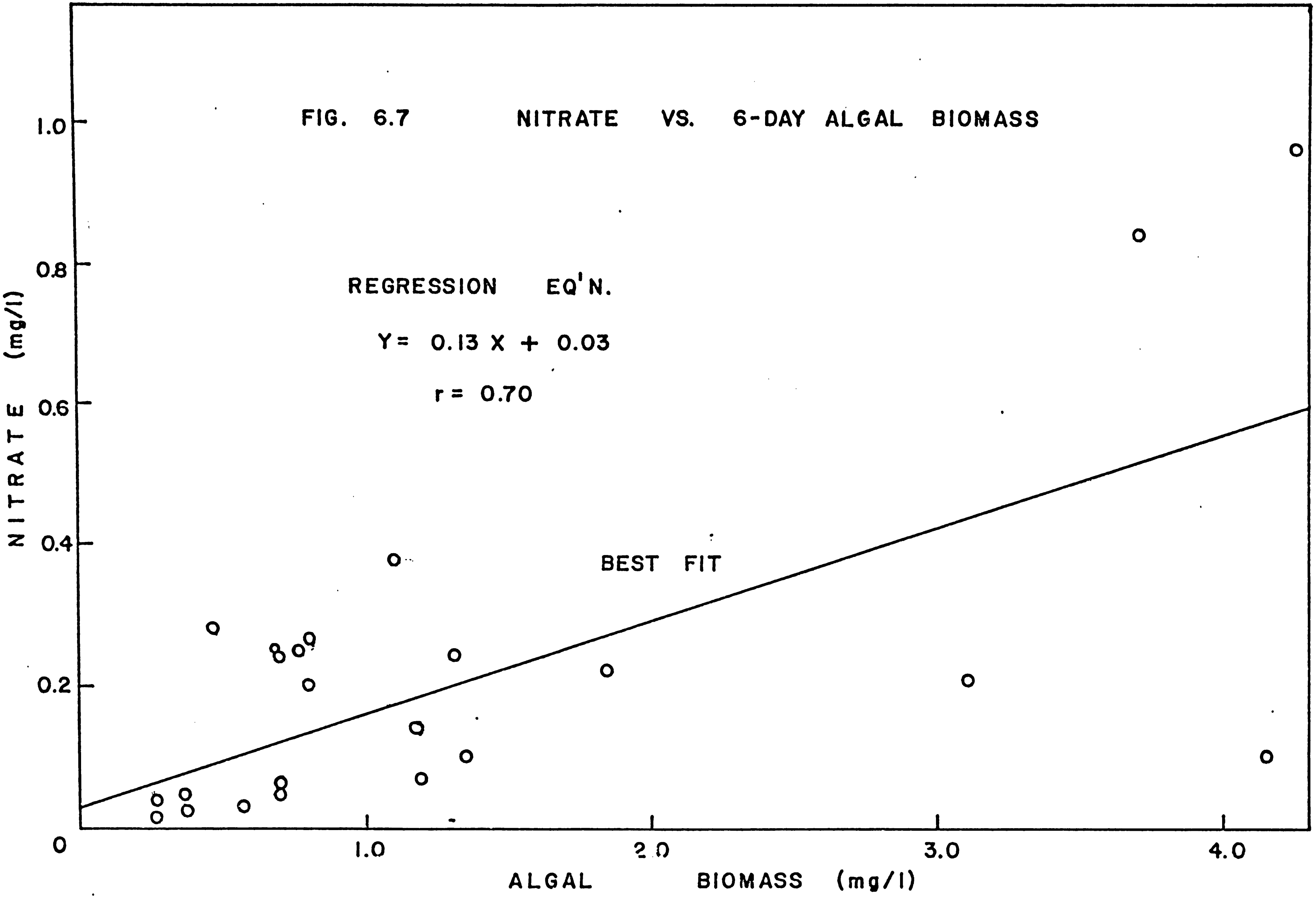


FIG. 6.7 NITRATE VS. 6-DAY ALGAL BIOMASS

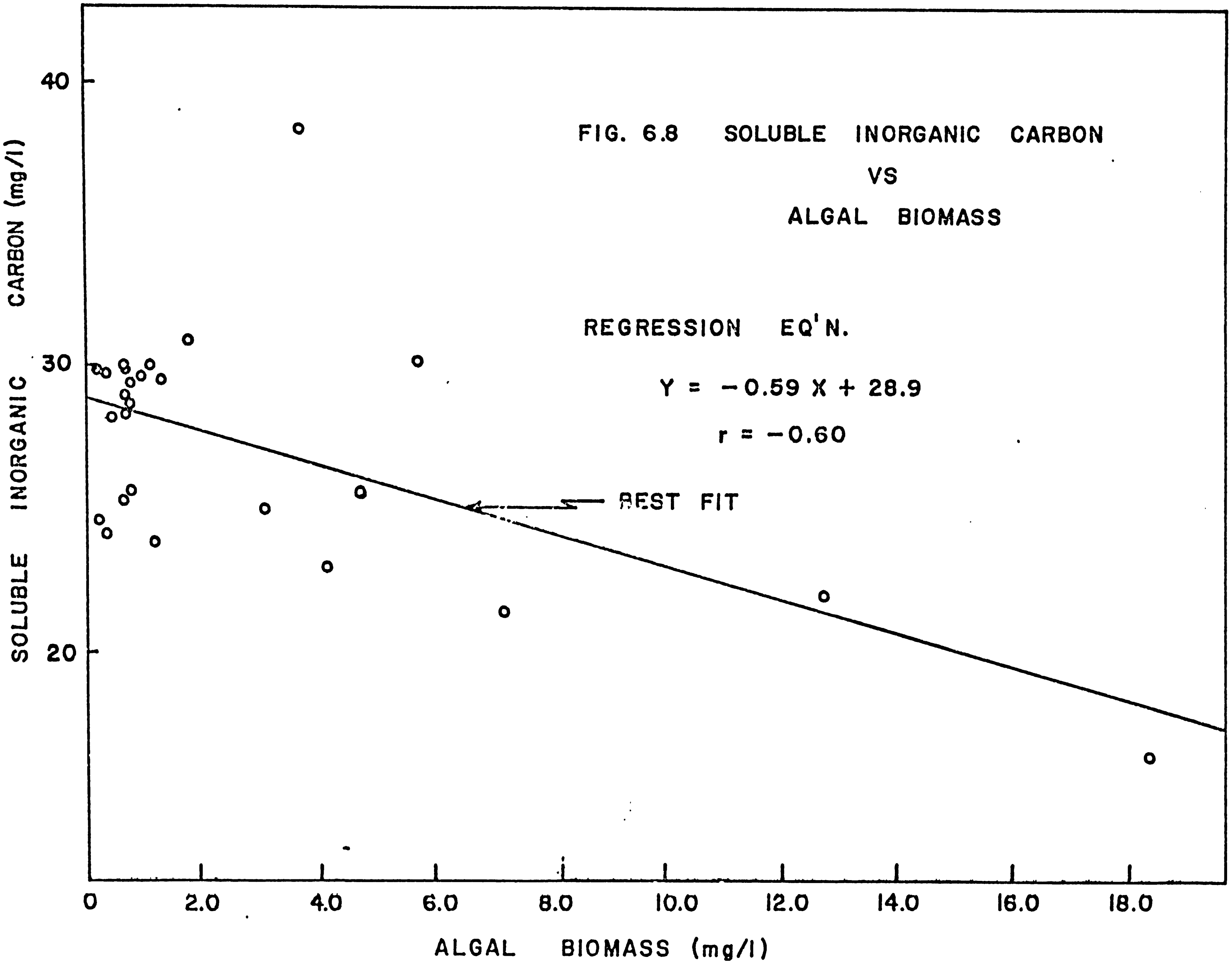


FIG. 6.8 SOLUBLE INORGANIC CARBON VS ALGAL BIOMASS

REGRESSION EQ'N.

$Y = -0.59\ X + 28.9$

$r = -0.60$

Table 6.1 Summary of Regression Analysis Statistics

Statistic	Parameter TP	TKN	NO_3	SIC
Slope $\frac{\text{mg nutrient}}{\text{mg algae}}$	0.015	0.24	0.13	-0.59
Correlation Coefficient (r)	0.57	0.84	0.70	-0.60
Coefficient of Variation (r^2)	0.33	0.71	0.49	0.35
Calculated Student's t	3.67	7.42	4.38	-
Critical t Value	2.47	2.50	2.53	-
Degrees of Freedom (d_f)	28	23	20	-

with the suspended solids could reduce algal growth. Because the 10 and 20 percent additions of untreated Saw Mill Creek water produced significantly greater algal biomasses than the Rideau samples, while the 10 and 20 percent treated additions produced biomasses that were not significantly different from the Rideau sample biomasses, treatment was considered to have some degree of success in reducing algal growth. However, when the treated samples were compared to their respective untreated additions, no significant difference was found. Thus, treatment did not result in any significant improvement over the natural situation.

