ENVIRONMENTAL PROTECTION SERVICE
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THE EFFECTS OF A SEWAGE LAGOON EFFLUENT ON THE WATER QUALITY OF THE COWICHAN RIVER DURING THE 1980 LOW FLOW PERIOD PLUS AN EVALUATION OF THE LAGOON'S BACTERIOLOGICAL REDUCTION PERFORMANCE AND EFFLUENT TOXICITY

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ABSTRACT

The water quality of the Cowichan River was monitored over the summer low flow period of 1979 and 1980. During August and September, 1980 the impact of the Duncan-North Cowichan sewage discharge was monitored. The discharge dramatically increased nutrient levels in the river and stimulated a large algal bloom. Intragravel dissolved oxygen levels were significantly lower downstream of the outfall in August and September, 1980. An onsite flow-through bioassay showed the effluent to be non-toxic to resident juvenile coho salmon. The lagoon system provided adequate disinfection to reduce fecal coliform levels and no significant water quality deterioration in the river with respect to fecal coliforms was found. Nutrient control considerations are discussed.

RÉSUMÉ

La qualité de la rivière Cowichan a été surveillée pendant la période de débit réduit en 1979 et 1980. Durant août et sepembre 1980, le déversement des eaux usées de Duncan-North Cowichan a été surveillé. Le déversement a augmenté de beaucoup les niveaux de matières nutritives dans la rivière et a favorisé une prolifération d'algues. Les niveaux d'oxygène dissous dans l'eau des interstices du gravier étaient beaucoup plus bas en aval du point de déchargement en août et septembre 1980. Une bioanalyse en milieu dynamique effectuée sur place révélé que l'effluent était non toxique pour les jeunes saumons coho. Le système d'étangs de stabilisation assure une désinfection adéquate pour abaisser les niveaux de coliformes fécaux. On n'aconstaté aucune détérioration de la qualité de l'eau de la rivière en ce qui a trait aux coliformes fécaux. La question de contrôle des matières nutritives est traitée.

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SUMMARY AND CONCLUSIONS

The water quality of the Cowichan River was monitored during the summer low flow period of 1979 and 1980. The 1979 monitor was to collect background data prior to an expected discharge in the autumn of 1979 of sewage effluent from a new outfall in the Cowichan River. The new outfall was part of a joint program to combine the discharges from the City of Duncan and District of North Cowichan sewage lagoon treatment facilities. The 1980 monitor was originally expected to assess the impact over a complete summer period. However, due to problems with dechlorination parts availability and decisions to hold off the discharge date until the dechlorination equipment was working, the discharge didn't start until August 13, 1980. Thus, the discharge was monitored in August and September, 1980.

During the period the effluent discharge was being monitored, the mean Cowichan River flow was 5.2 m^3/s and the sewage flow was 0.062 m^3/s. The river flow was considered to be representative for the Cowichan River during the summer low flow period and the sewage flow was considered to be representative of present sewage flow volumes. The theoretical dilution was 84:1 assuming instantaneous complete mixing. Based on nutrient levels in the effluent and those monitored in the river, the 84:1 dilution potential was not reached until approximately 350 meters downstream. The dilution 150 meters downstream of the outfall was estimated to be approximately 35:1.

The Cowichan River was found to be very low in background dissolved nutrients. Mean total dissolved phosphorous (TDP) levels never exceeded 7.4 ug/l. Mean ammonia levels never exceeded 9.4 ug/l and at certain times ammonia levels at or near detectable levels (2 ug/l) were common. Mean nitrate-nitrite levels never exceeded 10.4 ug/l and for the most part levels were at or near detectable levels (2 ug/l). Compared to the Thompson Rivers, the TDP levels were not unlike those reported for the South and North Thompson Rivers where benthic algae were considered to show severe and intermediate phosphorous deficiency. Whereas the Thompson Rivers

have mean total dissolved inorganic nitrogen levels between 57 ug/l to 175 ug/l, concentrations in the Cowichan River were less than 2 ug/l to 17 ug/l. The ratio of the mean total dissolved inorganic nitrogen concentration to the mean total dissolved phosphorous concentration for the Thompson Rivers ranged from 18:1 to 46:1 and ratios for the Cowichan River never exceeded 4.1:1 . Ratios of N:P have been considered as useful in preliminary assessments of algal growth limitation. Waters containing N:P ratios <10 may be considered nitrogen limiting while those >10 may be phosphorous limiting to algal growth. Thus, the Cowichan would fall in the nitrogen limited criteria. The use of N:P ratios is by no means a rigid classification. Preliminary findings of an algal bioassay conducted by the Department of Fisheries and Oceans indicated both N and P were required in background water to stimulate an algal growth response.

The sewage discharge increased downstream TDP levels by a factor of 17 at station 2 and by a factor of 5.9 at station 4 in August and by factors of 27 and 15 times respectively in September. For ammonia, levels increased by a factor of 53 at station 2 and by a factor of 20 at station 4 in August and by factors of 70 and 31 times respectively in September. There were only marginal increases noted for nitrate-nitrite. The high ammonia levels in the effluent reflect a lack of nitrification in the lagoon system. As a result of these large nutrient increases, an algal bloom occurred and was visually noticeable beyond the station 350 meters downstream of the outfall. Along with the increased algal growth, intragravel dissolved oxygen levels were found to be significantly lower downstream of the outfall. These reduced oxygen levels were detected within a week of the discharge starting. The reduced intragravel dissolved oxygen levels are likely attributable to restricted water circulation within the gravel due to the attached algae as well as a build up of decaying organic matter originating from the algae and possibly from the sewage discharge. Even lower intragravel oxygen levels might be expected to occur after sewage has been discharged over a complete summer low flow period. The 1979 background results indicated low intragravel oxygen levels occur naturally. In areas where oxygen levels are naturally low and the potential affects (reduced circulation, buildup of organic matter) attributable to the increase in attached algae are added, serious problems might conceivably occur. The low intragravel oxygen levels in the summer could be detrimental to benthic organisms and result in a loss of the more sensitive organisms and a restructuring of the benthic community. If major food chain constituents disappeared, the change could be considered deleterious and reduce the use by rearing juvenile salmon of the area downstream of the sewage outfall.

The area downstream of the outfall is a major chum salmon spawning ground. The influence on chum salmon spawning areas of the attached algae growth on the rocks and the reduced intragravel oxygen levels found during the summer low flow period might presumptively be minimal during the fall spawning and winter incubation periods if during the onset of high river flows in October, the algae is washed out of the system plus during redd formation the algae is dislodged thus, leaving a clean spawning gravel. It is not anticipated large algal accumulations would develop during the winter high flow period.

The effluent did not have an appreciable affect on other water quality parameters. River dissolved oxygen levels, pH, temperature, non-filterable residue, turbidity and anionic surfactants did not appear to be affected within the study area. Slight increases in alkalinity, conductivity and total organic carbon were still detectable at station 4, 350 meters downstream.

Studies conducted in 1979 and 1980 by the Department of Fisheries and Oceans on attached algal growth and benthic invertebrates will serve to document the severity of changes in those components.

A 96 hour on-site field laboratory flow-through bioassay on an aerated final effluent showed the discharge to be non-toxic to resident coho salmon. However, Winkler dissolved oxygen levels in the final effluent (prior to aeration in the test vessels) were at levels low enough to be acutely toxic to fish and the need for aeration of the final effluent should be assessed.

The Duncan-North Cowichan lagoon system provided adequate disinfection of the effluent during the sampling period to reduce fecal coliform levels. However, total coliform levels were not reduced to as great an extent. The cause of this was not determined but may be due to two main factors (i) the higher densities of total coliforms (relative to fecal coliforms) combined with a low chlorine addition rate did not result in appreciable total coliform reduction (ii) fecal coliform organisms were more likely to be stressed in the lagoon environment than were total coliform organisms and were therefore more susceptible to chlorination. The total fecal coliform reduction of 5.29 log 10 units was similar to that reported at the smaller Lake Cowichan sewage lagoon of 5.58 log 10 units in February, 1978 and 4.54 log 10 units in September, 1977.

A chlorine residual was not detected in the final effluent indicating that the dechlorination facilities were operating adequately and/or that effective dechlorination was being achieved at lagoon cell #5.

The sewage discharge into the Cowichan River did not result in any significant water quality deterioration downstream with respect to fecal coliforms. The sampling was conducted during dry weather and the bacteriological quality of the effluent and receiving water may be adversely affected by increased rainfall.

Additional control measures are required at the Duncan-North Cowichan sewage lagoon to reduce nutrient loadings to the Cowichan River during the summer low flow period. The nutrient control considerations could include: (i) a seasonally regulated discharge incorporating no discharge or a very minimal discharge for an approximate 3.5 month period between June and September. A variable schedule would have to be adopted to coincide with the onset of the low flow and high autumn flow periods, (ii) using treatability studies or a full-scale pilot study, assess the capability to reduce phosphorous levels in the final effluent to a point where available phosphorous (effluent plus background levels) in combination with the high dissolved inorganic nitrogen fraction in the effluent will not promote excessive algal growth, (iii) assess the future effluent treatment needs of the community with advanced wastewater treatment options in mind.

1 INTRODUCTION

The Corporation of the City of Duncan made application to the Waste Management Branch (formerly the Pollution Control Branch) in May, 1978 to amend permit PE-1497 in their name to the Duncan-North Cowichan Joint Utilities Board. Included in the application were proposals to combine the City of Duncan aerated lagoon and Corporation of North Cowichan aerated lagoon into one sewage treatment facility with a common discharge to the mainstream of the Cowichan River. The single discharge was to replace the City of Duncan's open ditch discharge into Fish Gut Alley (which subsequently flowed into the Cowichan River via Somenos Creek) and the Corporation of North Cowichan's discharge into the Cowichan River (which had plugged up and effluent was flowing overland and also into Somenos Creek).

An amended permit was issued December, 1978 for a maximum discharge of 13,600 m^3/d (.157 m^3/s), BOD_5 of 35 mg/L, TSS of 40 mg/L, chlorination-dechlorination and a single outfall in the mainstem Cowichan River. During the processing of the amendment application concerns were expressed by the Department of Fisheries and Oceans (DFO) that downstream of the proposed outfall site, nutrient enrichment might enhance algal growth during the summer flow period and which in turn would impair benthic invertebrate production, reduce sub-gravel dissolved oxygen levels and clog salmon spawning gravel.

The Cowichan River is one of the most important fish producing rivers on Vancouver Island. Indigenous species include: chum salmon (*Oncorhynchus keta*), spring salmon (*O. tshawtscha*), coho salmon (*O. kisutch*), cutthroat trout (*Salmo clarkii*), steelhead and rainbow trout (*S. gairdneri*) and Dolly Varden (*Salvelinus malma*) (1). In addition, brown trout (*Salmo trutta*), an introduced species to the Cowichan River, appear to have become established (1).

The Environmental Protection Service (Freshwater Group) and the Department of Fisheries and Oceans (Water Quality Unit) in consultation with the Waste Management Branch initiated a joint study in 1979 on the effect the sewage discharge would have on the water quality and macroinvertebrate and periphyton standing crop of the Cowichan River. The new diffuser was placed in the river in July, 1979 and the initial discharge did not commence until August 13, 1980, halfway through the post discharge program. This report presents the water quality data collected on the Cowichan River over June to September of 1979 and 1980, bacteriological samples collected over September 15-18, 1980 to assess bacterial reduction in the lagoon system and an on-site flow-through fish bioassay conducted over September 15-18, 1980 on the final effluent.

2 DESCRIPTION OF STUDY AREA

The Cowichan River originates in Cowichan Lake and flows eastward for approximately 47 km and discharges into Cowichan Bay (Figure 1). The Cowichan River at the point of study drains an area of approximately 826 km^2. Flows on the river have been regulated since 1965 and a minimum flow of 4.25 m^3/s is required during the summer low flow period to maintain the fishery but flows may be reduced below that under special circumstances. Daily stream flows are recorded at Water Survey of Canada station 08HA011 located at the Allemby Road bridge, one km upstream of the study area. The only other permitted discharge on the Cowichan River is the Lake Cowichan sewage lagoon discharge (Figure 1).

The water quality study area encompassed the mainstream Cowichan River from control station #1 approximately 50 meters upstream of the diffuser to station #4 approximately 350 meters downstream from the diffuser. (Figure 2, Plate 1). Stations #2 and #3 were located approximately 50 meters and 150 meters respectively downstream of the diffuser. Samples were collected from the main river flow, approximately 2.5 meters from the northbank at stations #1 and #2 and from midstream at stations #3 and #4. An additional sample station #5, just upstream of Somenos Creek, was sampled during the bacteriological portion of the study.

The Duncan-North Cowichan sewage treatment lagoons are located approximately 250 m north of the Cowichan River. Bacteriological samples were collected at various stages of effluent treatment from the Duncan-North Cowichan sewage lagoons. The sewage lagoons and sample stations are shown in Figure 3, Plate 2.

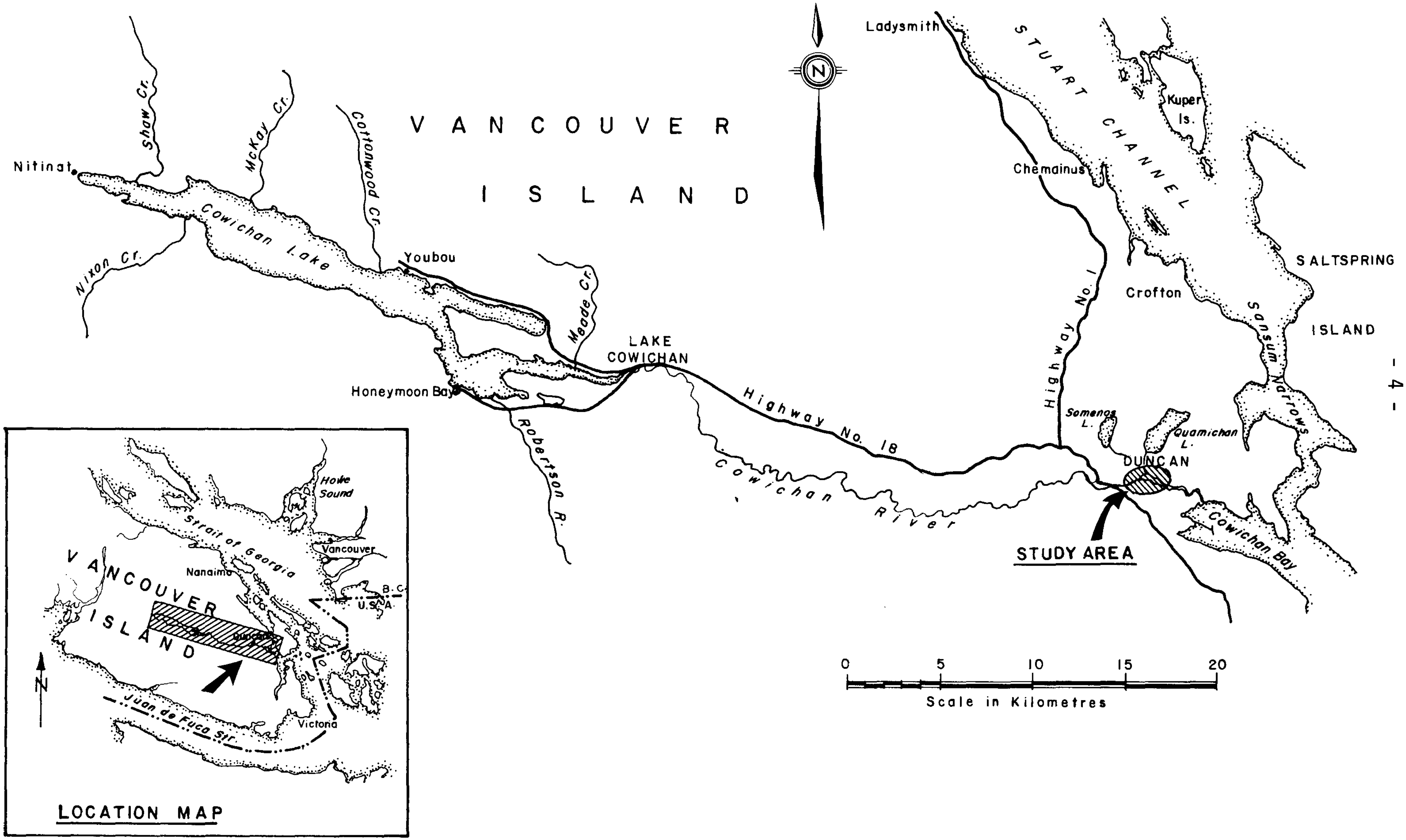

FIGURE I LOCATION MAP OF COWICHAN RIVER

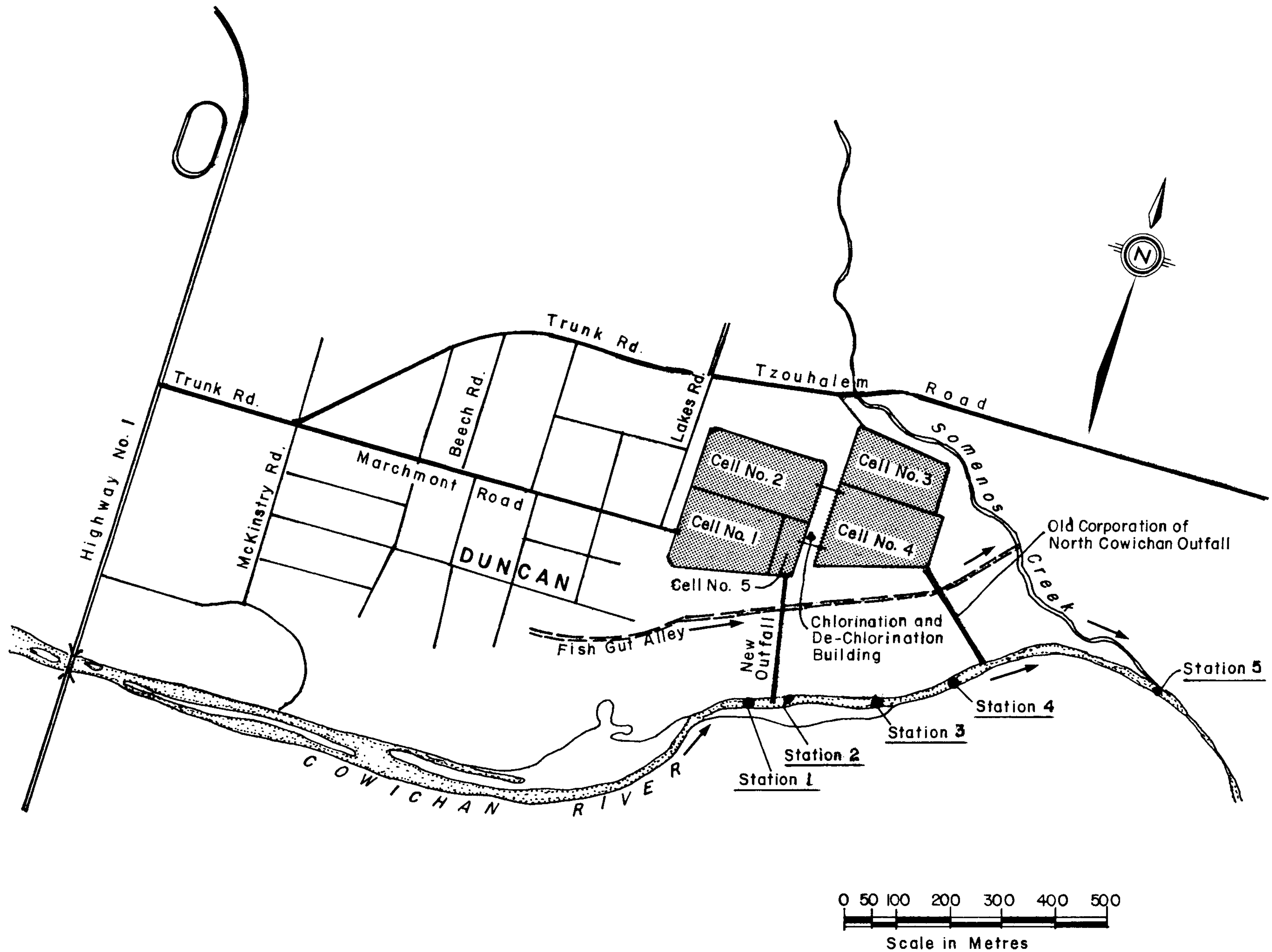

FIGURE 2 LOCATION MAP OF SEWAGE LAGOONS AND WATER QUALITY SAMPLE STATIONS

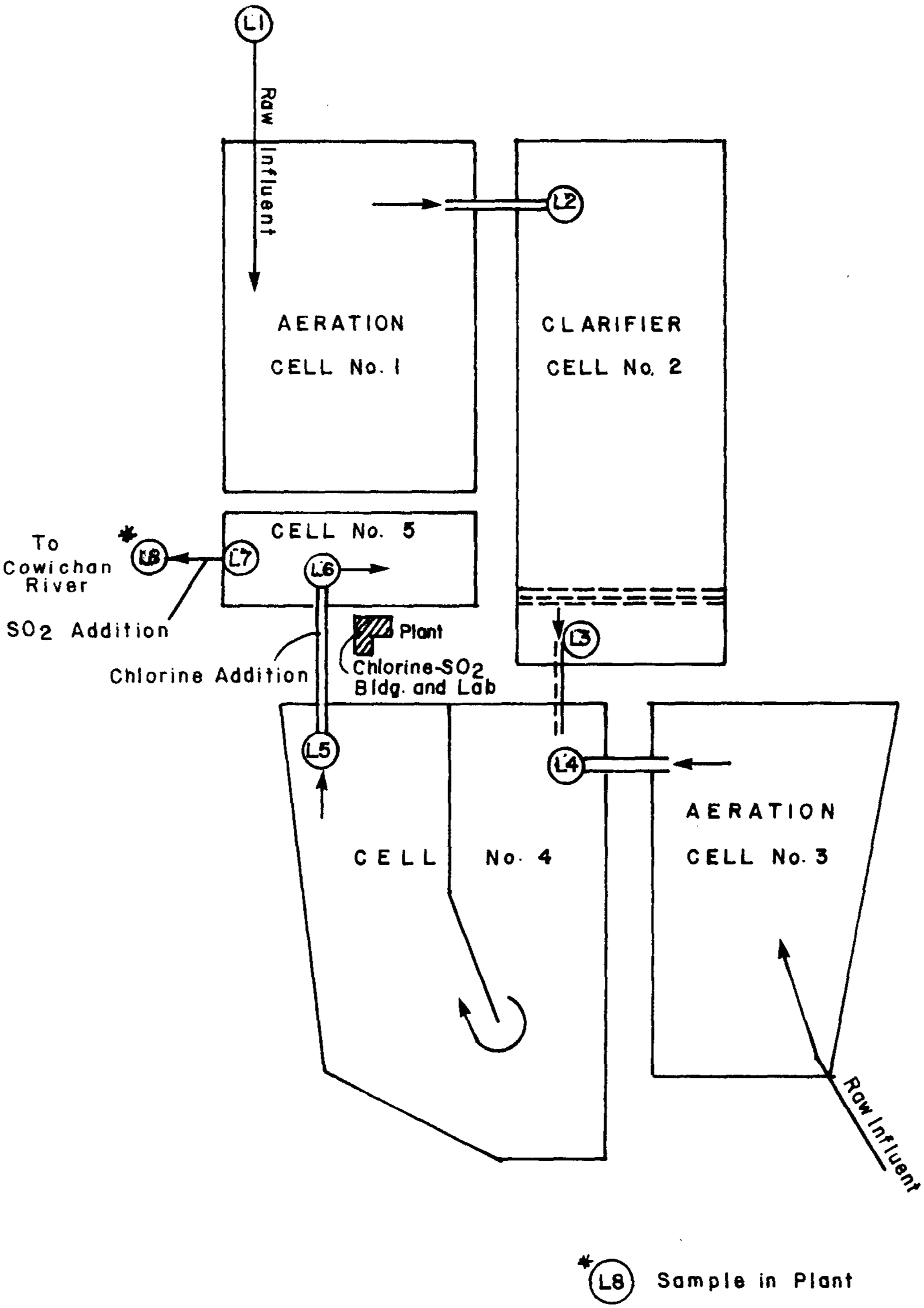

FIGURE 3 LAGOON SAMPLE LOCATIONS

Plate 1
COWICHAN RIVER
STUDY AREA

Plate 2
NORTH COWICHAN -
CITY OF DUNCAN
SEWAGE LAGOON

3 METHODS AND MATERIALS

3.1 Water Quality Studies

3.1.1 Replicate Sampling

The Environmental Protection Service sampled the Cowichan River, at Duncan, over the low flow period (June to September) of 1979 and 1980. Water samples were collected with a replicate sampler modified after that described by Oguss and Erlebach (2). The sampler is able to hold up to 6 individual sample bottles that can range from a 500 ml wide mouth polyethylene bottle to a 50 ml glass Sovril bottle. Three simultaneous samples were taken for the following parameters: anionic surfactants (LAS), total organic carbon (TOC), total inorganic carbon (TIC), silica, total phosphorous (TP), total dissolved phosphorous (TDP), nitrate-nitrite (NO_3- NO_2), total ammonia (NH_3 + NH_4) and total dissolved nitrogen (TDN). Duplicate samples were collected for dissolved oxygen, turbidity, non-filterable residue (NFR), pH, alkalinity and conductivity. Duplicate samples for intragravel dissolved oxygen were collected, with a 600 ml capacity stainless steel syringe (3). The water temperature was recorded with a handheld thermometer. Sample preparation, handling and analytical methods are reported in Appendix I(a).

With the exception of the July 28, 1980 survey when only one set of replicate samples were collected, replicate samples were collected on three occasions during a 24 hour period on each of the following surveys in 1979: June 19-20; July 10-11; July 31-August 1; September 4-5 and in 1980: June 16-17; July 7-8; August 19-20; September 8-9. These periods basically fall into three categories: Period 1 - mid afternoon of day 1, Period 2 - early morning of day 2 and Period 3 - late morning of day 2.

3.1.2 Sequential Sampling

Sequential sampling was conducted at station 2 on each of the surveys in 1979 and in all but the July 28 and September 8-9 surveys in

1980. Two Sirco model #MK-V57 samplers running concurrently were used at station 2 in 1979. A Sirco model #MK-VS6 sampler was used at station 2 in 1980. Sequential sampling was conducted for TP, $NH_3 + NH_4^+$, NO_3/NO_2, and TDN. The samplers were enclosed in 45 gallon drums and chained to a nearby tree to deter tampering with the samplers. The samplers were left without refrigeration over the complete 24 hour period. Sample preparation, handling and analytical methods are reported in Appendix 1(a).

3.2 Bacteriological Studies

Bacteriological sampling of the Duncan-North Cowichan sewage treatment lagoons and receiving waters of the Cowichan River was conducted from September 15 to 18, 1980. Stations #1 to #5 were sampled on the Cowichan River to assess the impact of the sewage discharge on the bacteriological quality of the river (Figure 2). Eight locations (L1 to L8) were sampled within the lagoon system to assess the bacteriological reduction performance of the lagoons (Figure 3).

All bacteriological samples were analyzed within two hours of collection in the mobile microbiology laboratory of the Environmental Protection Service, located on-site at the sewage treatment plant. Samples were collected in sterile wide-mouth glass bottles and were stored at temperatures not exceeding 10°C until processed.

Samples were analayzed for total coliforms (TC), fecal coliforms (FC) and fecal streptococci (FS) organisms using the membrane filtration procedure described in Section 902 (Part 5) of the Environmental Protection Service Laboratory Manual (27). Standard Plate Count (35°C) (SPC) determinations were made on some samples according to the procedure described in Section 904 of the EPS Manual (27).

3.3 Flow-Through Bioassay

The Environmental Protection Service conducted an on-site flow-through fish bioassay on the final dechlorinated effluent of the Duncan-

North Cowichan sewage lagoon as part of an evaluation of the lagoon's operating efficiency over September 15 to 19, 1980. Conducting an onsite fish bioassay on sewage negates problems of detoxification caused by loss of unstable elements during the transportation or storage of a sample. A flow-through bioassay with continuous sampling of the effluent will catch transient events in the flow which could be missed by grab sampling, or by aliquot batching samplers. The flow-through bioassay is consequently a much more sensitive analytical tool than the static bioassay. A description of the flow-through apparatus and methods is provided in Appendix I(b).

4 RESULTS AND DISCUSSION

4.1 Water Quality Studies

The analytical results from this study represent the water quality of the Cowichan River during the low flow period of 1979 and 1980. During the low flow period the influence of the sewage discharge would be expected to be greatest. The flow regime of the Cowichan River for 1979 and 1980 can be seen in Figure 4 (4,5). Sewage was only being discharged within the study area during August and September, 1980.

4.1.1 Alkalinity (as $CaCO_3$) and pH

Alkalinity is a measure of the capacity of water to neutralize acids and is usually considered equal to carbonate hardness. The alkalinity of the Cowichan River is low and mean values generally didn't exceed 26 mg/l (Table 1) indicating a low buffering capacity. An increase of 2.0 mg/l and 2.7 mg/l above the mean background level was found at station 2 in August, 1980 and September, 1980 respectively. A slight increase was still evident at station 4, 350 meters downstream.

"pH" is a measure of the hydrogen ion activity in water and is an important factor in the chemical and biological systems of natural waters. A criteria range of 6.5-9.0 is considered to provide adequate protection for freshwater fish and bottom dwelling invertebrate fish food organisms (14). The mean pH of the Cowichan River ranged between 7.4 and 8.0 and is within the above criteria range (Table 1). The effluent discharge did not affect river pH levels.

4.1.2 Conductivity

Conductivity is a measure of the ion concentration of water. If the total concentration of salts is increased sufficiently above background levels, this may cause osmotic stress in fish. The conductivity of the Cowichan River is low and mean background values didn't exceed 64 umhos/cm

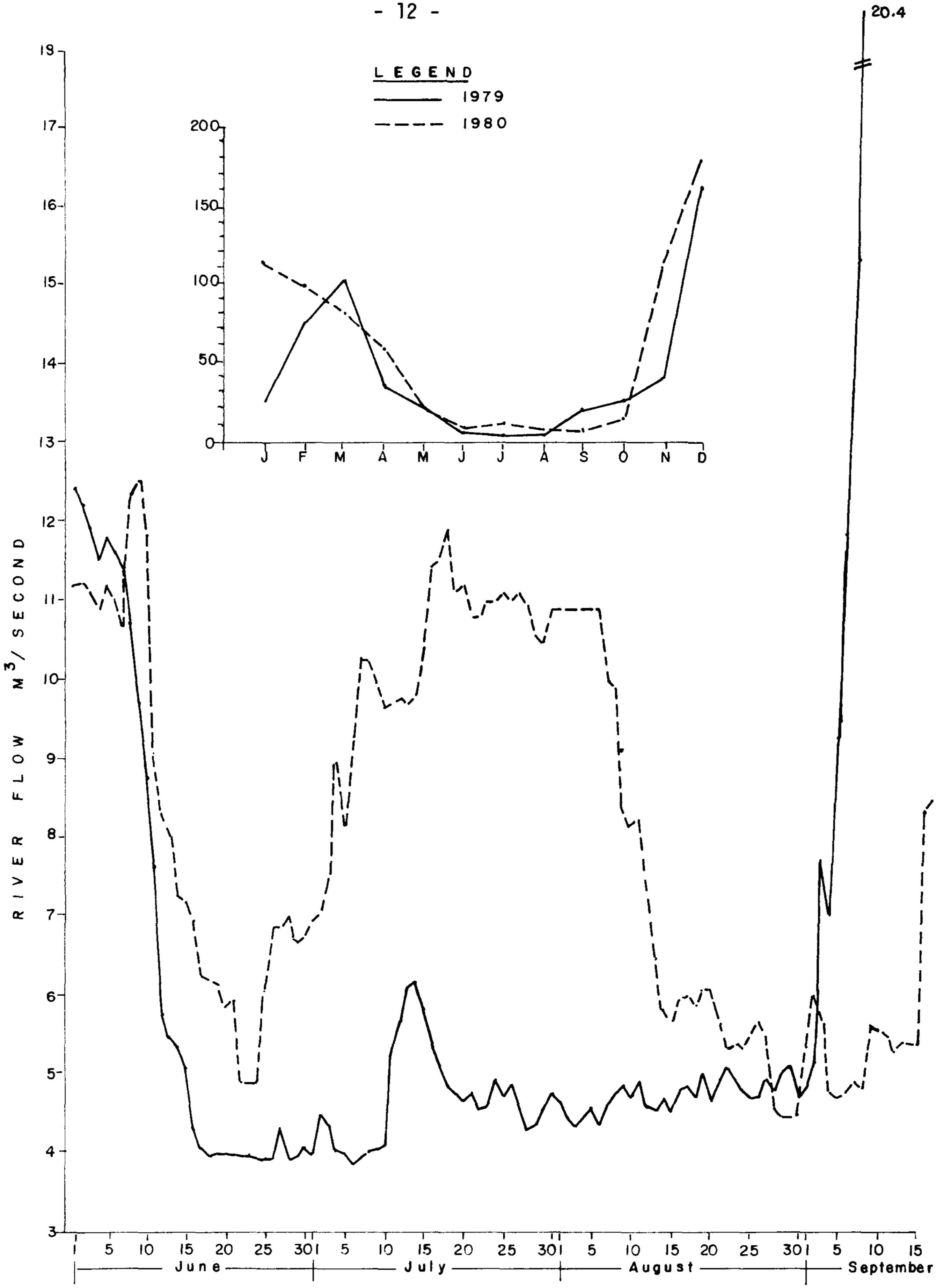

FIGURE 4 THE MONTHLY MEAN FLOW AND DAILY FLOW OF THE COWICHAN RIVER FROM JUNE 1 TO SEPTEMBER 15 OF 1979 AND 1980

TABLE 1 Alkalinity, Conductivity and pH for The Cowichan River Low Flow Period (1979/80).

PARAMETER : Alkalinity (mg/l)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	26.0	1.1	6	25.7	.3	6	24.4	.5	6	23.8	.3	6			
2	26.0	1.2	6	25.8	.3	6	24.3	.4	6	23.7	.4	6			
3	25.7	.2	6	25.6	.2	6	24.3	.3	6	23.8	.3	6			
4	25.8	.2	6	25.7	.3	6	24.2	.5	6	24.0	.4	6			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	24.8	.4	6	24.8	.3	6	23.3	.4	2	24.4	.1	6	25.6	.8	6
2	24.7	.4	6	24.9	.3	6	23.6	.0	2	26.4	.2	6	28.3	.9	6
3	25.0	.0	6	26.0	3.3	6	23.9	1.1	2	26.4	.2	6	27.9	.5	6
4	25.0	.3	6	24.7	.3	6	23.7	.1	2	25.2	.3	6	26.7	.3	6

PARAMETER : Conductivity (umhos/cm)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	63.8	.2	6	62.7	.8	6	60.1	.4	6	60.0	.4	6			
2	63.4	.4	6	62.7	.5	6	60.0	.6	6	59.9	.4	6			
3	63.6	.3	6	62.8	.6	6	60.0	.5	6	60.1	.4	6			
4	63.2	.6	6	62.6	.6	6	60.0	.8	6	59.9	.4	6			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	62.8	.6	6	61.7	.3	6	59.0	1.4	2	60.7	1.2	6	61.8	.5	6
2	62.2	.4	6	61.7	.4	6	60.0	.0	2	68.5	.5	6	70.0	4.5	6
3	62.4	.5	6	61.5	.4	6	59.0	.0	2	68.2	.8	6	71.5	1.1	6
4	63.1	.4	6	61.6	.1	6	59.0	.0	2	63.4	.9	6	56.2	1.4	6

PARAMETER pH (.)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	7.6	.1	6	7.7	.1	6	8.0	.4	6	7.6	.2	6			
2	7.7	.1	6	7.7	.1	6	8.0	.4	6	7.7	.2	6			
3	7.7	.1	6	7.7	.1	6	8.0	.4	6	7.7	.3	6			
4	7.7	.1	6	7.7	.1	6	8.0	.4	6	7.7	.3	6			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	7.4	.1	6	7.6	.1	6	7.6	.0	2	7.5	.1	6	7.6	.3	6
2	7.4	.1	6	7.6	.1	6	7.6	.0	2	7.4	.1	6	7.4	.2	6
3	7.5	.1	6	7.8	.3	6	7.7	.1	2	7.5	.1	6	7.4	.2	6
4	7.5	.1	6	7.6	.1	6	7.6	.0	2	7.5	.1	6	7.6	.2	5

(Table 1). A minor increase of 7.8 uhmos/cm and 8.2 umhos/cm above the mean background level was found at station 2 in August, 1980 and September, 1980 respectively and should not impart any stress on fish. An increase in conductivity was still detectable at station 4.