It must be noted here that the 5 percent addition, treated or untreated, did not produce significantly greater algal biomass than the Rideau samples. In fact, the average untreated sample biomass was 0.71 mg/l, virtually the same as the treated biomass of 0.78 mg/l. This indicates that dilution was as effective in reducing algal growth as was treatment.

During the experimental period, the flow ratio of the peak Saw Mill to Rideau averaged 9 percent, but never exceeded 13 percent. Hauck (21) recorded an average wet weather flow of 25 cfs, which corresponds to a flow ratio of 8.3 percent when compared with the average 1975 summer flow in the Rideau.

During dry weather, the average flow in Saw Mill Creek recorded in 1975 and 1974 by Hauck (21) was 3.8 cfs. This represents 1.2 percent of the average summer flow in the Rideau.

The calculated flow ratios correspond to the complete mix assumption. Thus, for a given flow ratio, sections of the Rideau will be under the influence of a higher percentage addition of Saw Mill Creek water, while other sections will be under a lower percentage influence of Saw Mill Creek. It must be noted that the spatial average will equal that of the calculated complete mix flow ratio. The higher the average percentage addition of Saw Mill Creek, the higher the localized maximum percentage ratio of Saw Mill Creek water (assuming mixing characteristics do not change from one flow event to the next).

6.3 Summary

Storm flows in Saw Mill Creek are capable of supplying sufficient nutrients to cause significant algal growth in the Rideau River. The average maximum concentration of TP is 0.190 mg/l and of TN, 2.5 mg/l. Part of this nutrient concentration is lost by sedimentation upon entry to the Rideau, and therefore it is suspected that the bioassay used in the experiment actually over-estimated the increased algal growth, except in the shallow sections of the Rideau where sediments play a large role in the supply of nutrients. The 10 and 20 percent additions of Saw Mill Creek water produced average 6-day biomasses of 0.96 mg/l and 1.96 mg/l, respectively. These were significantly greater than the 6-day biomass of 0.50 mg/l produced by the Rideau River.

In sections of the Rideau River where the addition ratio is 5 percent or less, the quantity of dilution water supplied by the Rideau is sufficient to render the 6-day algal biomass statistically equivalent to that of the Rideau sample biomass. Therefore, the increased nutrient concentrations in flows where localized maximum addition of Saw Mill Creek water does not exceed 5 percent, would have little effect on algal growth in the Rideau.

Treatment of samples for phosphorus removal (85 percent average removal of TP) only minimally reduced algal growth in the 10 and 20 percent addition samples. At the 5 percent addition level, treatment and dilution yielded virtually the same mean algal biomass, indicating that alum treatment was incapable of reducing algal growth during flows of 5 percent or less.

Reduction of any loading of nitrogen and phosphorus to the Rideau would not necessarily reduce algal growth. The algal growth rate, μ, is a function of the rate limiting nutrient concentration (Section 3.2), S. Therefore, it is the increase in concentration of that nutrient due to Saw Mill Creek, not the load which adversely affects algal growth in the Rideau. If sufficient dilution water is available, e.g., 5 percent addition, then the increased growth rate, and consequently the 6-day algal biomass, is insignificant. At high concentrations of nutrient, the increased growth rate would produce a 6-day biomass significantly greater than the unenriched receiving water, e.g., 10 and 20 percent additions.

Thus, increased algal growth is not just a question of nutrient loading, but also relies on the mixing characteristics of the receiving water as well as the quantity of the dilution water available.

CHAPTER 7

CONCLUSIONS

The conclusions are based upon batch algal bioassays conducted from July through September of 1976. Samples for the bioassays were collected at peak storm flows in Saw Mill Creek, and therefore represent nutrient concentrations at elevated levels. Rideau River samples were collected shortly thereafter. All samples were chemically characterized. Thus, it was concluded that:

(1) Algal bioassays are a valuable technique in the analysis of the eutrophication of a receiving water by urban drainage water.

(2) Saw Mill Creek can have significant effects on the algal growth in the Rideau River during peak flow conditions when both nutrient concentrations and flow ratios are high.

(3) At addition ratios of 5 percent or less, which probably include most dry weather flows, Saw Mill Creek has no significant effect on algal growth in the Rideau.

(4) Alum removal of phosphorus from Saw Mill Creek water does not significantly reduce algal growth in the Rideau.