4.1.3 Turbidity and Non-Filterable Residue (Suspended Solids)

Turbidity in water is attributable to suspended and colloidal matter, the effect of which is to reduce water clarity and diminish light penetration. The effluent discharge did not appear to affect river turbidity and levels were below or near the detection level of 1.0 FTU. Levels were marginally higher downstream of the outfall in August, 1980 but unchanged in September (Table 2).

Suspended solids are attributable to the organic and inorganic particulate matter in water. The effects of suspended solids may be to act directly on fish through abrasive injuries and clogging gills or by blanketing the stream bottom thus effecting spawning beds and fish food organisms. Suspended solids may also screen out light and organic wastes may deplete oxygen levels. Suspended solids levels in the Cowichan River were generally below or near the detection level (5 mg/l) and the effluent discharge did not affect river suspended solids levels (Table 2).

4.1.4 Anionic Surfactants

Detergents are a common component of sewage effluents and are derived in large amounts from household cleaning agents. The primary surfactants in present detergents are linear alkylate sulfonates (LAS) and are anionic surfactants which can be toxic to aquatic life. There was no indication of LAS in the Cowichan River (Table 2).

4.1.5 Temperature

In 1979 the mean water temperature ranged between 16°C in June to approximately 22°C in late July. For 1980 the mean water temperature ranged from approximately 15°C in June to 21°C in late July (Table 3). A maximum temperature of 23.5°C was reported for the afternoon sampling on July 31, 1979. The sewage discharge had no affect on river temperatures.

TABLE 2 Turbidity, Non Filterable Residue and Anionic Surfactant for The Cowichan River Low Flow Period (1979/80).

PARAMETER : Turbidity (FTU)

STATION	Jun 19-20 1979 MEAN	S.D.	N	Jul 10-11 1979 MEAN	S.D.	N	Jul 31 - Aug 1 1979 MEAN	S.D.	N	Sep 4-5 1979 MEAN	S.D.	N	MEAN	S.D.	N
1	<1.0	.0	6	<1.0	.0	6	<1.0	.0	6	1.0	.1	6			
2	<1.0	.0	6	<1.0	.0	6	<1.0	.0	6	1.0	.1	6			
3	<1.0	.0	6	<1.0	.0	6	<1.0	.0	6	1.0	.0	6			
4	<1.0	.0	6	<1.0	.0	6	<1.0	.0	6	<1.0	.0	6			

STATION	Jun 16-17 1980 MEAN	S.D.	N	Jul 7-8 1980 MEAN	S.D.	N	Jul 28 1980 MEAN	S.D.	N	Aug 19-20 1980 MEAN	S.D.	N	Sep 8-9 1980 MEAN	S.D.	N
1	<1.0	.0	6	1.1	.1	6	1.2	.3	2	<1.0	.0	6	<1.0	.0	6
2	<1.0	.0	6	1.2	.2	6	<1.0	.0	2	1.3	.1	6	<1.0	.0	6
3	<1.0	.0	6	1.2	.2	6	<1.0	.0	2	1.3	.1	6	<1.0	.0	6
4	<1.0	.0	6	1.2	.1	6	1.1	.1	2	1.1	.1	6	<1.0	.0	6

PARAMETER : Non Filterable Residue (mg/l)

STATION	Jun 19-20 1979 MEAN	S.D.	N	Jul 10-11 1979 MEAN	S.D.	N	Jul 31 - Aug 1 1979 MEAN	S.D.	N	Sep 4-5 1979 MEAN	S.D.	N	MEAN	S.D.	N
1	<5.0	.0	6	<5.0	.0	6	<5.0	.0	6	6.2	1.8	6			
2	5.3	.8	6	<5.0	.0	6	5.3	.5	6	5.2	.4	6			
3	<5.0	.0	6	<5.0	.0	6	5.2	.4	6	5.5	.8	6			
4	5.3	.5	6	5.2	.4	6	6.7	2.7	6	5.3	.5	6			

STATION	Jun 16-17 1980 MEAN	S.D.	N	Jul 7-8 1980 MEAN	S.D.	N	Jul 28 1980 MEAN	S.D.	N	Aug 19-20 1980 MEAN	S.D.	N	Sep 8-9 1980 MEAN	S.D.	N
1	<5.0	.0	6	<5.0	.0	6	<5.0	.0	2	<5.0	.0	4	<5.0	.0	6
2	<5.0	.0	6	<5.0	.0	6	<5.0	.0	2	<5.0	.0	6	<5.0	.0	6
3	<5.0	.0	6	<5.0	.0	6	<5.0	.0	2	<5.0	.0	6	<5.0	.0	6
4	<5.0	.0	6	<5.0	.0	6	<5.0	.0	2	<5.0	.0	6	<5.0	.0	6

PARAMETER : Anionic Surfactant (mg/l)

STATION	Jun 19-20 1979 MEAN	S.D.	N	Jul 10-11 1979 MEAN	S.D.	N	Jul 31 - Aug 1 1979 MEAN	S.D.	N	Sep 4-5 1979 MEAN	S.D.	N	MEAN	S.D.	N
1	< .04	.00	9	< .04	.00	9	< .04	.00	9	.04	.01	9			
2	< .04	.00	9	< .04	.00	9	< .04	.00	9	< .04	.00	9			
3	< .04	.00	9	< .04	.00	9	< .04	.00	9	< .04	.00	9			
4	< .04	.00	9	< .04	.00	9	< .04	.00	9	< .04	.00	9			

STATION	Jun 16-17 1980 MEAN	S.D.	N	Jul 7-8 1980 MEAN	S.D.	N	Jul 28 1980 MEAN	S.D.	N	Aug 19-20 1980 MEAN	S.D.	N	Sep 8-9 1980 MEAN	S.D.	N
1	< .04	.00	9	< .04	.00	9	< .04	.00	3	< .04	.00	9	< .04	.00	9
2	< .04	.00	9	< .04	.00	9	< .04	.00	3	< .04	.00	9	< .04	.00	9
3	< .04	.00	9	< .04	.00	9	< .04	.00	3	< .04	.00	9	< .04	.00	9
4	< .04	.00	9	< .04	.00	9	< .04	.00	3	< .04	.00	9	< .04	.00	9

TABLE 3 Temperature, Dissolved Oxygen - water and Percent Saturation for The Cowichan River Low Flow Period (1979/80).

PARAMETER Temperature (C)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	16.0	1.6	6	17.6	.6	6	22.1	1.1	6	17.5	.6	6			
2	16.0	1.6	6	17.6	.6	6	22.1	1.1	6	17.5	.6	6			
3	16.2	2.2	6	17.6	.6	6	22.4	1.2	6	17.5	.6	6			
4	16.7	2.5	6	17.6	.6	6	22.4	1.2	6	17.5	.6	6			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	15.4	1.0	6	17.7	.8	6	21.0	.0	2	18.5	1.3	6	16.7	1.1	6
2	15.4	1.0	6	17.7	.8	6	21.0	.0	2	18.5	1.3	6	16.6	1.0	6
3	15.2	1.1	6	17.8	.9	6	20.8	.0	2	18.5	1.3	6	16.5	.9	6
4	15.2	1.1	6	17.8	.9	6	20.6	.0	2	18.4	1.4	6	16.5	.9	6

PARAMETER Dissolved Oxygen - water (mg/l)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	9.6	.4	6	9.4	.2	6	8.9	.8	6	9.6	.8	6			
2	9.7	.5	6	9.4	.3	6	8.9	.9	6	9.6	.8	6			
3	9.8	.4	6	9.4	.2	6	9.0	.7	6	9.9	.7	6			
4	9.8	.4	6	9.5	.2	6	9.0	.8	6	9.6	.6	6			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	9.6	.2	6	9.5	.3	6	9.4	.3	2	9.2	.5	6	9.7	.6	6
2	9.6	.3	6	9.4	.4	6	9.4	.0	2	8.9	.3	6	9.7	.7	6
3	9.4	.3	6	9.3	.3	6	9.4	.0	2	8.9	.6	6	9.5	.6	6
4	9.6	.4	6	9.3	.5	6	9.3	.1	2	9.0	.6	6	9.8	.8	6

PARAMETER Percent Saturation (%)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	99.8	4.9	6	101.5	3.0	6	104.4	11.5	6	103.6	9.4	6			
2	101.1	5.5	6	101.6	3.3	6	104.6	11.7	6	103.8	10.1	6			
3	103.0	3.9	6	101.9	2.4	6	106.7	9.6	6	106.8	9.0	6			
4	103.1	4.2	6	102.0	2.8	6	106.4	11.7	6	103.4	8.0	6			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	99.2	1.9	6	102.7	4.4	6	108.2	3.3	2	100.8	7.5	6	102.8	8.0	6
2	99.2	2.6	6	101.3	5.1	6	108.2	.0	2	97.3	6.1	6	102.4	9.2	6
3	97.1	3.0	6	100.7	4.6	6	107.8	.0	2	98.4	5.4	6	100.9	7.7	6
4	98.2	4.5	6	101.1	6.9	6	105.8	.8	2	98.4	8.6	6	103.3	9.8	6

4.1.6 Dissolved Oxygen and Percent Saturation

In 1979 and 1980 the mean dissolved oxygen levels ranged between 8.9 mg/l and 9.9 mg/l (Table 3). The mean percent saturation ranged between 97% and 108% (Table 3). Variations in daily dissolved oxygen levels were found and as would be expected, oxygen levels were lowest in the early morning samplings. The sewage discharge did not appear to have an affect on mean dissolved oxygen levels.

4.1.7 Intragravel Dissolved Oxygen

In 1979, intragravel dissolved oxygen levels showed a variability existed between duplicate samples, between stations and between sample months (Table 4). The variation between duplicate samples and stations and months was not pronounced in 1980, at least, up until the influence of the sewage discharge was detected at the downstream stations in August, 1980 and September, 1980 (Table 4). An analysis of variance showed that during this period the intragravel dissolved oxygen levels, except for station 4 in August, were significantly ($\alpha = 0.5$) lower than control station values. The most noticeable drop from background levels was at station 3, 150 meters downstream, where a reduction in mean intragravel dissolved oxygen levels of 2.6 mg/l and 2.7 mg/l in August, 1980 and September, 1980 respectively were found. While some of the actual values downstream of the outfall in August and September were not unlike some of these reported in 1979 when there was no discharge, it should be stressed that the naturally low mean levels of 1.9 mg/l and 2.8 mg/l at station 3 in July, 1979 in conjunction with depressed oxygen levels due to the sewage discharge could be detrimental to invertebrate life forms, namely fish food organisms. It is also important to consider that these depressed levels were recorded approximately 1 week and 4 weeks respectively after the discharge started. During a complete low flow period and in a year such as 1979 (Figure 4) with very low flows, the intragravel oxygen levels could be much lower. There was a recovery in intragravel oxygen levels by station 4, 350 meters downstream of the outfall. Station 4 showed the least variation between duplicates and monthly means in 1979.

TABLE 4 Dissolved Oxygen - **Intragravel** Total Organic Carbon and Total Inorganic Carbon for The Cowichan River Low Flow Period (1979/80).

PARAMETER : Dissolved Oxygen - **Intragravel** (mg/l)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	3.5	2.4	6	1.8	1.2	6	5.4	.6	6	4.5	1.0	6			
2	4.9	1.9	6	5.1	.9	6	5.3	1.2	6	6.3	1.0	6			
3	6.4	.5	6	1.9	.3	6	2.8	1.2	6	4.4	1.8	6			
4	8.1	.7	6	7.4	.6	6	6.0	.6	6	7.1	.8	6			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	7.1	.4	6	7.2	.4	6	6.9	.3	2	6.2	.5	6	6.8	.3	6
2	7.7	.9	6	7.6	.4	6	7.4	.6	2	4.0	.8	5	5.0	.6	6
3	7.3	.6	6	7.2	.6	6	7.2	.1	2	3.6	.7	6	4.1	.8	6
4	8.0	.6	6	7.1	.5	6	7.4	.3	2	5.7	.6	6	5.2	.6	6

PARAMETER : Total Organic Carbon (mg/l)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	1.0	.0	9	2.0	.0	9	2.0	.0	9	1.0	.0	9			
2	1.0	.0	9	2.0	.0	9	2.0	.0	9	1.0	.0	9			
3	1.0	.0	9	2.0	.0	9	2.0	.0	9	1.0	.0	9			
4	1.0	.0	9	2.0	.0	9	2.0	.0	9	1.0	.0	9			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	1.0	.0	9	1.0	.0	9	1.0	.0	3	1.0	.0	9	1.4	.5	9
2	1.0	.0	9	1.0	.0	9	1.0	.0	3	2.2	.7	9	2.2	1.1	9
3	1.0	.0	9	1.0	.0	9	1.0	.0	3	2.4	.7	9	1.8	.4	9
4	1.0	.0	9	1.0	.0	9	1.0	.0	3	1.3	.5	9	2.2	.4	9

PARAMETER : Total Inorganic Carbon (mg/l)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	-	-	-	5.0	.0	9	4.2	.4	9	5.0	.0	9			
2	-	-	-	5.0	.0	9	4.4	.5	9	5.0	.0	9			
3	-	-	-	5.0	.0	9	4.3	.5	9	5.0	.0	9			
4	-	-	-	5.0	.0	9	4.4	.5	9	5.0	.0	9			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	5.0	.0	9	5.0	.0	9	5.0	.0	3	6.0	.0	9	6.0	.0	9
2	5.0	.0	9	5.0	.0	9	5.0	.0	3	6.0	.0	9	7.0	.0	9
3	5.0	.0	9	5.0	.0	9	5.0	.0	3	6.0	.0	9	6.9	.3	9
4	5.0	.0	9	5.0	.0	9	5.0	.0	3	6.0	.0	9	6.1	.3	9

The content of dissolved oxygen in intragravel water is controlled both by biological and physical factors (16). It is reduced by oxidation of organic detritus and respiration of organisms and replenished primarily by stream water entering the streambed (16). Interchange between stream and intragravel water is affected by streamflow, gradient, curvature of the streambed and coarseness and permeability of bed materials (16). The lower intragravel dissolved oxygen levels recorded in 1979 are likely attributable to a variability in substrate composition where some areas may have had larger amount of fine sediment clogging the interstital spaces, thus reducing water circulation and oxygen levels. The low values in 1980 can more likely be attributed to the large accumulations of benthic algae downstream of the outfall where the heavy growths result in a poor interchange of water between the stream and the intragravel and in a build-up of fine organic materials in the interstial spaces thus further leading to poor water circulation and to oxygen depletion through organic decomposition. In addition, organic solids in the sewage effluent could settle out downstream of the outfall and also contribute to an oxygen deficiency. However, as no increase in suspended solids (section 4.1.3) and only a small increase in TOC (section 4.1.8) was detected in the river downstream of the outfall, the influence of settled organic matter on reduced oxygen levels is not likely of concern.

In terms of impact on the environmental quality of the Cowichan River, suppressed intragravel oxygen levels are of significance to benthic invertebrates and to egg-to-fry survival in spawning beds. The change in the oxygen regime within the river substrate in conjunction with the large accumulations of attached algae could result in a loss of the more sensitive invertebrate organisms (mayflies, stoneflies, caddisflies) and a restructure of the benthic community would occur. New species, tolerant to low oxygen, could move into the community or those already in the community could become more numerous (15). Alternatively, no replacement could occur leading to a net reduction in biomass (15). Davis (15) reported that whether a change in an invertebrate community is necessarily bad from an ecological point of view may be hard to determine but if major food chain constituents drop out, the change would be considered deleterious. The benthic invertebrate data collected by the Department of Fisheries and Oceans should help to assess if a faunal change occurred between the short period the discharge started in mid August, 1980 and when samples were collected in September, 1980.

It would be hard to assess the impact of the large algal accumulations and suppressed intragravel oxygen levels documented during the low flow period on the spawning beds downstream of the outfall in the autumn. Salmon do not spawn in the Cowichan river during the low flow period but the study area is heavily utilized by rearing juvenile salmon. Adult fish start ascending the Cowichan River in mid-October with the first fall rains and increased river flows (1). The study area is a major spawning area for chum salmon which have peak spawning in the latter half of November (1). As it relates to spawning in the fall, the influence of the large attached algae growth and reduced dissolved oxygen levels could, presumptively, be minimal if during the fall wet season with high river flows the attached algae is washed out of the system plus during redd formation the algae is dislodged and thus leaving a clean spawning gravel. It is unlikely large algal accumulations would occur during the high flow period.

4.1.8 Total Organic and Inorganic Carbon and Silica

Total organic carbon levels increased dowstream of the sewage outfall in August, 1980 and September, 1980 but were still low and mean concentrations didn't exceed 2.5 mg/l (Table 4). An increase in total organic carbon was still detectable at station 4. Total inorganic carbon concentrations didn't show any change due to the sewage discharge in August, 1980 but in September, 1980 a small 1 mg/l increase was noted at station 2 (Table 4).

Silica levels were monitored only in 1979 and mean levels ranged from 1.3 mg/l in June and progressively declined to 0.7 mg/l in September (Table 5).

TABLE 5 Silica, Total Phosphorus and Total Dissolved Phosphorus for The Cowichan River Low Flow Period (1979/80).

PARAMETER : Silica (mg/l)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	1.3	.0	9	1.0	.0	9	.8	.0	9	.7	.0	9			
2	1.2	.1	9	1.0	.0	9	.8	.0	9	.7	.0	9			
3	1.2	.1	9	1.0	.0	9	.8	.0	9	.7	.0	9			
4	1.3	.0	9	1.0	.0	9	.8	.0	9	.7	.0	9			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

PARAMETER : Total Phosphorus (ug/l)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	6.0	.7	9	7.2	1.3	9	8.1	.7	8	7.6	1.4	9			
2	8.0	1.5	9	7.1	1.2	9	7.3	.5	9	7.5	2.6	9			
3	7.7	1.7	9	7.1	1.2	9	7.4	.3	9	6.3	1.1	9			
4	7.2	.9	9	7.2	1.0	9	7.7	.5	9	7.2	1.8	9			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	6.8	2.1	9	8.6	1.6	9	9.6	.2	3	10.4	1.2	9	7.9	1.7	9
2	6.0	1.1	9	8.5	.5	9	9.2	.7	3	157.1	29.4	9	184.2	15.2	9
3	5.8	.4	9	8.8	1.0	9	9.0	.9	3	135.1	44.7	9	206.2	67.0	9
4	7.7	3.9	9	8.7	.5	9	9.8	.6	3	63.7	5.7	9	81.3	9.6	9

PARAMETER : Total Dissolved Phosphorus (ug/l)

STATION	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D.	N
	Jun 19-20 1979			Jul 10-11 1979			Jul 31 - Aug 1 1979			Sep 4-5 1979					
1	3.7	1.2	9	3.1	.8	7	5.0	.8	8	4.1	1.5	9			
2	4.2	1.9	9	2.5	.6	9	4.4	.7	9	3.5	.2	9			
3	4.7	2.2	9	2.7	.3	9	4.6	.4	9	4.1	1.0	8			
4	4.5	1.0	8	3.1	.3	9	4.4	.2	8	3.6	.3	9			
STATION	Jun 16-17 1980			Jul 7-8 1980			Jul 28 1980			Aug 19-20 1980			Sep 8-9 1980		
1	3.0	.4	8	5.1	1.0	9	5.0	.6	3	7.4	.6	9	4.8	1.2	9
2	4.2	1.5	9	5.5	.3	9	5.5	.3	3	130.4	33.9	9	135.2	17.1	9
3	3.9	1.1	9	5.2	.8	9	5.3	.4	3	112.0	6.6	9	147.6	16.5	9
4	4.0	1.0	9	5.5	1.5	9	5.8	.3	3	51.0	5.2	9	75.8	5.5	9

4.1.9 Total Phosphorous and Total Dissolved Phosphorous

A distinguishing hydrological feature of the Cowichan River in 1980 compared to 1979 was the increased flow over the low flow period (Figure 4). A second and more important feature of 1980 was the discharge of sewage lagoon effluent which began on August 13, 1980.

From Figure 5 it can be seen that for June 1979 and June 1980 the range of the mean total phosphorous (TP) concentrations for the four stations was similar and a degree of station variability existed (Table 5). As there was no sewage discharge in June of 1979 and 1980, all the data for the respective stations for each of the two years was combined. A one way analysis of variance showed no significant difference ($\alpha = .05$) between the years. The same was done for early-July of both years and a significant ($\alpha = .05$) difference was found between the years. For late-July, but using only the first set of replicates collected in 1979 (as only one set was collected in 1980 for that period) and combining datum from all stations, a significant difference ($\alpha = .05$) was again found. The obvious significant increases in TP downstream of the outfall in August, 1980 and September, 1980 can be seen in Figure 5.

It would appear that the significant differences between the two years for July could be flow related. Kleiber and Erlebach (6) reported an empirical relationship existed between phosphorous concentrations and flow and that the increase in phosphorous with discharge could be related to the increase in concentration of suspended solids containing the bulk of the phosphates present. They reported these phosphorous containing solids are resuspended from the river bed by the increased turbulence and entrained by increased surface run-off accompanying high flows. The influence of the sewage discharge on TP concentrations was dramatic. For all stations prior to the sewage discharge and for station 1 after the discharge started, mean TP levels never exceeded 10.4 ug/l (Table 5). After the discharge started, for August and September, 1980, mean TP levels for the downstream stations (2,3,4) ranged between 64 ug/l to 206 ug/l.

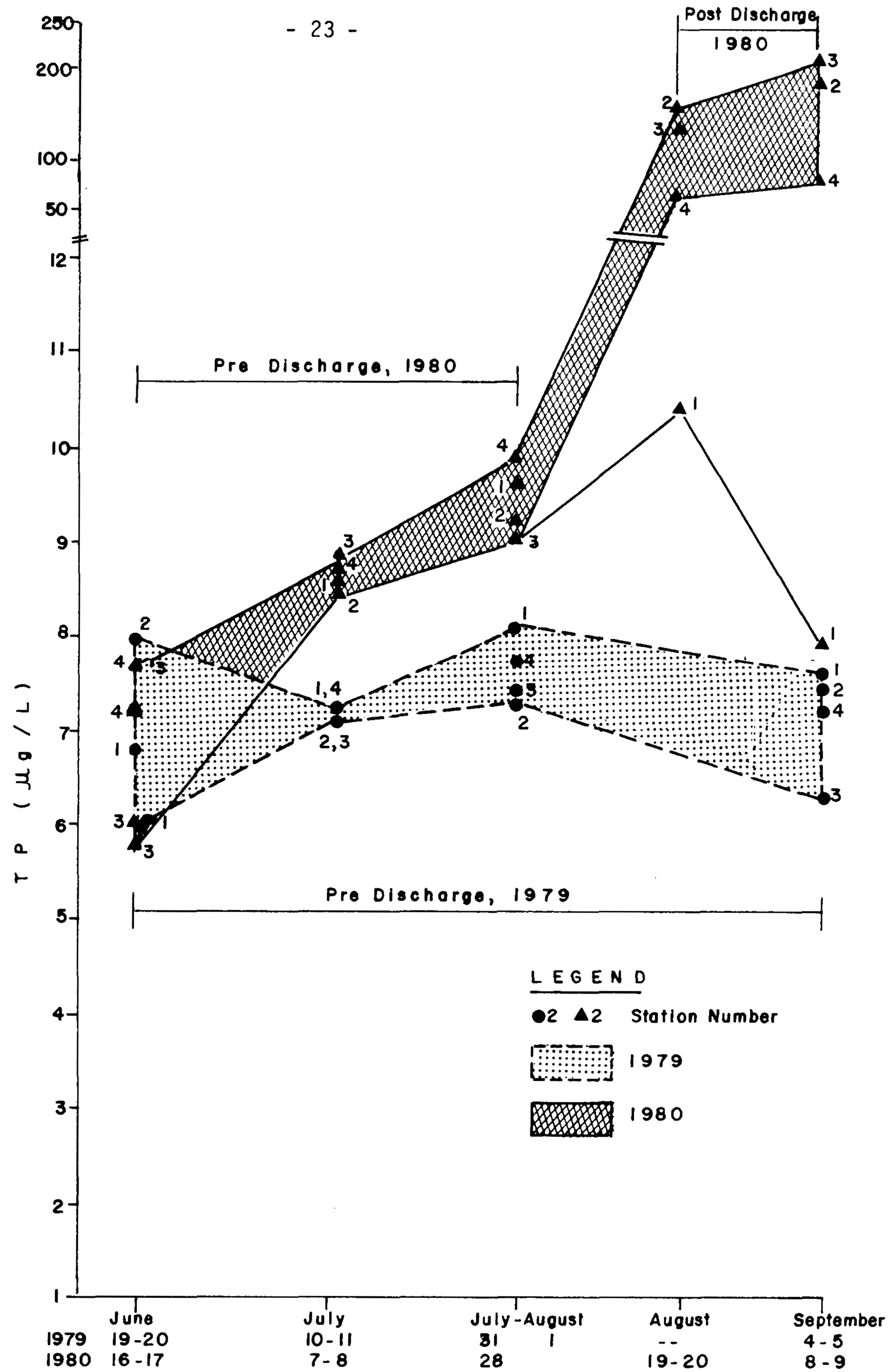

FIGURE 5 THE MEAN TOTAL PHOSPHOROUS CONCENTRATION OF THE FOUR COWICHAN RIVER STATIONS FOR EACH SURVEY IN 1979 AND 1980

From Figure 6, it can be seen that total dissolved phosphorous (TDP) (considered here to be representative of the biologically available phosphorous) followed the pattern for TP and the influence of the sewage discharge was highly significant. For all stations prior to the sewage discharge and for station 1 after the sewage discharge started, mean TDP levels never exceeded 7.4 ug/l (Table 5). After the discharge started, for August and September, 1980, mean TDP levels for the downstream stations ranged between 51 ug/l to 148 ug/l. For the Cowichan River without the influence of sewage effluent, TDP made up 57% of the TP. Under the influence of the sewage effluent the TDP portion increased up to approximately 79% of the TP. Phosphorous may enter a wastewater treatment system in one of three forms: organic phosphorous found in organic matter and cell protoplasm, complex inorganic phosphates such as those in cleaning compounds and as soluble inorganic orthophosphate the final breakdown product in the phosphorous cycle (17). In wastewater that has been treated by biological processes most of the phosphorous will be soluble, although a small amount of insoluble organic phosphorous may be present in the form of cell protoplasm (17). Thus, the increased proportion of TDP in the Cowichan River samples can be attributed to an increase of TDP in the sewage effluent.

Sequential samples for TP were collected at station 2 over the same period as the three sets of replicate samples were collected to assess if samples collected by an automatic sampler would provide similar results and indicate any temporal (over 24 hours) trends [Appendix II(a)]. A one way analysis of variance was used to test for significant differences. In total six trials were conducted before the discharge of sewage started and one trial was conducted during the discharge of sewage. In all cases there were no significant differences ($\alpha = 0.05$) between the two sets of data indicating the automatic sampler is adequate for monitoring TP. There were no obvious temporal trends in the sequential data.

The significance of the elevated phosphorous levels detected downstream of the sewage outfall in August and September, 1980 are discussed in Section 5.

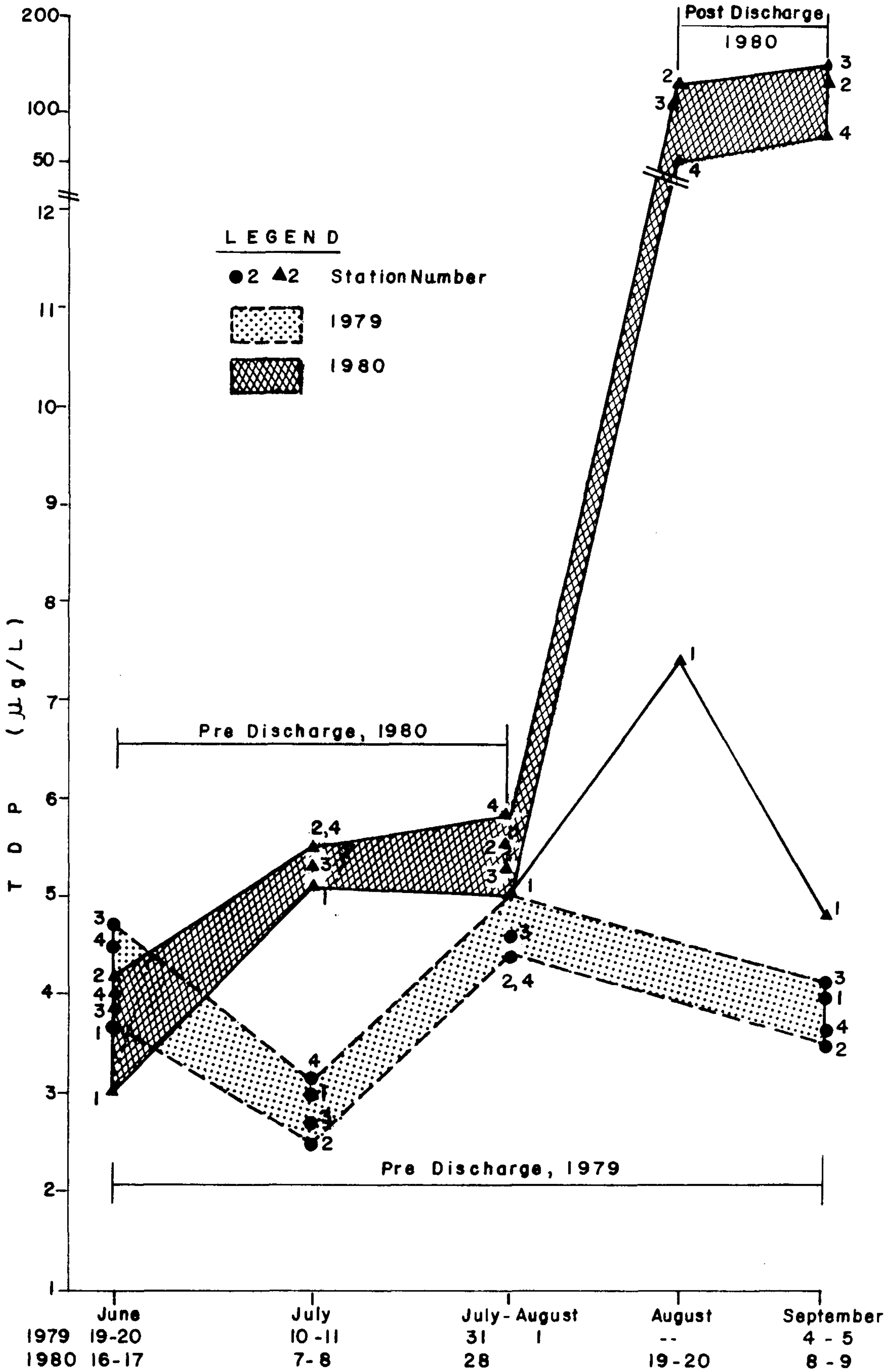

FIGURE 6 THE MEAN TOTAL DISSOLVED PHOSPHOROUS CONCENTRATION OF THE FOUR COWICHAN RIVER STATIONS FOR EACH SURVEY IN 1979 AND 1980

4.1.10 Total Dissolved Nitrogen, Nitrate-Nitrite and Ammonia

The results of nitrogen fractions obtained in this study refer to the fraction analyzed after filtration through a distilled water washed 0.45 u cellulose acetate membrane filter. Prior analysis of distilled water samples filtered through the above treated filters did not show any contamination. This procedure was a variation of that reported in the Inland Waters Manual (28) which reports the use of heat treated GF/F filters. In the latter case, the GF/F filters are used to determine particulate carbon and particulate nitrogen and with the subsequent filtrate being analyzed for the dissolved nitrogen fractions. Prior filtration removes suspended material that in the case of domestic sewage might breakdown between collection and analysis and affect the outcome of the final results.

From Figure 7 it can be seen that there was not that much variability in mean total dissolved nitrogen (TDN) levels between stations and months in 1979 whereas in 1980, the variability between stations was larger. As there was no sewage discharge in June of 1979 and 1980, all the data for the respective stations for each of the two years was combined. A one way analysis of variance didn't show any significant difference ($\alpha = .05$) between the two years. The same was done for early-July and again no significant differences between the two years was found. The same was true for late-July (using only the first set of replicates collected in 1979 as only one set was collected in 1980 for that period) and September (using only the control station data). The influence of the sewage discharge on TDN levels is indicated by a large increase at the downstream stations (2,3, 4) in August and September, 1980 (Table 6). The large TDN increase is related primarily to the large increase in the ammonia (NH_3) component of the sewage (TDN = NH_3 + NO_3/NO_2 + total dissolved organic nitrogen)(Table 6).

For ammonia and using the same periods of comparison for TDN, background mean ammonia levels were found to be significantly different ($\alpha = .05$) between the two years. With the exception of the control station in September 1980, mean ammonia levels were all lower in 1980 than in 1979. The influence of the sewage discharge on the ammonia concentrations was

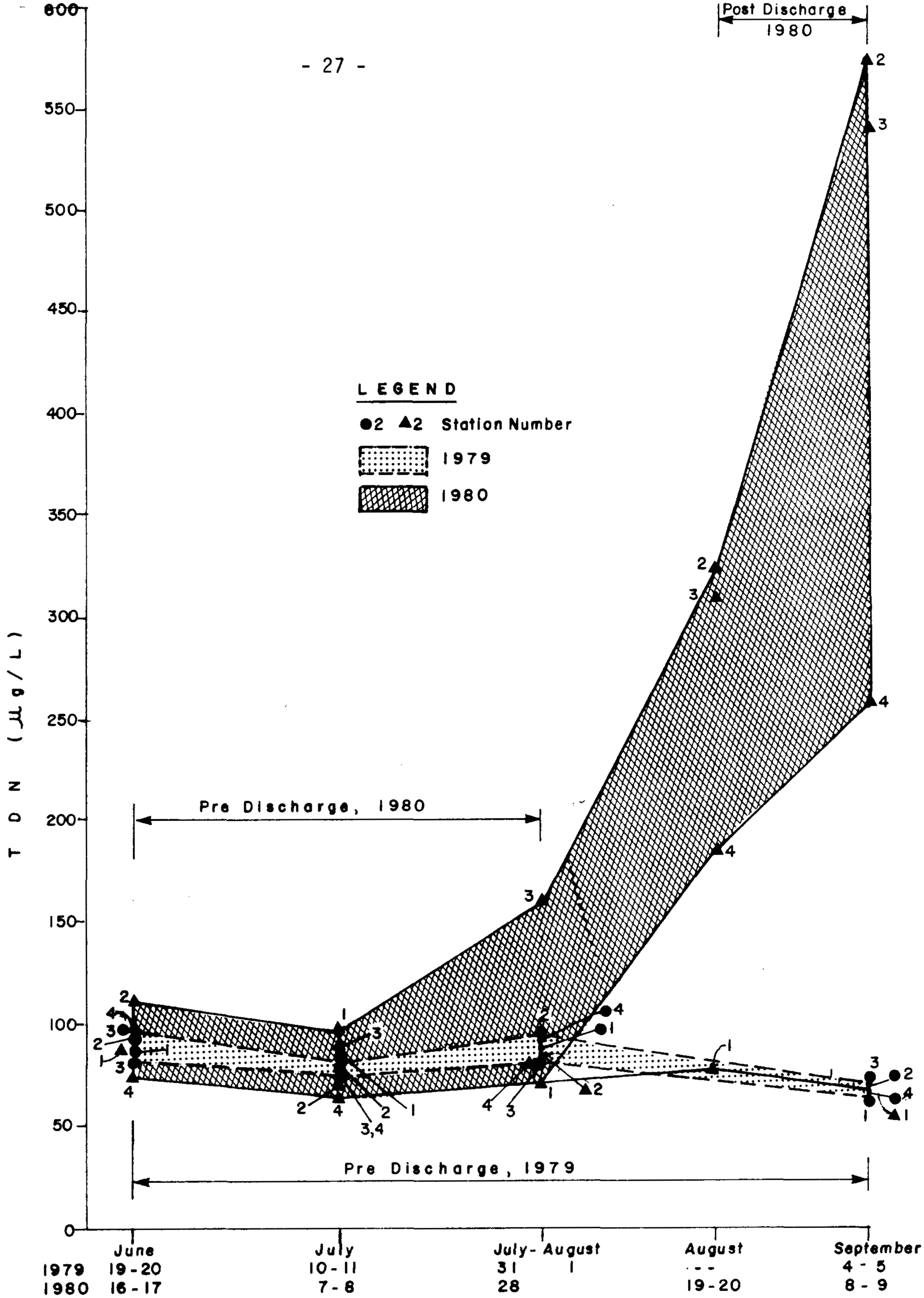

FIGURE 7 THE MEAN TOTAL DISSOLVED NITROGEN CONCENTRATION OF THE FOUR COWICHAN RIVER STATIONS FOR EACH SURVEY IN 1979 AND 1980

TABLE 6 Nitrate-Nitrite, Ammonia and Total Dissolved Nitrogen for The Cowichan River Low Flow Period (1979/80).