CHAPTER 8

SIGNIFICANCE AND RECOMMENDATIONS

8.1 Engineering Significance

Concentrations of the nutrients, nitrogen and phosphorus in the Rideau could be considered limiting, and therefore the addition of these nutrients from Saw Mill Creek have the ability to increase algal growth in the river. Certainly a significant increase in growth is observed at the 10 and 20 percent additions of Saw Mill Creek water to Rideau River water. However, because the occurrence of these conditions is expected to be most severe during high flow periods, it is recommended that particular concern be given to storm flow conditions, if any abatement for Saw Mill Creek is to be considered at all.

Primary consideration should be given to the reduction of storm flow in Saw Mill Creek, as well as other urban drainage waterways to the Rideau. In areas under the planning stage, the zero increase in runoff should be incorporated into the design of the subdivision. In already developed areas, reduction in runoff could be achieved in several ways:

(1) Roof leaders should be disconnected from direct connection

with storm sewers, (2) In areas of high imperviousness, installation of controlled flow roof drains will utilize the extra storage space on roofs, (3) In more pervious areas, green space should be used to its fullest infiltration capacity.

The main benefit of storm flow reduction is in reducing the concentration of nutrients, as well as other pollutants, especially those of the particulate form. The decreased mass of runoff would have less kinetic energy available for the transport of all pollutants from the land surface to the waterway. Decrease in the concentration of nutrients would decrease the eutrophication potential of the drainage water.

Reduction of flow would have the secondary benefit in increasing the quantity of dilution water available in the Rideau. Just as was demonstrated by the 5 percent addition bioassay, dilution to this level would result in a biomass that was not significantly different from that of the Rideau.

8.2 Recommendations

In view of the preceding discussion the following recommendations are made:

(1) The feasibility of reducing storm flow volumes by non-structural methods for Saw Mill Creek should be investigated.

(2) Further investigation of other pollutants in urban drainage water flowing into the Rideau should be undertaken.

(3) The public, particularly homeowners, should be informed of the effects of storm drainage in order that they may understand how the problems might be alleviated.

(4) Mixing characteristics of Saw Mill Creek should be examined. In the distance that the complete mixing assumption can be made, algal growth due to Saw Mill Creek will have already created a problem in the Rideau.

(5) Frequency and duration of storm events should be calculated for Saw Mill, as well as other urban drainage waterways.

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APPENDIX I
Calculation of Significant Difference for Rideau River Chlorophyll a Measurements

Data collected by Middleton and Adamowski (1) was partitioned into two groups by the geographic locations of sampling location, i.e., the reaches within the Regional Municipality of Ottawa-Carleton (downstream) and those reaches outside of the Region (upstream). Calculations for the F-ratio were made as follows :

		$\bar{x}$	s	s^2	n	sum of squares
A	Upstream	15.1 mg/m³	8.59	71.52	32	2288.6
B	Downstream	21.5 mg/m³	9.61	88.64	25	2216.0
	Total	17.9	9.53	89.64	57	5084.4

$$\text{Within sample sum of squares (WSS)} = (s_a^2 \times n_a) + (s_b^2 \times n_b)$$
$$= 4505$$

To obtain the Between Samples Sum of Squares (BSS), the equation :

$$\begin{aligned} \text{BSS} &= \text{TSS} - \text{WSS} \\ &= 5084 - 4505 \\ &= 579 \end{aligned}$$

Now the analysis of variance data table is tabulated.