PARAMETER . Nitrate-Nitrite (ug/l)

STATION	Jun 19-20 1979 MEAN	S.D.	N	Jul 10-11 1979 MEAN	S.D.	N	Jul 31 - Aug 1 1979 MEAN	S.D.	N	Sep 4-5 1979 MEAN	S.D.	N
1	7.3	1.1	9	3.3	1.0	9	<2.0	.0	9	2.3	.5	9
2	9.6	2.6	9	3.7	1.4	9	2.2	.7	9	<2.0	.0	9
3	7.1	1.6	9	3.0	1.0	9	<2.0	.0	9	2.1	.3	9
4	10.4	4.9	8	3.7	2.1	9	<2.0	.0	9	<2.0	.0	9

STATION	Jun 16-17 1980 MEAN	S.D.	N	Jul 7-8 1980 MEAN	S.D.	N	Jul 28 1980 MEAN	S.D.	N	Aug 19-20 1980 MEAN	S.D.	N	Sep 8-9 1980 MEAN	S.D.	N
1	4.9	.3	9	<2.0	.0	9	5.0	.0	3	<2.0	.0	9	2.2	.7	9
2	4.7	1.1	9	<2.0	.0	9	6.0	.0	3	<2.0	.0	9	2.6	.5	9
3	4.3	1.0	9	<2.0	.0	9	6.0	.0	3	2.1	.3	9	4.8	.8	9
4	5.1	.9	9	<2.0	.0	9	6.0	.0	3	<2.0	.0	9	4.1	1.5	9

PARAMETER . Ammonia (ug/l)

STATION	Jun 19-20 1979 MEAN	S.D.	N	Jul 10-11 1979 MEAN	S.D.	N	Jul 31 - Aug 1 1979 MEAN	S.D.	N	Sep 4-5 1979 MEAN	S.D.	N
1	9.4	4.7	9	3.2	1.8	9	5.1	1.7	9	2.4	1.0	9
2	9.8	2.3	9	3.2	1.7	9	6.8	4.6	9	2.3	.5	9
3	7.1	3.9	9	2.2	.7	9	4.7	1.9	9	2.4	.9	9
4	7.9	4.0	8	3.1	2.1	9	5.4	2.7	9	2.7	.9	9

STATION	Jun 16-17 1980 MEAN	S.D.	N	Jul 7-8 1980 MEAN	S.D.	N	Jul 28 1980 MEAN	S.D.	N	Aug 19-20 1980 MEAN	S.D.	N	Sep 8-9 1980 MEAN	S.D.	N
1	5.4	1.8	9	<2.0	.0	9	<2.0	.0	3	4.0	1.3	9	6.4	2.4	9
2	5.1	2.2	9	<2.0	.0	9	<2.0	.0	3	215.6	18.7	9	(453)*	-	-
3	4.4	2.4	9	<2.0	.0	9	<2.0	.0	3	206.8	10.9	9	(427)*	-	-
4	2.4	.7	9	<2.0	.0	7	<2.0	.0	3	82.8	5.0	9	203.6	18.2	9

PARAMETER . Total Dissolved Nitrogen (ug/l)

STATION	Jun 19-20 1979 MEAN	S.D.	N	Jul 10-11 1979 MEAN	S.D.	N	Jul 31 - Aug 1 1979 MEAN	S.D.	N	Sep 4-5 1979 MEAN	S.D.	N
1	88.9	8.6	9	80.0	15.8	9	88.3	7.9	9	64.4	3.0	9
2	91.7	12.5	9	79.4	8.8	9	94.2	33.2	9	65.6	6.3	9
3	84.4	10.1	9	75.0	5.6	9	81.1	4.9	9	68.3	4.3	9
4	95.6	12.7	8	75.0	9.0	9	90.7	14.7	9	65.0	4.3	9

STATION	Jun 16-17 1980 MEAN	S.D.	N	Jul 7-8 1980 MEAN	S.D.	N	Jul 28 1980 MEAN	S.D.	N	Aug 19-20 1980 MEAN	S.D.	N	Sep 8-9 1980 MEAN	S.D.	N
1	88.3	47.9	9	96.1	80.8	9	71.7	5.8	3	77.2	40.9	9	67.2	6.7	9
2	111.1	92.6	9	72.8	10.3	9	83.3	28.4	3	321.7	29.9	9	573.9	87.3	9
3	95.6	58.6	9	89.4	42.2	9	158.3	55.1	3	306.7	12.5	9	539.4	41.1	9
4	75.0	34.0	9	63.9	3.3	9	81.7	20.2	3	184.4	48.9	9	253.9	34.2	9

* estimated value

significant as seen in Figure 8. For all stations prior to the sewage discharge and for control station #1 after the discharge started, mean NH_3 levels never exceeded 9.4 ug/l and values at or near detectable levels (2 ug/l) were particularily evident in 1980 (Table 6). Ammonia levels were highest in June of each year just at the onset of the low flow period. After the sewage discharge started, for August and September, 1980, mean NH_3 levels for the downstream stations ranged between approximately 83 ug/l to 216 ug/l in August. Due to an analytical problem only station #1 and station #4 ammonia levels have been used for September and the mean for station 4, 350 meters downstream, was 204 ug/l. Ammonia levels at stations #2 and #3 would be less than the TDN values (574 ug/l and 540 ug/l respectively and based on a ratio of 0.79:1 (NH_3:TDN) at station #4, values of 453 ug/l and 427 ug/l respectively would be rough estimates.

From Figure 9, it is evident that in 1979, nitrate-nitrite (NO_3-NO_2) levels followed a progressive decline from mean values in the order of 7.1 ug/l - 10.4 ug/l in June to just detectable or below detectable (2.0 ug/l) levels in late-July and September (Table 6). This pattern was reflected again in 1980 with June values in the order of 4.3 ug/l - 5.1 ug/l declining to below detectable levels by early-July. Levels increased in late-July, 1980 but than NO_3-NO_2 levels subsquently declined to near detectable levels again in August. The influence of the sewage effluent on NO_3 - NO_2 dowstream of the outfall was not pronounced, with no real change in August and a slight increase in September (Table 6). This reflects a lack of nitrification occurring in the lagoon i.e. conversion of ammonia to nitrite and then nitrite to nitrate.

The significance of the elevated nitrogen levels recorded downstream of the sewage outfall are discussed in Section 5.

Sequential samples for TDN, NH_3 and NO_3-NO_2 were collected at station 2 to assess if samples collected by an automatic sampler would provide similar results and indicate any temporal (over 24 hours) trends. Results for five of the predischarge trials and one postdischarge trial are reported in Appendix II(b,c, d). A one way analysis of variance was used to test for significant differences. For TDN, in all cases there were no

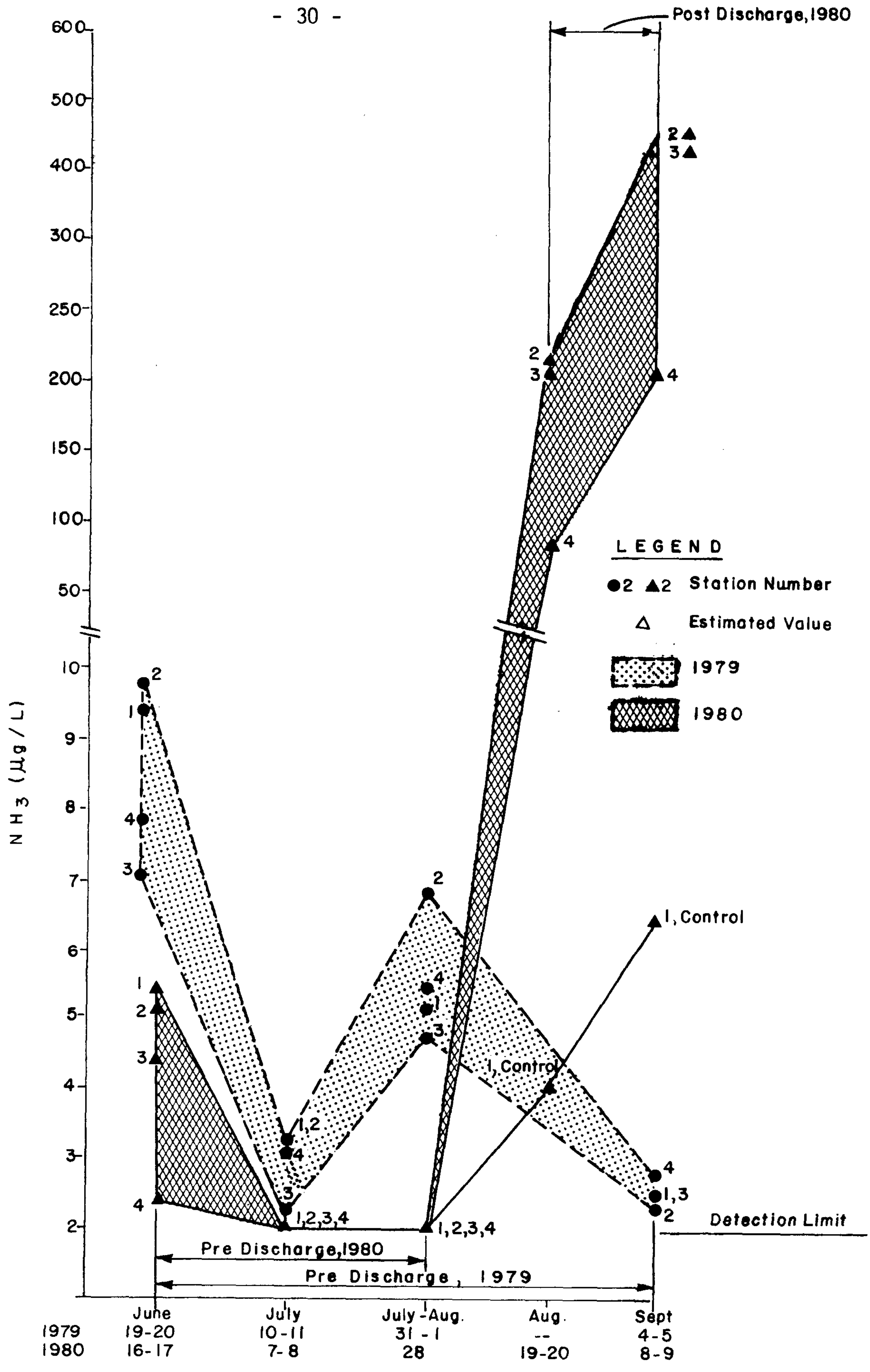

FIGURE 8 THE MEAN AMMONIA CONCENTRATION OF THE FOUR COWICHAN RIVER STATIONS FOR EACH SURVEY IN 1979 AND 1980

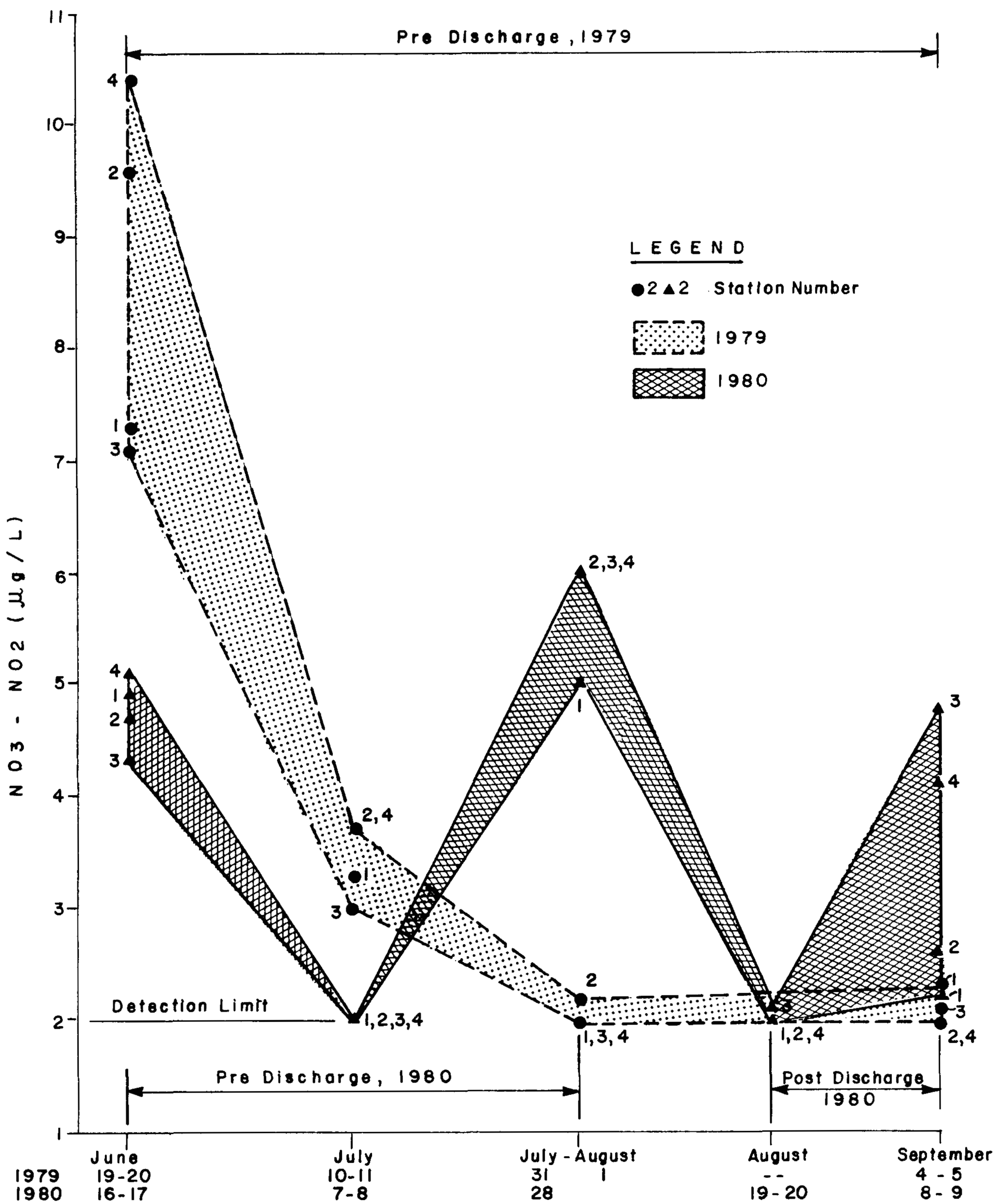

FIGURE 9 THE MEAN NITRATE - NITRITE CONCENTRATION OF THE FOUR COWICHAN RIVER STATIONS FOR EACH SURVEY IN 1979 AND 1980

significant differences (α= .05) between the two sets of data indicating the automatic sampler was adequate for monitoring TDN.

For ammonia, the only trial that showed significant differences (α= .05) between the methods was in September, 1979. However, the NH_3 results for the sequential samples in September included several outliers (relatively high single values) and suggests a possible source of contamination [Appendix II(c)]. With the exception of September 1979, the data indicates samples collected by the automatic sampler compare favorably with replicated grab samples. For NO_3-NO_2, four of the six trials indicated significant differences (α= .05) existed between the results of the two sample methods. For September 1979 this difference might reflect the potential contamination problem identified for the NH_3 samples. For the August, 1980 trial during which sewage effluent was being discharged, the difference definitely exists due to the nitrification of ammonia in the sample bottle. The sequential samples had a mean NO_3 - NO_2 concentration of 12.4 ug/l compared to $<$ 2 ug/l for the replicated samples. The replicated grab samples were all below detectable levels, while for the sequential samples, the samples at the end of the run were just at detectable levels while the samples collected on the previous day and overnight were about 10x higher [Appendix II(c)]. Thus, for sampling a sewage discharge, unless adequate refrigeration of the samples in the automatic sampler is provided or the samples can be routinely removed and kept cool the results obtained can not be considered representative. The latter option would negate the advantage of the automatic sampler, namely not having to routinely be onsite to collect a grab sample.

4.2 Bacteriological Studies

The daily bacteriological results are reported in Appendix III. The arithmetic mean for each parameter at each sample station was calculated and the results are presented in Table 7. The sample stations for the Cowichan River and Duncan-North Cowichan (D-NC) sewage lagoon are shown on Figure 2 and 3 respectively. The efficiency of the D-NC treatment system in removing indicator bacteria is expressed in terms of a $\log_{10}$ reduction and these results are presented in Tables 8 and 9. The $\log_{10}$ reduction value was determined by calculating the $\log_{10}$ of the appropriate mean values shown in Table 7 and obtaining the difference in the $\log_{10}$ values between progressive treatment stages. This method of data interpretation was deemed more appropriate than expressing the results in terms of a percentage decrease due to the large orders of magnitude in the data. For example, a 5 $\log_{10}$ reduction is equivalent to approximately 99.999% removal of fecal coliforms in this system.

During the sample period, the treatment effected a total coliform reduction of 2.78 $\log_{10}$ units (99.835%) and a fecal coliform reduction of 5.29 $\log_{10}$ units ($>$99.999%). The log reduction of total and fecal coliforms after each stage of treatment are presented in Tables 8 and 9.

For comparative purposes the fecal coliform reduction achieved at the smaller Lake Cowichan (LC) sewage lagoon during the various treatment stages are reported in Table 10. A total fecal coliform reduction of 5.58 $\log_{10}$ units and 4.54 $\log_{10}$ units was observed at the L.C. treatment system in February, 1978 and September, 1977 respectively. The D-NC treatment system obtained comparable results in terms of total fecal coliform reduction. For total coliforms, a total reduction of 3.26 $\log_{10}$ units was obtained at the L.C. treatment system in September, 1977 (9), somewhat better than that achieved in this study at the D-NC treatment system. The total fecal coliform reduction achieved by aeration [prior to chlorination, station L5] was 1.80 $\log_{10}$ units for the D-NC system compared to 3.13 $\log_{10}$ units and 4.00 $\log_{10}$ units for the LC system in February, 1978 and September, 1977 respectively. For total coliforms, the total reduction achieved by aeration

TABLE 7: SUMMARY OF BACTERIOLOGICAL RESULTS FOR DUNCAN-NORTH COWICHAN SEWAGE TREATMENT LAGOONS AND THE COWICHAN RIVER

LAGOONS	SAMPLE STATION	MEAN BACTERIAL COUNT/100 ml							
		TC	LOG_{10}	FC	LOG_{10}	FS	LOG_{10}	35°SPC/ml	LOG_{10}
Raw	L1	$2.0x10^7$ (4)*	7.30	$2.8x10^6$ (4)	6.45	$7.4x10^5$ (4)	5.87		
After aeration cell #1	L2	$2.4x10^5$ (3)	5.38	$2.4x10^4$ (4)	4.38				
After cell #2	L3	$3.1x10^5$ (4)	5.49	$2.9x10^3$ (4)	3.46				
End of aeration cell #3	L4	$2.7x10^5$ (3)	5.43	$4.5x10^4$ (4)	4.65				
After cell #4, pre-chlorination[1]	L5	$1.2x10^5$ (3)	5.08	$4.5x10^4$ (4)	4.65				
Post-chlorination	L6	$4.1x10^4$ (3)	4.61	$1.7x10^2$ (4)	2.23			$4.4x10^4$	4.64
After cell #5, pre-dechlorination	L7	$2.3x10^4$ (4)	4.36	65.0 (4)	1.80			$5.2x10^5$ (4)	5.72
Final effluent, post-dechlorination[1]	L8	$3.3x10^4$ (14)	4.52	14.5 (21)	1.16	$3.4x10^3$ (20)	3.53	$4.8x10^5$ (21)	5.68
COWICHAN RIVER	1			35.0 (4)		77.5 (4)			
	2			96.7 (4)		105.0 (4)			
	3			65.0 (4)		100.0 (4)			
	4			86.7 (4)		85.0 (4)			
	5			30.0 (3)		130.0 (3)			

* number in brackets indicates number of samples collected

[1] average daily flow of 6900 m^3/d

TABLE 8: TOTAL COLIFORM AND FECAL COLIFORM REDUCTION THROUGH PROGRESSIVE TREATMENT STAGES

STATIONS	LOG_{10} REDUCTION (INCREASE) BETWEEN STAGES OF TREATMENT TOTAL COLIFORM	FECAL COLIFORM	35°C SPC
L1 - L2	1.92	2.07	
L2 - L3	(0.11)	0.92	
L3 - L4	0.06	(1.19)	
L3 - L5	0.41	(1.19)	
L4 - L5	0.35	0.0	
L5 - L6	0.47	2.42	
L6 - L7	0.25	0.43	(1.08)
L6 - L8	0.09	1.07	(1.04)
L7 - L8	(0.16)	0.64	0.04

TABLE 9: TOTAL COLIFORM AND FECAL COLIFORM REDUCTION FROM RAW INFLUENT AT VARIOUS TREATMENT STAGES

STATION	Total Coliforms LOG_{10}	Fecal Coliforms LOG_{10}
Post aeration L2	1.92	2.07
Pre-chlorination L5	2.22	1.80
Post-chlorination L6	2.69	4.22
Final-dechlorination L8	2.78	5.29

TABLE 10: SUMMARY OF BACTERIOLOGICAL ANALYSES FOR LAKE COWICHAN SEWAGE LAGOON DISCHARGE

STATION	Mean Bacteria Counts (Fecal Coliforms*/100 ml)				Percent Reduction** (FC)	
	Feb/78 (2)		Sept/77 (3)		Feb/78	Sept/77
	FC	LOG_{10}	FC	LOG_{10}		
Raw	$3.8x10^6$ (8)	6.58	$4.5x10^6$ (4)	6.65		
After aeration basin #1	$1.4x10^5$ (9)	5.15	$2.6x10^4$ (4)	4.41	96.32	99.43
After aeration basin #2	$2.8x10^3$ (9)	3.45	$4.5x10^2$ (3)	2.65	99.93	99.989
Head of chlorine contact tank	$1.7x10^2$ (9)	2.23	$3.1x10^2$ (5)	2.49	99.995	99.993
End of chlorine contact tank	<10 (8)	1.00	$1.0x10^3$ (5)	3.00	>99.997	99.976
Final effluent after dechlorination cell (1)	<10 (8)	1.00	$1.3x10^2$ (5)	2.11	>99.9997	99.997

* membrane filtration
** reduction from mean raw sewage count

( ) number of samples collected

(1) average daily flows of 980 m^3/d
(2) reference #8
(3) reference #9

was 2.22 log_{10} units for the D-NC system compared to 2.79 log_{10} units for the L.C. system in September, 1977(9).

Generally as the raw influent moved through the lagoon system, total and fecal coliform levels dropped. Higher total coliform and 35°C SPC levels at station L8 would be attributed to regrowth of non-fecal coliforms as fecal coliforms indicated a reduction of 0.64 log_{10} units. Higher fecal colforms levels found at stations L4 and L5 were due to high fecal coliform input from cell no.3 (Figure 3) which initiates treatment of raw influent from another sector of the North Cowichan District.

The sewage treatment system operated well with respect to bacterial reduction, where aeration up to the point of chlorination removed 1.80 log_{10} units (98.4%) of fecal coliforms. Chlorination reduced fecal and total coliform levels below those achieved by the lagoon treatment. The effectiveness of chlorination on total coliform reduction was less than that for fecal coliform reduction. The total coliform levels did not change significantly between stations L6, L7 and L8 while fecal coliform levels showed a dramatic reduction and this is likely to be due to additional contact time.

The final effluent (L8) was sampled on an hourly basis from 0800 to 1400 h daily. This was done to assess the efficiency of the chlorination system in disinfecting the effluent over a variety of flow conditions. Both fecal coliform and total coliform values remained relatively constant during the day indicating that the flow did not have any bearing on the bacteriological quality of the effluent.

No chlorine was detected in the final effluent during the study. Results from the chlorine residual analyses conducted by the Waste Management Branch, Victoria are presented in Table 11.

On the Cowichan River, four stations were established downstream and one upstream from the discharge. The fecal coliform levels found downstream of the discharge were elevated from those observed at the upstream station, although none of the river results were exceptionally high (Table 7).

TABLE 11: PRELIMINARY RESULTS FOR CHLORINE RESIDUAL FROM DUNCAN-NORTH COWICHAN SEWAGE LAGOON

Cl_2 Residual/Demand[1] SO_2 addition at approximately 0.5 kg/day and chlorine addition at approximately 9.1 kg/day.

Date		At Cl_2 injection	End of Spillway (L6)	Final Effluent (L8)
Sept. 3	10:00	(+) 2.2 ppm Cl_2	(+) 0.4 ppm Cl_2	(-) 0.75 ppm Cl_2
Sept. 15	10:30			(-) 0.83 ppm Cl_2
	13:00	(+) 2.4 ppm Cl_2	(+) 0.64 ppm Cl_2	(-) 0.73 ppm Cl_2
	15:00			(-) 0.63 ppm Cl_2
Sept. 16	13:00	(+) 2.7 ppm Cl_2	(+) 0.25 ppm Cl_2	(-) 0.72 ppm Cl_2
Sept. 17	13:00	(+) 0.41 ppm Cl_2	(-) 0.50 ppm Cl_2 (-) 0.55 ppm Cl_2	(-) 0.85 ppm Cl_2
Sept. 18	09:30	(+) 1.15 ppm Cl_2	0.0 ppm Cl_2	(-) 0.82 ppm Cl_2

Cl_2 demand in Final Effluent at various SO_2 injection rates on Sept. 19, 1980 (Flow approximately 4545 m^3/d)

SO_2 rate	Test	Result
.45 kg/day SO_2	Test #1	(-) 0.81 ppm Cl_2
	#2	(-) 0.83 ppm Cl_2
	#3	(-) 0.82 ppm Cl_2
	$\bar{x}$ =	(-) 0.81
4.5 kg/day SO_2	Test #1	(-) 0.88 ppm Cl_2
	#2	(-) 0.89 ppm Cl_2
	#3	(-) 0.87 ppm Cl_2
	$\bar{x}$ =	(-) 0.88
9.1 kg/day SO_2	Test #1	(-) 1.09 ppm Cl_2
	#2	(-) 1.09 ppm Cl_2
	$\bar{x}$ =	(-) 1.09
22.7 kg/day SO_2	Test #1	(-) 1.30 ppm Cl_2
	#2	(-) 1.56 ppm Cl_2
	#3	(-) 1.28 ppm Cl_2
	$\bar{x}$ =	(-) 1.38

[1] Fisher Porter Amperometric Titrator, Residual (+), Demand (-).

The impact of the sewage discharge on the bacteriological quality of the Cowichan River was therefore not significant during this study.

The fecal streptococci levels found downstream of the discharge were higher than the upstream station. The final effluent could be the contributing factor since fecal streptococci levels were relatively high. Fecal streptococci analyses were conducted to assist in determining the source of fecal pollution to the Cowichan River, i.e., human or animal. However, the levels were too low to make any conclusions as to the source.

4.3 Flow-through Bioassay

The lagoon effluent was non-acutely toxic to coho salmon fry during the period of September 15 to September 19, 1980. There were no fish mortalities during the acclimation period. Dissolved oxygen and pH data collected from the test vessels are presented in Table 12. Temperatures in the test vessels remained in the range of 16°C to 18.5°C.

A daily grab sample of non-aerated 100% effluent and control dilution water were obtained during the course of the bioassay and the results are presented in Tables 13 and 14 respectively. Except for the low dissolved oxygen levels of 1.6 to 3.6 mg/l obtained by the Winkler dissolved oxygen method, other parameters in the 100% effluent sample were at levels that would not be expected to be acutely toxic to fish. Oxygen levels in the test vessels containing sewage (recorded with an oxygen meter) exhibited adequate dissolved oxygen levels of 5.3 to 8.6 mg/l (Table 12). Oxygen levels in the control vessel (measured by the oxygen meter) were 9.4 - 10.0 mg/l and by the Winkler method they were 8.6 to 9.7 mg/l. The azide method is reported not to be applicable for samples containing sulfite (27). Dechlorination at the D-NC lagoon is achieved with the addition of sulfur-dioxide (SO_2) after the chlorine contact basin. In the dissociation of SO_2 in water at neutral pH, it is found primarily as sulfite (SO_3^{--}). The lower Winkler dissolved oxygen values may inpart reflect an interference due to a sulfite residual. However, the higher dissolved oxygen levels measured in the bioassay vessels are probably a reflection of the aeration of the test solutions, whereas, the Winkler samples were collected prior to the effluent entering the test vessel. Sulfur dioxide reacts with dissolved oxygen and raises the possibility that reaeration may be required to maintain dissolved oxygen levels in the effluent (33).

No chlorine was detected in the final effluent during the bioassay period at a chlorine (9.1 kg/day) to SO_2 (0.5 - 1.0 kg/day) addition rate of 10:1 (Table 11). Sulfite residuals were not measured onsite due to a problem with the test kit. It should be noted that partial or total dechlorination may occur in the contact basin prior to any SO_2 addition.(33)

TABLE 12: DISSOLVED OXYGEN AND pH LEVELS WITHIN THE FLOW-THROUGH BIOASSAY TEST VESSELS

CONCENTRATION (by volume)	SEPT. 15/80 1140 hrs.		SEPT. 16/80 0830 hrs.		SEPT. 19/80 1040 hrs.	
	pH	DO (mg/l)	pH	DO (mg/l)	pH	DO (mg/l)
100%	7.2	6.0	--	6.8	7.4	--
90%	7.2	6.5	--	5.3	7.4	5.6
75%	7.3	7.4	--	7.3	7.3	5.7
68%	7.3	7.7	--	8.3	--	--
56%	7.3	8.1	--	7.5	7.5	8.6
Control	7.5	9.9	--	9.4	7.5	10.0

TABLE 13: EFFLUENT QUALITY OF THE DUNCAN-NORTH COWICHAN SEWAGE LAGOON DURING THE FLOW-THROUGH BIOASSAY

VARIABLE*	SEPT 15/80	SEPT 16/80	SEPT 17/80	SEPT 18/80
TOC	30	31	30	30
TIC	30	33	32	32
Phenol	0.032	0.030	0.046	0.031
Dissolved Oxygen (Winkler)	3.6	1.6	2.9	2.4
Sulfide	< 0.050	< 0.050	< 0.050	< 0.050
LAS (surfactants)	0.098	0.098	0.085	0.098
COD	90	85	85	100
NFR	14	16	12	15
Conductivity (uhmos/cm)	387	395	392	398
Alkalinity (as $CaCO_3$)	117	120	120	119
Turbidity (FTU)	2.3	6.7	6.0	19.0
Hardness	47.4	48.1	47.0	48.1
pH	7.0	--	--	7.0
NO_2	< 0.0050	< 0.0050	< 0.0094	< 0.0050
NO_3	< 0.010	< 0.010	< 0.010	< 0.010
$NH_3 + NH_4^+$	12.6	16.1	20.0	--
Undissociated NH_3***	0.037	0.047	0.059	--
TDN	13.0	11.0	16.0	14.5
TP	5.57	4.78	4.85	4.45
TDP	4.84	3.99	4.85	4.42
Extractable**				
Cu	0.021	0.017	0.017	0.020
Pb	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Cd	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Zn	0.0186	0.0070	0.0260	0.0094
Fe	0.237	0.277	0.215	0.336
Dissolved**				
Cu	0.014	0.0088	0.029	0.021
Pb	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Cd	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Zn	0.073	0.0077	0.0074	0.0110
Fe	0.106	0.135	0.114	0.157
Flow (m^3/d)	4906	4906	4612	4563

* as mg/l, single grab sample

** Inductively Coupled Plasma Spectrograph and Flameless Atomic Absorption (27)

*** Caluclated from Emerson et al (10) for pH 7 and 16°C.

TABLE 14: QUALITY OF THE COWICHAN RIVER CONTROL WATER USED IN FLOW-THROUGH BIOASSAY

VARIABLE*	SEPT 15/80	SEPT 16/80	SEPT 17/80	SEPT 18/80
TOC	1.0	1.0	3.0	2.0
TIC	5.0	6.0	6.0	6.0
Phenol	< 0.020	<0.020	< 0.020	< 0.020
Dissolved Oxygen (Winkler)	9.7	9.3	--	8.6
Sulfide	< 0.050	<0.050	< 0.050	< 0.050
LAS (surfactants)	< 0.040	<0.040	< 0.040	< 0.040
COD	< 20	< 20	< 20	< 20
NFR	< 5	< 5	< 5	< 5
Conductivity (uhmos/cm)	60.5	59.0	62.0	61.0
Alkalinity (as $CaCO_3$)	23.8	24.5	25.0	24.5
Turbidity (FTU)	< 1.0	< 1.0	1.0	< 1.0
Hardness	24.0	23.1	24.3	24.3
pH	7.4	--	--	7.5
NO_2	< 0.0050	<0.0050	< 0.0050	<0.0050
NO_3	< 0.010	< 0.010	0.0169	< 0.010
$NH_3 + NH_4^+$	0.0104	0.0076	0.0057	0.0076
TDN	0.080	0.105	0.120	0.110
TP	< 0.0050	0.0069	0.0142	0.0074
TDP	< 0.0050	0.0097	0.0155	0.0061
<u>Extractable</u>**				
Cu	< 0.0010	<0.0010	< 0.0010	<0.0010
Pb	< 0.0010	<0.0010	< 0.0010	<0.0010
Cd	< 0.0010	<0.0010	< 0.0010	<0.0010
Zn	0.0085	0.0016	0.0036	<0.0010
Fe	0.033	0.034	0.037	0.042
<u>Dissolved</u>**				
Cu	0.0015	<0.0010	< 0.0010	<0.0010
Pb	< 0.0010	<0.0010	< 0.0010	<0.0010
Cd	< 0.0010	<0.0010	< 0.0010	<0.0010
Zn	0.023	0.0010	0.0016	0.0014
Fe	0.017	0.011	0.016	< 0.010
River Flow (m^3/d)	395,778	627,368	641,195	612,678

* as mg/l, single grab sample

** Inductively Coupled Plasma Spectrograph and Flameless Atomic Absorption (27)

The results in Table 11 indicate there is a high background chlorine demand in the final effluent and an addition rate of approximately ten times that during the bioassay was required to show an additional demand of 0.07 ppm. Further work would have to be done to assess if complete dechlorination could be achieved on a year-round basis with the contact basin alone. The addition of SO_2 in the final effluent provides a safe guard against incomplete dechlorination and possible fish toxicity due to residual chlorine.

Undissociated ammonia levels (0.037 - 0.059 mg/l) were at levels below the 96-hr LC_{50} of 0.45 mg/l for fingerling coho salmon (11) and (0.5 - 0.8 mg/l) for cutthroat trout fry (12). Thurston et al (29) reported that for rainbow trout, ammonia toxicity increased as dissolved oxygen decreased. The lowest dissolved oxygen level at which 90% of the control fish survived 96 hrs was 2.6 mg/l and the 96-hr LC_{50} was 0.316 mg/l undissociated ammonia (pH = 7.89, temp. = 12.5°C) (29).

The low nitrite and nitrate levels of the final effluent indicate that, in September, nitrification of ammonia is not occuring in the lagoon.

5 IMPACT AND CONSIDERATIONS RELATED TO INCREASED NUTRIENT CONCENTRATIONS

5.1 Impact of Increased Nutrient Concentrations on Attached Algae

The impact on the Cowichan River of the increased nutrient concentrations from to the Duncan-North Cowichan sewage can be seen by comparing the attached algae community seen in photographs taken September 9, 1980. There are striking differences between the upstream periphyton community (Plate 3) to that at station 3 (Plate 4), station 4 (Plate 5) and downstream of the study area (Plate 6). At station 1 (upstream) the natural substrate was composed of a heavy diatom and blue-green (Dichothrix sp.) cover and a few short green tufts (Oedegonium spp.) (K. Munro, DFO preliminary results, 1980). Maximum growth was visually observed to be at station 3 (150 meters downstream) and station 4 (350 meters downstream). On September 9, 1980 the growth at station 3 consisted of a thick blue-green (Phormidium autumnale) and thick slimey green (Stigeoclonium stagnatile) cover (K. Munro, DFO preliminary results, 1980). At station 4 the growth consisted of a thick growth of (Phormidium autumnale) and long green filaments (up to 30 cm) of (Oedegonium spp.). A comprehensive analysis of the attached algae community in terms of biomass and species identification is being prepared by the Department of Fisheries and Oceans (S. Samis, per. comm., DFO, 1980). The point to be made here is that the impact of the nutrient additions on the attached algae community was large. Visual observations of the attached algae showed that the effluent, which was being discharged into the main stream flow, was initiallly restricted to a narrow band downstream to station 2. From there the direction of the main flow shifted towards the other side of the river and by station 3 (150 meters downstream), the algal growth showed the influence of the discharge to have extended right across the river. The area affected within the study area (to the narrows upstream of Somenos Creek, Plate 1) is estimated to be approximately 2.25 hectares.