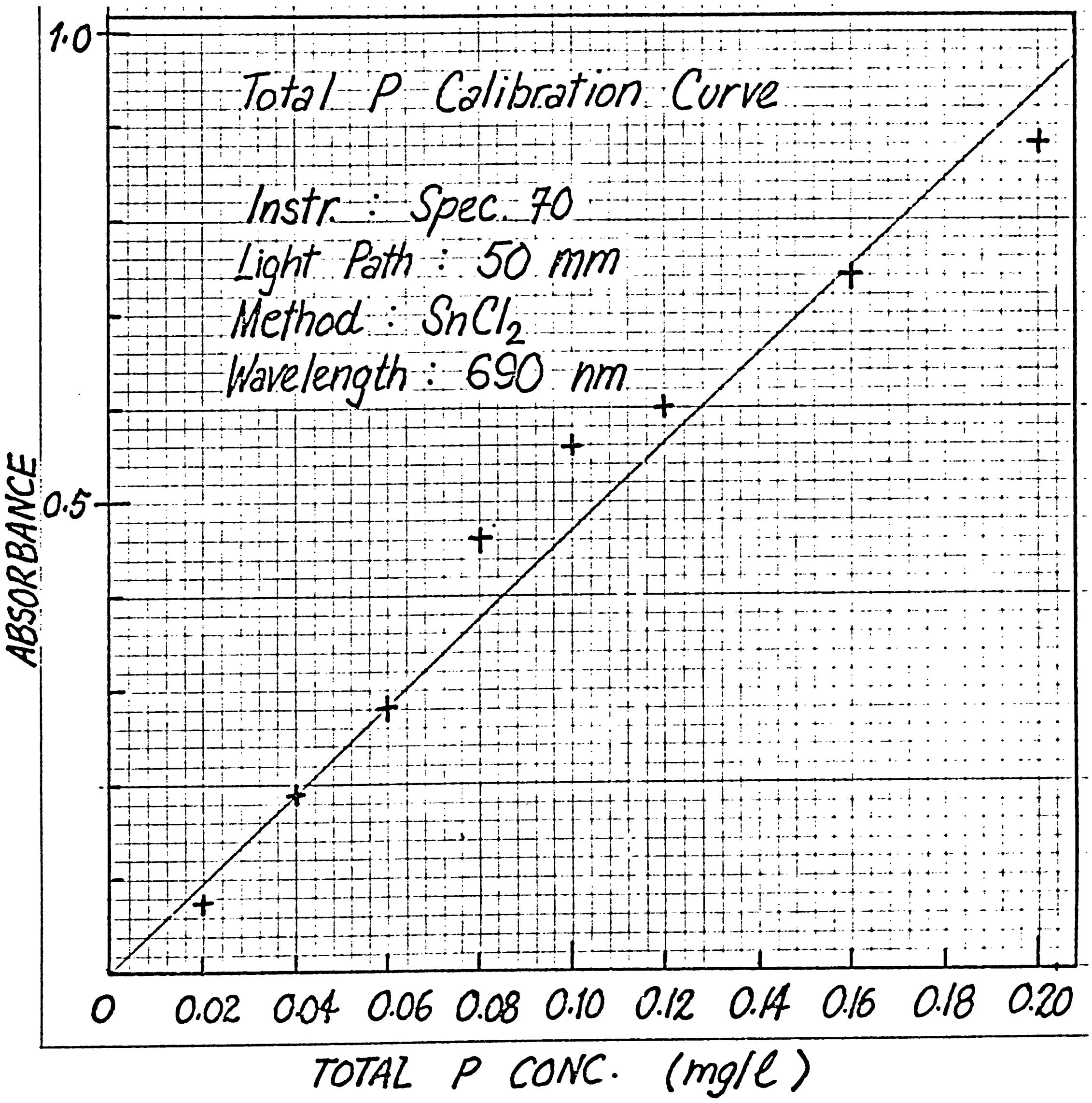
Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
BSS	579	1	579
WSS	4504.6	55	81.9
TSS	5084.4	56	-

$$\text{Thus, the calculated F-ratio} = \frac{579.8}{81.9} = 7.08$$

Since the calculated value exceeds the critical value at P 0.0 of F_{crit} = , the null hypothesis of no significant difference between the samples must be rejected.

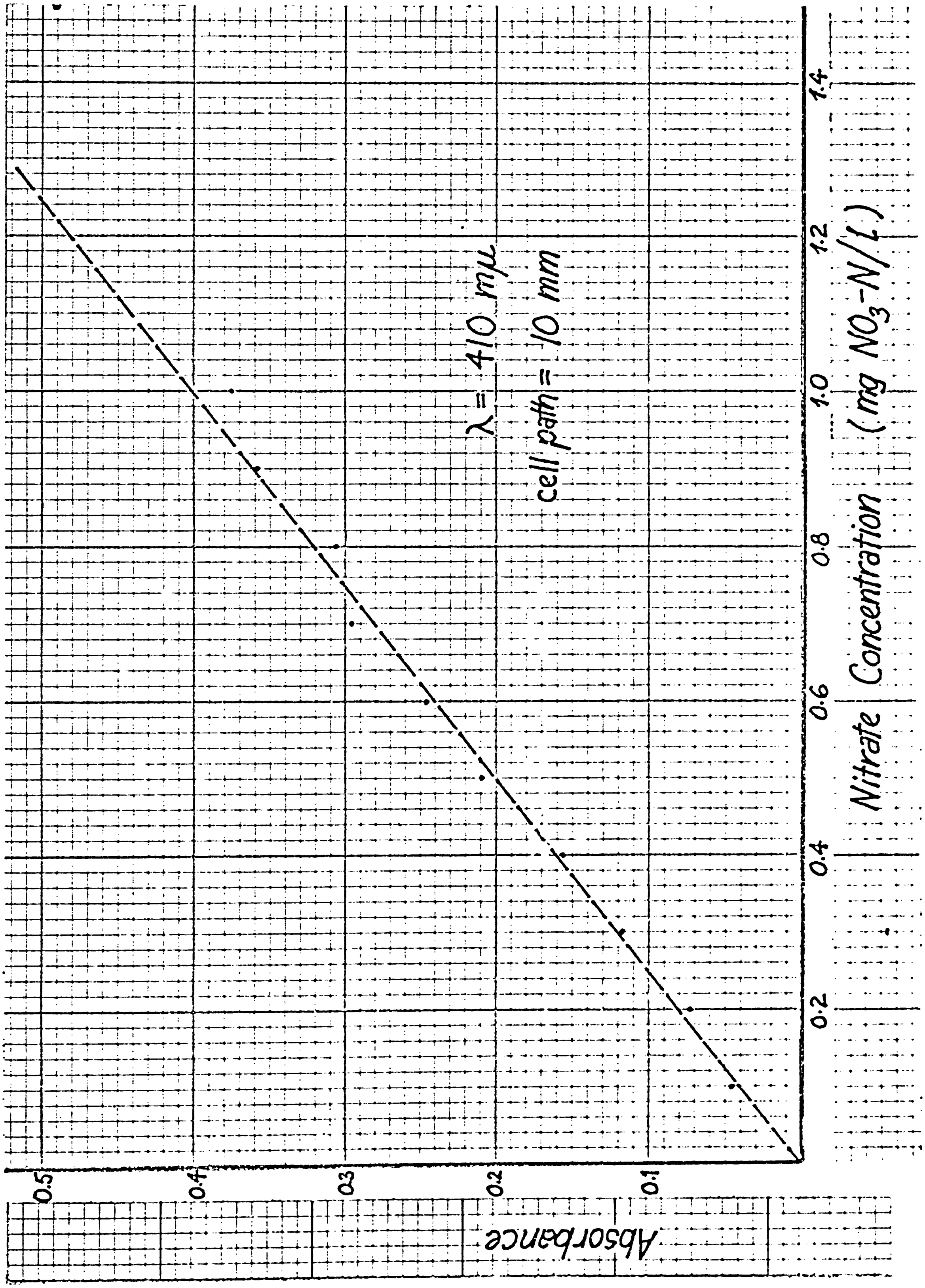
APPENDIX II

Phosphorus Calibration Curve



Appendix III

Nitrate Calibration Curve - Brucine Method



APPENDIX IV

Calculation of Soluble Inorganic Carbon

From the definition of alkalinity, we have

$$[ALK] = [HCO_3^-] + 2\,[CO_3^{-2}] + [OH^-] - [H^+] \qquad (1)$$

$$[ALK] = C_T\,(\alpha_1 + 2\,\alpha_2) + [OH^-] \quad [H^+] \qquad (2)$$

rearranging, it becomes

$$C_T = [ALK] - [OH^-] + [H^+] \,/(\alpha_1 + 2\,\alpha_2) \qquad (3)$$

where

$$\alpha_1 = \left(\frac{[H^+]}{K_1} + \frac{K_2}{[H^+]} + 1 \right)^{-1} \qquad (4)$$

$$\alpha_2 = \left(\frac{[H^+]}{K_1K_2} + \frac{[H^+]}{K_2} + 1 \right)^{-1} \qquad (5)$$

For every hydrogen ion concentration (pH), α_1 and α_2 were calculated, and then used in equation 3.

Since $K_w = [OH^-]\,[H^+]$ we may replace $[OH^-]$ with $K_w/[H^+]$.