Plate 3
RIVER SUBSTRATE
UPSTREAM OF
SEWAGE OUTFALL
(September 1980)

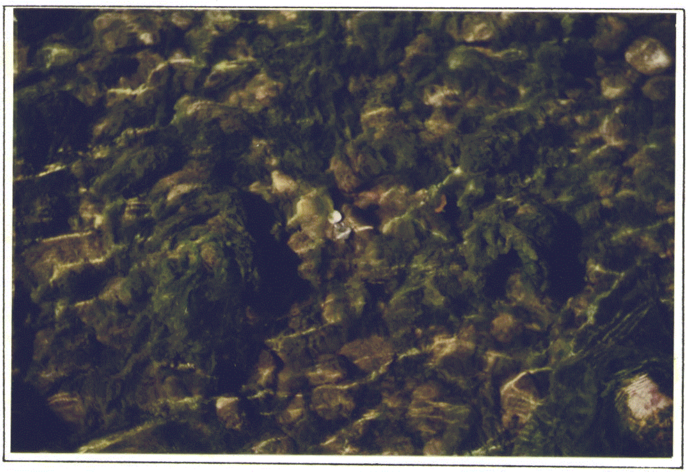

Plate 4
RIVER SUBSTRATE
AT STATION 3,
150 METERS
DOWNSTREAM OF
SEWAGE OUTFALL
(September 1980)

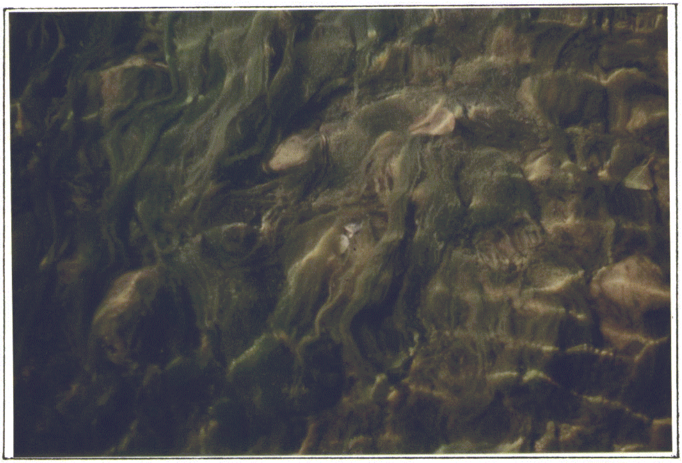

Plate 5
RIVER SUBSTRATE
AT STATION 4,
350 METERS
DOWNSTREAM OF
SEWAGE OUTFALL
(September 1980)

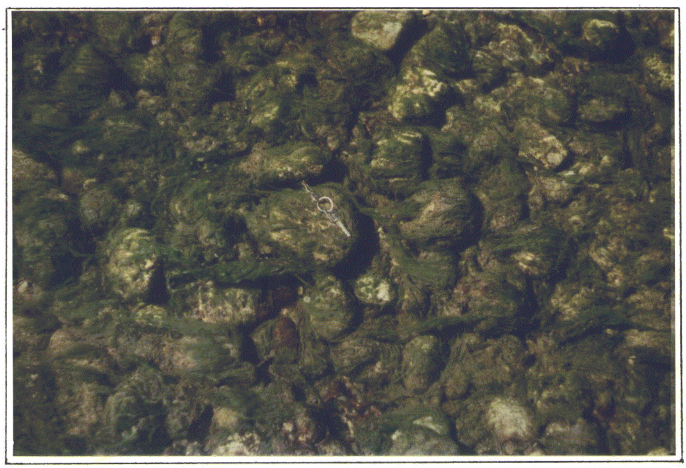

Plate 6
RIVER SUBSTRATE
500 METERS
DOWNSTREAM OF
SEWAGE OUTFALL
(September 1980)

5.2 Effluent Dilution Considerations

The mean Cowichan River flow over August 19, 1980 to September 9, 1980 was 5.2 m^3/s and the mean sewage discharge for September, 1980 was 0.062 m^3/s. The latter is considered to be representative of summer sewage flow volumes. Under these flow conditions, the theoretical dilution is 84:1 assuming instantaneous complete mixing. The present Pollution Control permit allows for a maximum discharge of 0.157 m^3/s or 2.5 times the September rate.

The increase in the nutrient fractions above background levels for the downstream stations is summarized in Table 15. The lack of dilution capacity is best demonstrated at station 4, 350 meters downstream of the outfall. For TDP and NH_3, increases in August were 5.9 and 20 times respectively and in September, increases were 15 and 31 times respectively. The higher levels in September reflect higher nutrient levels in the effluent (Table 16) plus slightly lower river flows. To have achieved background levels at station 4 in August, river flows would have had to be in the order of 36 m^3/s for TDP and 109 m^3/s for NH_3. For September, river flows in the order of 78 m^3/s for TDP and 161 m^3/s for NH_3 would be required to reduce levels to background.

From TDP and NH_3 effluent concentrations and levels reported in the Cowichan River (less background) rough approximations of effluent dilution have been calculated (Table 15). In August, 1980 the dilution at station 2, 3 and 4 respectively was approximately 31:1, 36:1 and 86:1 respectively. Similar dilutions were also found in September 1980.

On an average basis, Cowichan River daily flows lower than 20 m^3/s can be expected to occur approximately 60%, 85%, 99%, 84% and 77% of the time for June, July, August, September and October respectively (Table 17). Daily flows less than 10 m^3/s can be expected to occur approximately 24%, 54%, 88%, 52% and 30% of the time respectively. August is the month minimum flows generally occur and between 1977 and 1980, from 52% to 100% ($\bar{x}$ = 78%) of the daily flows were between 4-6 m^3/s. In a year such as 1979 which had very low flows, 63%, 93% and 100% of the daily flows for June, July and August respectively were below 6 m^3/s.

TABLE 15: TIMES INCREASE IN NUTRIENT CONCENTRATIONS ABOVE BACKGROUND LEVELS IN AUGUST, 1980 AND SEPTEMBER, 1980 AND ESTIMATED DILUTION

	August, 1980			September, 1980		
	Stn 2 50 m*	Stn 3 150 m*	Stn 4 350 m*	Stn 2 50 m*	Stn 3 150 m*	Stn 4 350 m*
TP	14	12	5	22	25	9.3
TDP	17	14	5.9	27	30	15
TDN	3.2	3.0	1.4	7.5	7.0	2.8
NH_3	53	51	20	(70)	(66)	31
$NO_3 - NO_2$	0	.05	0	0.2	1.2	0.9

(Estimated)
* downstream from diffuser

Example Calculation: $\frac{[\text{Stn 2}] - [\text{Stn 1}]}{[\text{Stn 1}]}$ = times increase

ESTIMATED DILUTION

	August 1980			September 1980		
	Stn 2	Stn 3	Stn 4	Stn 2	Stn 3	Stn 4
TDP	31:1	36:1	86:1	39:1	35:1	71:1
NH_3	36:1	37:1	95:1	33:1	35:1	75:1

Example Calculation: $\frac{[\text{Average Effluent from Table 16}]}{[\text{Stn 2}] - [\text{Stn 1}]}$ = estimated dilution

TABLE 16: DUNCAN-NORTH COWICHAN SEWAGE EFFLUENT QUALITY

	August, 1980*		September 1980*						$\bar{x}$
	19	20	8	9	15	16	17	18	
TP (mg/l)	4.12	4.07	5.19	5.12	5.57	4.78	4.86	4.45	4.77
TDP (mg/l)	3.48	4.07	--	5.04	4.84	3.99	4.85	4.42	4.38
NO_2 (mg/l)	--	--	.0033	< .003	< .005	< .005	.0094	<.005	.005
NO_3 (mg/l)	--	--	.0064	< .002	< .01	< .01	< .01	< .01	< .01
NH_3 (mg/l)	6.55	8.48	13.9	15.9	12.6	16.1	20.0	--	13.4
TDN (mg/l)	9.05	9.00	14.1	14.3	13.0	11.0	16.0	14.5	12.6

*Grab samples collected as part of the river water monitoring program and during the flow-through bioassay

TABLE 17: COWICHAN RIVER FLOW SUMMARY 1971-1980, NUMBER OF DAYS AT SPECIFIC FLOW REGIMES UNDER 20 m^3/s

River Flow (m^3/s) # of days	MAY ≤4	MAY ≥4 ≤6	MAY ≥6 ≤10	MAY ≥10 ≤20	MAY mean (m^3/s)	JUNE ≤4	JUNE ≥4 ≤6	JUNE ≥6 ≤10	JUNE ≥10 ≤20	JUNE mean (m^3/s)
1980	0	0	0	18	21.8	0	5	15	10	8.19
1979	0	0	0	13	21.6	11	8	3	8	6.71
1978	0	0	0	22	18.2	0	0	11	19	11.3
1977	0	0	6	14	20.4	0	2	8	14	13.1
1976	0	0	0	0	61.5	0	0	0	4	32.9
1975	0	0	0	0	52.1	0	0	8	10	20.7
1974	0	0	0	0	51.3	0	0	0	3	45.3
1973	0	0	7	14	20.0	0	0	0	20	20.1
1972	0	0	0	0	43.6	0	0	1	23	16.3
1971	0	0	0	0	65.9	0	0	0	27	34.1
$\bar{x}$	0	0	1.3	8.1	37.6	1.1	1.5	4.6	13.8	20.9
% ≤ 10 m^3/s			4.2					24		
% ≤ 20 m^3/s				30.3					60	

River Flow (m^3/s) # of days	JULY ≤4	JULY ≥4 ≤6	JULY ≥6 ≤10	JULY ≥10 ≤20	JULY mean (m^3/s)	AUGUST ≤4	AUGUST ≥4 ≤6	AUGUST ≥6 ≤10	AUGUST ≥10 ≤20	AUGUST mean (m^3/s)
1980	0	0	12	19	10.1	0	16	9	6	7.14
1979	4	25	2	0	4.69	0	31	0	0	4.73
1978	0	5	26	0	6.46	0	27	4	0	5.44
1977	0	11	19	0	6.06	0	22	9	0	5.69
1976	0	0	5	20	14.9	0	7	9	15	8.81
1975	0	0	18	13	10.8	0	0	27	2	9.01
1974	0	0	0	11	24.4	0	0	28	3	7.93
1973	0	2	24	5	7.96	0	16	14	0	5.81
1972	0	0	9	11	19.2	0	0	31	0	6.62
1971	0	0	4	19	18.6	0	1	23	7	8.48
$\bar{x}$	0.4	4.3	11.9	9.8	12.3	0	12	15.4	3.3	6.97
% ≤ 6 m^3/s							38.7			
% ≤ 10 m^3/s			53.5					88.4		
% ≤ 20 m^3/s				85.2					99	

River Flow (m^3/s) # of days	SEPTEMBER ≤4	SEPTEMBER ≥4 ≤6	SEPTEMBER ≥6 ≤10	SEPTEMBER ≥10 ≤20	SEPTEMBER mean (m^3/s)	OCTOBER ≤4	OCTOBER ≥4 ≤6	OCTOBER ≥6 ≤10	OCTOBER ≥10 ≤20	OCTOBER mean (m^3/s)
1980	0	14	15	1	7.05	0	0	2	29	13.4
1979	0	2	3	5	20.2	0	0	0	24	25.4
1978	0	0	8	4	24.4	0	0	0	15	22.3
1977	0	7	16	7	8.13	0	0	0	24	20.2
1976	0	0	4	26	12.6	0	0	19	12	9.83
1975	0	0	0	20	17.4	0	0	0	4	75.9
1974	0	0	30	0	7.31	3	7	21	0	6.52
1973	0	30	0	0	4.96	0	12	8	6	11.6
1972	0	3	17	10	9.97	0	2	18	11	9.15
1971	0	0	8	22	12.5	0	0	0	21	21.9
$\bar{x}$	0	5.6	10.1	9.5	12.4	0.3	2.1	6.8	14.6	21.6
% ≤ 6 m^3		18.7					7.7			
% ≤ 10 m^3			52.3					29.7		
% ≤ 20 m^3				84					76.8	

From the observed nutrient increases and the resultant algal bloom in the Cowichan River during a period when river flows were representative of what would be expected during the low flow period, it is obvious the Cowichan River doesn't have the dilution capacity to handle the discharge. Any effluent volume increases would just increase the overall nutrient loadings. Abundant algal growth was observed downstream of the study area (Plate 6) but there are no previous records to assess if conditions had improved or remained unchanged since sewage effluents were removed from the Somenos Creek drainage to the present location.

5.3 Comparison of Dissolved Nutrient Levels to Other River Systems

A comparison of Cowichan River background dissolved nutrient levels with other river systems shows that nutrient levels are low, particularly the dissolved inorganic nitrogen fraction (Table 18). From the large increases in nutrients from the sewage effluent and the low background river nutrient levels, likely, both P and N have contributed to the large increase in algal standing crop. As adequate dilution potential isn't available during low flow period and present nutrient loadings are responsible for large growths of attached algae, adequate control measures should be considered for both P and N. The Cowichan River dissolved inorganic nitrogen levels are extremely low and nitrogen could well be the limiting nutrient controlling algal production.

The Department of Fisheries and Oceans conducted a laboratory algal bioassay in 1981 using Cowichan River water and tentatively found both N and P were required to get an increased growth response from Cowichan River control water (G. Carlson, DFO, per. comm., 1981). For river water collected downstream of the outfall an increased growth response was found when both N and P were added together and when only N was added (G. Carlson, per. comm., 1981). A complete evaluation of the algal bioassay results could serve as a course of direction for additional effluent treatment controls.

TABLE 18: COMPARISON OF THE MEAN BACKGROUND DISSOLVED NUTRIENT LEVELS OF THE COWICHAN RIVER WITH OTHER BRITISH COLUMBIA RIVERS

Total Dissolved Phosphorous (ug/l)

River	June	July	August	September
Cowichan (1979)	4.2	2.8	--	4.1
(1980)	3.8	5.3	7.4	4.8
North Thompson*	5	3	--	4
South Thompson*	2	3	--	7
Lower Thompson*	5	4	--	5
Chilliwack**	--	--	(< 2-3)	--
Capilano**	--	--	(< 2)	(<2)
Big Qualicum**	(1.5-4.8)	(3.8-5.3)	(6.3)	(6.8)
Upper Puntledge**	--	--	(< 2)	(<2)
Quinsam**	--	(3)	(3)	(2)

Nitrate - Nitrite (ug/l)

River	June	July	August	September
Cowichan (1979)	8.5	3.4	--	2.3
(1980)	4.7	< 2.0	< 2.0	2.2
North Thompson*	90	76	77	55
South Thompson*	54	33	22	9.5
Lower Thompson*	86	61	52	34
Chilliwack**	(63-71)	(60)	(58-66)	--
Capilano**	(85)	(108)	(85-90)	(129)
Big Qualicum**	(44-74)	(64-68)	(63)	(52)
Upper Puntledge**	(36)	(21-32)	(13)	(18)
Quinsam**	(19)	(13-27)	(26)	(26)

Continued...

( ) single grab sample or range of grab samples, all others are mean values.

TABLE 18: COMPARISON OF THE MEAN BACKGROUND DISSOLVED NUTRIENT LEVELS OF THE COWICHAN RIVER WITH OTHER BRITISH COLUMBIA RIVERS

(Continued)

Ammonia (ug/l)

River	June	July	August	September
Cowichan (1979)	8.6	2.9	--	2.4
(1980)	4.4	2.0	4.0	6.4
North Thompson	--	--	--	--
South Thompson	--	--	--	--
Lower Thompson	--	--	--	--
Chilliwack**	(< 2-4)	(8)	(3-5)	--
Capilano**	(5)	(7)	(8-10)	(12)
Big Qualicum**	(5-8)	(3-9)	(6)	(6)
Upper Puntledge**	(3)	(< 2-7)	(4)	(3)
Quinsam**	(6)	(4-10)	(12)	(6)

* Oguss and Erlebach (24)

** unpublished data, supplied courtesy of the Dept. of Fisheries and Oceans, Hatchery Waste Water Program

(-) grab sample or range of grab samples, all others are mean values

Healey (18) reported that when both nitrate and ammonia are present together, ammonia is usually taken up to exhaustion before the uptake of nitrate begins. Forsberg (26) reported that organic nitrogen compounds may serve as a nitrogen source when inorganic nitrogen compounds do become low or exhausted. Bothwell and Daley (19) concluded that nuisance growths of benthic algae in the lower Thompson river, in winter, are caused by elevated phosphorous levels. South Thompson and North Thompson River algae were reported to show severe and intermediate phosphorous deficiency respectively (19). Nutrient levels for the Thompson rivers have been compared to levels in the Cowichan River in Table 19. While the TDP concentrations are low in the Cowichan River and comparable to rivers considered to show phosphorous deficiency, the major dissimilarity is the difference in the total dissolved inorganic nitrogen fractions (NO_3- NO_2 plus NH_3). Where mean levels in the Thompson system exceeded 57 ug/l to up to 175 ug/l, concentrations in the Cowichan River were below the detectable level of 2 ug/l to 17 ug/l. The ratio of total dissolved inorganic nitrogen to total dissolved phosphorous averaged 21:1, 28:1 and 39:1 for the lower Thompson, South Thompson and North Thompson rivers respectively (Table 19). The same ratio for the Cowichan River ranged between 0.7:1 to 4.1:1. Miller et al (30) reported that the N:P ratio was useful in a preliminary assessment of algal growth limitation in natural waters. Waters containing N:P ratios $<$10 maybe considered nitrogen limiting while those waters with N:P ratios $>$10 maybe phosphorous limiting to algal growth (30). On this basis, the Cowichan River would fall well within the nitrogen limited criteria.

5.4 Nutrient Control Considerations

For the Cowichan River situation, it will initially be necessary to consider the potential for the control of both phosphorous and nitrogen inputs. For phosphorous, removal by chemical addition (alum, ferric chloride, lime) to wastewaters has been studied extensively and has been shown to be a viable technique for contolling phosphorous discharges (20).

TABLE 19: COMPARISON OF MEAN DISSOLVED NUTRIENT LEVELS OF THE THOMPSON RIVERS AND THE COWICHAN RIVER

	North Thompson*			South Thompson*			Lower Thompson*		
	Feb.	Mar.	Apr.	Feb.	Mar.	Apr.	Feb.	Mar.	Apr.
TDP (ug/l)	3.8	4.9	2.1	3.2	2.8	1.9	8.7	8.2	6.1
NO_3 - NO_2 ug/l	155	110	83	74	60	52	144	140	150
NH_3 ug/l	20	20	8.8	13	15	5.3	10	13	3
N:P***	46:1	26:1	44:1	27:1	27:1	30:1	18:1	19:1	25:1

* From Bothwell and Daley (19).