Since the constants K_1, K_2 and K_w are somewhat temperature dependent, the average temperature of the Rideau (21°C) and of Saw Mill Creek (17°C) were used in the appropriate calculation or chosing of these constants.

$$\log K_w = 4470.99/T + 6.0875 - 0.01706$$

$$K_1 = 4.22 \times 10^{-7} \qquad 21^\circ\ C$$

$$= 3.95 \times 10^{-7} \qquad 17^\circ\ C$$

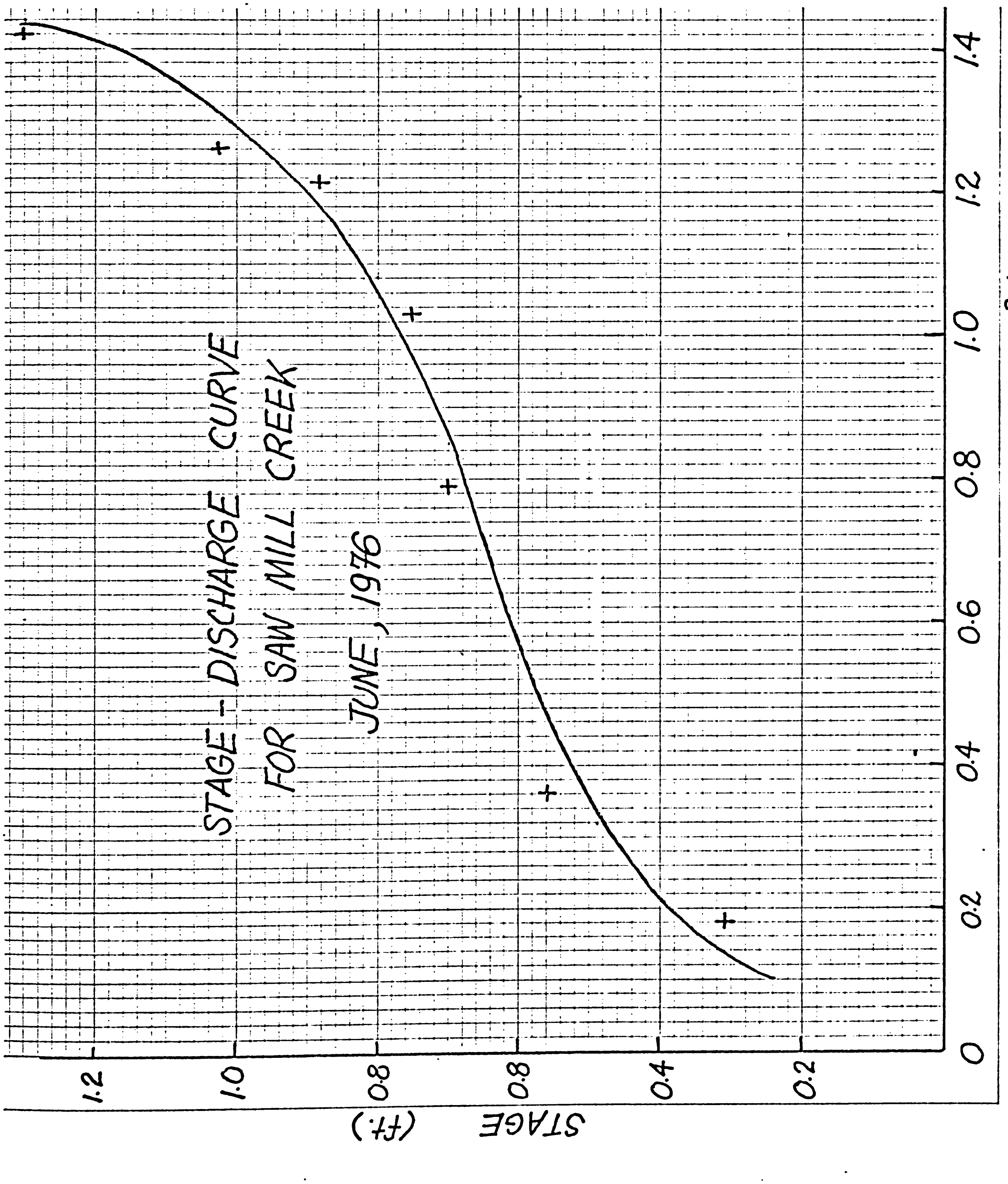
$$K_2 = 4.30 \times 10^{-11} \qquad 21^\circ\ C$$

$$= 3.91 \times 10^{-11} \qquad 17^\circ\ C$$

Ionic strengths of the samples were considered negligible and therefore no correction was required.

APPENDIX V

Stage-discharge Curve for Saw Mill Creek



APPENDIX VI

Calculation of F-ratios for Various Treatments

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : Rideau with Saw Mill (Control)

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	205344	1	205,344
Within Sample	73355	10	7,335
Total	278,699	11	-

Calculated F-Ratio = $\frac{205,344}{7,336}$ = 28.0

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 10% Untreated with Saw Mill (Control)

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	182,769	1	182,769
Within Sample	161,624	10	16,162
Total	344,394	11	-

Calculated F-Ratio = $\frac{182,769}{16,162}$ = 11.3

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 20 % Untreated with Saw Mill (Control)

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	139,200	1	139,200
Within Samples	170,760	10	17,076
Total	309,960	11	-

Calculated F-Ratio = $\frac{139,200}{17,076}$ = 8.15

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 5% Untreated with Saw Mill (Control)

Source of Variance	Sum of Squares.	Degrees of Freedom	Variance Estimate
Between Samples	195,100	1	195,100
Within Sample	161,400	10	16,140
Total	356,500	11	-

Calculated F-Ratio = $\frac{195{,}100}{16{,}140}$ = 12.1

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 20 % treated with Saw Mill (Control)

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	189,000	1	189,000
Within Sample	163,700	10	16,370
Total	352,700	11	-

Calculated F-Ratio = $\frac{189{,}000}{16{,}370}$ = 11.5

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 10 % Treated with Saw Mill (Control)

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	175,430	1	175,430
Within Samples	151,200	10	15,120
Total	326,630	11	-

Calculated F-Ratio = $\frac{175{,}430}{15{,}120}$ = 11.6

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 5 % Treated with Saw Mill (Control)

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	191,700	1	191,700
Within Sample	161,400	10	16,140
Total	353,100	11	-

$$\text{Calculated F-Ratio} = \frac{191,700}{16,140} = 11.9$$

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 20 % Untreated with Rideau

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	6411	1	6411
Within Sample	10365	10	1037
Total	16776	11	-

$$\text{Calculated F-Ratio} = \frac{6411}{1037} = 6.18$$

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 10 % Untreated with Rideau

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	657,531	1	657,531
Within Samples	1,123,216	10	112,322
Total	1,780,748	11	-

$$\text{Calculated F-Ratio} = \frac{657,531}{112,322} = 5.85$$

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 5 % Untreated with Rideau

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	134,620	1	134,620
Within Sample	1,148,854	10	114,885
Total	1283,475	11	-

$$\text{Calculated F-Ratio} = \frac{134,620}{114,885} = 1.17$$

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 20 % Treated with Rideau

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	340,033	1	340,033
Within Sample	3,289,934	10	328,993
Total	3,629,967	11	-

$$\text{Calculated F-Ratio} = \frac{340,033}{328,993} = 1.03$$

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 10 % Treated with Rideau

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	260,520	1	260,520
Within Samples	2,368,400	10	236,840
Total	2,629,920	11	-

$$\text{Calculated F-Ratio} = \frac{260,520}{236,840} = 1.10$$

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 5% Treated with Rideau

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	856	1	856
Within Sample	1,694,900	10	169,490
Total	1,695,760	11	-

Calculated F-Ratio $= \frac{856}{169{,}490} =$ 198

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 20 % Treated with 20 % Untreated

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples.	5,547	1	5547
Within Sample	16,295	10	1630
Total	21,842	11	-

Calculated F-Ratio $= \frac{5547}{1630} =$ 3.41

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 10 % Treated with 10 % Untreated

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	1999	1	1999
Within Samples	10,057	10	1006
Total	12,056	11	-

Calculated F-Ratio $= \frac{1999}{1006} =$ 1.99

Analysis of Variance Data Table

Variable : 6-Day Algal Biomass

Comparison : 5% Treated with 5% Untreated

Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate
Between Samples	482	1	482
Within Sample	816,500	10	81,650
Total	817,000	11	-

Calculated F-Ratio = $\frac{81,650}{482}$ = 170.1

APPENDIX VII

Calculation of Mixing Distance for the Rideau

Holley *et al.* assumed a straight rectangular channel with a uniform velocity, a constant transverse diffusion coefficient and negligible longitudinal dispersion, and were able to reduce the two dimensional conservation of mass equation to obtain the longitudinal distance required for complete mixing of a source to the channel to occur. The analytical solution was:

$$\frac{x_m}{B} = \frac{0.445\ B}{\alpha\ H}$$

where x_m is the flow distance required for the material released at one bank to be come completely mixed wtih the flow; B is the width of the receiving stream and H is the depth; α is a constant which generally ranges from 0.02-0.04 for well defined river channels.

For the Rideau: $B = 110$ m
$H = 3$ m
$\alpha = 0.02$

thus $x_m = 89$ km

Holley states that this equation " should give order of magnitude estimates for x_m".