	Cowichan River							
	June		July		August**		September**	
	1979	1980	1979	1980	1979	1980	1979	1980
TDP (ug/l)	4.2	3.8	2.8	5.3	--	7.4	4.1	4.8
NO_3 - NO_2 (ug/l)	8.5	4.7	3.4	< 2.0	--	<2.0	2.3	2.2
NH_3 (ug/l)	8.6	4.4	2.9	< 2.0	--	4.0	2.4	6.4
N:P	4.1:1	2.4:1	2.2:1	<0.7:1	--	< 0.8:1	1.1:1	1.8:1

** For 1980- station 1 only

*** N:P = ratio of NO_3 - NO_2 + NH_3: TDP, calculated by author.

Essentially, both suspended and soluble forms of phosphorous present in the wastewater are transferred to the sludge by-product. Phosphorous is generally present in wastewater in more than one chemical form (ortho-phosphate - 1/3, polyphosphate - 1/3 and particulate phosphorous - 1/3) and the final effluent total phosphorous concentration attainable depends on the degree of conversion of soluble phosphorous to an insoluble form through reaction with a chemical coagulant/precipitant and the efficiency of liquid-solids separation and suspended solids removal in the treatment plant (21). Stepko and Schroeder (21) reported that to achieve total phosphorous concentrations of 0.3 mg/l or less, virtually complete conversion of soluble phosphorous to particulate phorphorous is necessary. Thus, the residual TP concentration in the final effluent then becomes a direct function of the efficiency of the treatment system for suspended solids removal (21). Wetter (22) reported on the operation in 1976/77 of full scale, continuous phosphorous removal facilities using alum at the Kamloops, B.C. sewage lagoon. Wetter (22) reported the alum treatment produced a final effluent in the lagoon that averaged 0.44 mg/l total phosphorous, 0.1 mg/l dissolved phosphorous and 0.08 mg/l orthophosphorous and that represented a 94% and 98% removal efficiency for TP and TDP, respectively. Raw effluent TP and TDP concentrations were 7 mg/l and 5.4 mg/l respectively. Stepko and Schroeder (21) reported that due to the variability of wastewater characteristics and treatment plant facilities, the choice of the most advantageous phosphorous removal system would have to be determined on a plant by plant basis. The effectiveness of the treatment method should be determined through treatability studies. (21).

In terms of nitrogen removal, the basic and most feasible physical -chemical processes presently available for removal of ammonia nitrogen include ammonia stripping, breakpoint chlorination and/or chlorination-dechlorination and ion exchange (23). All of these processes are based on the removal of ammonia or ammonium ion and have a process advantage over biological systems in that prior conversion of ammonia to nitrate is not a prerequisite. Studies of physical-chemical nitrogen removal methods have generally been confined to proving that a particular process is feasible

(23). Nitrogen removal is relatively expensive and since the technology is still in its infancy many data gaps and unknowns still exist (23). Leslie (31) reported that for nitrogen removal processes, the one thing they have in common is that they are extremely expensive. The plants are highly complex, capital costs are high, and operating costs exorbitant (31).

From the previous discussion certain considerations become evident. The Cowichan River during the summer low flows wouldn't normally have the dilution capacity to prevent eutrophication problems with the present effluent quality and further volume increases would only worsen the problem. The Cowichan River appears to have unusually low dissolved inorganic nitrogen levels indicating it could be a nitrogen limited system. Cowichan River dissolved phosphorous levels are also low. The effect of the added nutrients from the Duncan-North Cowichan sewage discharge into the mainstem Cowichan River was to initiate a large algal bloom. In order to reduce the impact on the Cowichan River several control options that potentially exist are:

(1) Assess the feasibility of a seasonally regulated discharge incorporating no discharge or a very minimal discharge for an approximate 3½ month period between June and September.

(2) Using treatability studies or a full scale pilot study, assess the capability to reduce phosphorous levels in the final effluent to a point that phosphorous (effluent plus background) in combination with the available dissolved inorganic nitrogen fraction in the effluent will not promote excessive algal growth. Algal bioassays could be run concurrently to assess if algal growth would be stimulated in the Cowichan River with only a high dissolved inorganic nitrogen input and a very high percentage removal of total phosphorous. A final analysis of the Department of Fisheries and Oceans algal bioassay may serve as a course of direction to take for treatability studies. Axler and Goldman (25) reported there still appears to be no fail safe assay for identifying algal growth limitation by nitrogen.

(3) assess the future effluent treatment needs of the community with advanced wastewater treatment options that remove nutrients without chemicals (31).

With respect to option (1) increased fall flows generally begin in October and flows over 40 m^3/s generally occur in November (Table 20). The 10 year mean flow for October was 22 m^3/s compared to 78.3 m^3/s in November. Any flow regulation would have to be somewhat flexible considering the variability of the onset of summer low flows and autumn high flows. At least a 3½ month period (mid-June to September or July to mid-September) should be considered. For option (2), it is important to conduct treatability studies and algal bioassays to assess the growth potential of reduced phosphorous effluent. Traaen (32) reported on the effects of various effluents from pilot plants on the primary productivity of artificial stream channels. Traaen (32) reported that at a 0.5% (200:1 dilution) load of effluent from sewage chemically treated with alum and followed by sewage pond treatment, the corresponding phosphorous increase was 0.7 ug P/l and gross primary productivity increased by a factor of 1.35. At a 5% (20:1 dilution) load of the same effluent, primary productivity more than doubled compared to the control. He found that high loads of chemical treated effluent usually led to algal communities sparse in diatoms and dominated by *Mougeotia* sp., *Scenedesmus* sp., and *Staurastrum spp*. This sort of community even prevailed with extremely efficient P removal, with less than 9 ug P/l at a 5% effluent load of alum treated sewage pond treated effluent. He reported that at high volume loadings of sewage effluents, factors other than P (such as N, organic matter, pH and micronutrients) change the water quality sufficiently to alter the original biota.

TABLE 20: COWICHAN RIVER FLOW SUMMARY 1971-1980, NUMBER OF DAYS AT SPECIFIC FLOW REGIMES OVER 10 m^3/s

River Flow (m^3/s) # of days	SEPTEMBER				OCTOBER				NOVEMBER			
	$>10 \leq 20$	$>20 \leq 40$	>40	mean (m^3/s)	$>10 \leq 20$	$>20 \leq 40$	>40	mean (m^3/s)	$>10 \leq 20$	$>20 \leq 40$	>40	mean (m^3/s)
1980	1	0	0	7.05	29	0	0	13.4	0	3	27	109
1979	5	20	0	20.2	24	1	6	25.4	0	18	12	40
1978	4	18	0	24.4	15	16	0	22.3	6	19	5	28.6
1977	7	0	0	8.1	24	3	4	20.2	0	0	30	118.7
1976	26	0	0	12.6	12	0	0	9.8	13	17	0	24.8
1975	20	10	0	17.4	4	10	17	76	0	0	30	212.5
1974	0	0	0	7.3	0	0	0	6.5	3	5	14	52.1
1973	0	0	0	5.0	6	5	0	11.6	0	9	21	79.6
1972	10	0	0	10.0	11	0	0	9.1	0	17	10	35.7
1971	22	0	0	12.5	21	5	5	21.9	0	1	29	81.9
$\bar{x}$	9.5	4.8	0	12.4	14.6	3.0	3.2	21.6	2.2	8.9	17.8	78.3

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APPENDIX I

(a) WATER QUALITY STUDIES - SAMPLE PREPARATION' HANDLING AND ANALYTICAL METHODS

(b) FLOW-THROUGH BIOASSAY PROCEDURES

APPENDIX I(a): WATER QUALITY STUDIES - SAMPLE PREPARATION, HANDLING AND ANALYTICAL METHODS

PARAMETER	FIELD PROCEDURE	ANALYTICAL REFERENCE AND COMMENT	TEST NUMBER
Dissolved Oxygen -Water	Collected in duplicate in a 300 ml BOD bottle and preserved in the field immediately with 2 ml each of $MnSO_4$ and alkaline iodide-sodium azide reagents	Environmental Laboratory Manual, (ELM), (27)	048
Dissolved Oxygen -Intragravel	Collected in duplicate with a 600 ml stainless steel syringe and transferred to 300 ml BOD bottle and preserved	ELM, (27)	048
pH Silica	Collected in triplicate in a 200 ml polyethylene sample bottle and kept in coolers with ice packs	ELM, (27)	080 118
Turbidity, Conductivity Total Alkalinity as $CaCO_3$	Collected in duplicate in a 200 ml polyethylene sample bottle and kept in coolers with ice packs	ELM, (27)	130, 044 006
Total Organic and Inorganic Carbon	Collected in triplicate in a 100 ml glass sample bottle and kept in coolers with ice packs	ELM, (27)	016
Surfactant (Linear Alkylate Sulfonates)	Collected in triplicate in a 100 ml glass sample bottle and kept in coolers with ice packs	ELM, (27)	890
Nonfilterable Residue	Collected in duplicated in a 500 ml polyethylene sample bottle and kept in coolers with ice packs	ELM, (27)	104
Total Phosphate	Collected in triplicate in a 50 ml acid washed Sovril brand glass sample bottle and kept in coolers with ice packs	ELM, (27). The sample was digested in the original sample bottle, in the laboratory.	086

Continued...

APPENDIX I(a): WATER QUALITY STUDIES - SAMPLE PREPARATION, HANDLING AND ANALYTICAL METHODS
Continued

PARAMETER	FIELD PROCEDURE	ANALYTICAL REFERENCE AND COMMENT	TEST NUMBER
Total Phosphate (cont.)	For sequential samples, samples were collected in a 60 ml acid washed Sovril brand test tube inserted into the mouth of the polyethlene bottle suppled with the sampler. Kept in coolers with ice packs when in transit.	For sequential samples the test tube was shaken and a 50 ml sample was poured into a regular 50 ml acid washed glass sample bottle and then treated in the regular manner	
Total Dissolved Phosphate	As for total phosphorous but samples were immediately field filtered with a distilled water washed 0.45 u cellulose acetate membrane filter	Treated for TP	086
Ammonia	In 1979 the samples were collected in triplicate in a 100 ml polyethylene sample bottle. Samples were field filtered within 30 minutes after collection using a distilled water washed 0.45u cellulose acetate membrane filter. Kept in cooler with ice packs. In 1980, the samples were collected in triplicate in a 200 ml polyethlene sample bottle, the 200 ml sample was field filtered in the regular manner, 100 ml for TDN and 100 ml for NO_3-NO_2 and NH_3. For sequential samples the sample was collected in the 250 ml polyethylene container supplied with the sample. At the end of the sample run each discrete sampler was shaken and 100 ml was filtered in the regular manner into a 100 ml polyethylene sample bottle.	Analysis for nitrogen fractions in 1979 was done using methods adapted by the Water Quality Branch Pacific and Yukon Region, Analytical Methods Manual (28). In 1980 TDN was analyzed as above. However, NO_3-NO_2 and NH_3 were analyzed by methods reported in ELM (27) as methods 072 and 058 respectively.	

APPENDIX I(b) FLOW THROUGH BIOASSAY PROCEDURES

The apparatus, designed and constructed by J.Baumann, Environmental Protection Service is a much modified Mount and Brungs (1) proportional diluter. Some design principles which were incorporated into proportional diluters built by Hemmer (2) and by Smith *et al*. (3) were used, as well as many valuable suggestions made by Ron G. Watts, the head of the Environmental Protection Service Aquatic Toxicity Laboratory.

The flow-through apparatus and a fish holding tank, were installed in a mobile laboratory (a twelve foot trailer) and moved onto the bank of a Cowichan River side channel near the lagoon outfall on September 8, 1980.

The test fish used in the flow-through bioassay were juvenile coho salmon (*Oncorhynchus kisutch*) which were seined from the Cowichan River, upstream of the lagoon outfall, on September 9, 1980. The average length of the fish was 7.4 centimeters, with a standard deviation of 0.78 centimeters, and the average weight was 4.69 grams, with a standard deviation of 1.68 grams. These fish were immediately placed in the mobile laboratory's holding tank, allowing 6 days of acclimation to laboratory conditions before the start of the bioassay on September 15, 1980. The fish were not fed during this time, or during the flow-through bioassay.

The fish holding facilities in the laboratory consisted of an oval, 200 litre fibreglass tank equipped with an external standpipe. The tank was supplied with a continuous flow of freshwater at a rate of approximately one litre a minute. The water for the holding tank, as well as for the flow-through bioassay, was taken from the side-channel of the Cowichan River (which diverges from the main channel upstream of the sewage outfall) by means of a continuously operating submersible pump, pumping through 15 meters of reinforced rubber hose.

Sewage lagoon effluent for the bioassay was obtained by means of a continously operating submersible pump suspended in the outfall pipe under an overflow cap located on the bank between the main and side channels of the Cowichan River. The effluent was conducted to the mobile laboratory by means of 60 meters of reinforced rubber hose. Approximately 10 meters of this length was immersed in the water of the side channel, allowing some temperature equalization to occur.

The flow-through apparatus was adjusted to deliver 300 millilitre volumes at 85 second intervals to each of the six test vessels which contained the test solutions and the test fish. The test solutions consisted of five different concentrations of the lagoon effluent and a river water control. The test vessels used were cylindrical polyethylene tanks with inside dimensions of 32 centimeters wide by 47 centimeters deep. Central glass standpipes were adjusted to maintain a volume of 30 litres, for which the 95% replacement time, according to Sprague's Chart (4), was 5 hours. The concentrations chosen for the bioassay, based on previous static bioassay data, were 100%, 90%, 75%, 68% and 56% by volume.

The waste water from the flow-through apparatus, the test vessels, and the fish-holding tank was piped into the side channel of the Cowichan River, downstream of the water intake pump. The test solutions were aerated by means of a small piston pump which delivered air through glass-weighted Pasteur pipettes suspended in the test solutions. Air deliveries were not measured, but were estimated to be 250 millilitres a minute at a minimum. Dissolved oxygen determination were made with a YSI dissolved oxygen meter with a self-stirring submersible probe. An Orion model 701 pH meter with an automatic temperature compensator and a pH combination electrode was used for the pH determinations.

Electrical power to operate the pumps, lights, and instruments was obtained by means of a propane fueled generator.

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APPENDIX II

COMPARISON OF SEQUENTIAL AND REPLICATE SAMPLES COLLECTED OVER AN IDENTICAL SAMPLE PERIOD ON THE COWICHAN RIVER -

(a) TOTAL PHOSPHOROUS

(b) TOTAL DISSOLVED NITROGEN

(c) AMMONIA

(d) NITRATE-NITRITE

APPENDIX II(a): COMPARISON OF SEQUENTIAL AND REPLICATE SAMPLES COLLECTED OVER AN IDENTICAL SAMPLE PERIOD ON THE COWICHAN RIVER - TOTAL PHOSPHOROUS

SEQUENTIAL SAMPLING STATION 2

	1979 - TP (ug/l)				1980 - TP (ug/l)		
	June 19-20	July 10-11	July 31-August 1	September 4-5	June 16-17	July 7-8	August 19-20
	6.2	6.4	9.8	5.4	9.1	21.7	172
	8.3	10.5	8.4	6.2	7.3	19.5	80.4
	9.3	7.5	8.8	6.1	7.3	20.6	134
	7.1	8.0	8.3	5.5	8.8	5.9	170
	7.1	6.9	8.3	5.4	4.7	10.4	160
	7.1	6.9	7.0	6.2	6.3	8.9	120
	7.1	7.5	3.9	5.5	4.6	10.7	157
	7.1	6.4	*	7.5	7.7	10.1	159
	7.1	7.5	•	7.8	6.8	10.1	121
	6.5	6.4	*	7.0	5.3	8.7	113
	7.1	8.5	•	7.7	6.3	10.2	131
	7.1	6.9	8.3	5.5	8.0	8.9	-
x̄(S.D)	7.3 (.8)	7.4 (1.2)	7.8 (1.8)	6.3 (.9)	6.8 (1.5)	12.1 (5.3)	138 (28)
95% limits	6.7-7.8	6.7-8.2	6.4-9.3	5.7-6.9	5.9-7.8	8.8-15.5	119-157

REPLICATE SAMPLING STATION 2

	1979 - TP (ug/l)				1980 - TP (ug/l)		
	June 19-20	July 10-11	July 31-August 1	September 4-5	June 16-17	July 7-8	August 19-20
	7.1	10.1	7.4	5.4	6.9	8.1	176
	8.5	6.9	7.9	5.3	7.8	8.8	176
	9.2	6.9	8.2	5.5	7.0	7.8	172
	10.2	5.5	7.1	7.6	6.3	8.5	98.3
	9.3	6.4	7.0	10.0	5.4	7.9	107
	5.5	7.5	7.3	13.0	4.7	8.7	98.5
	6.5	6.9	6.5	5.8	5.5	8.4	112
	8.5	6.9	6.8	8.2	5.0	9.0	116
	7.1	6.9	7.2	6.3	5.2	9.3	118
x̄(S.D)	8.0 (1.5)	7.1 (1.2)	7.3 (0.5)	7.5 (2.6)	6.0 (1.1)	8.5 (0.5)	130 (34)
95% limits	6.8-9.1	6.2-8.0	6.9-7.7	5.5-9.4	5.2-6.8	8.1-8.9	105-156

• sample spout stuck.

NOTE: Sequential: discrete samples collected every two hours.

Replication: 3 replicate samples collected on 3 occasions over sequential sampling run.

APPENDIX II(b): COMPARISON OF SEQUENTIAL AND REPLICATE SAMPLES COLLECTED OVER AN IDENTICAL SAMPLE PERIOD ON THE COWICHAN RIVER - TOTAL DISSOLVED NITROGEN

SEQUENTIAL SAMPLING STATION 2

	1979 - TDN (ug/l)				1980 - TDN (ug/l)	
	June 19-20	July 10-11	July 31-August 1	September 4-5	June 16-17	August 19-20
	95	75	85	65	80	265
	95	80	95	70	85	350
	100	85	100	71	80	280
	90	80	95	68	70	350
	90	80	120	66	90	280
	90	80	105	61	85	285
	80	75	95	61	90	305
	80	80	97	60	420	320
	80	75	96	63	85	265
	80	80	95	61	80	260
	80	70	86	60	85	295
	80	65	96	65	75	370
x̄(S.D	87 (7)	77 (5)	97 (9)	64 (4)	110 (98)	302 (37)
95% limit	82-92	74-80	91-103	62-67	49-172	279-326

REPLICATE SAMPLING STATION 2

	1979 - TDN (ug/l)				1980 - TDN (ug/l)	
	June 19-20	July 10-11	July 31-August 1	September 4-5	June 16-17	August 19-20
	95	85	85	65	105	350
	100	85	85	80	85	330
	90	80	182	70	150	345
	80	70	75	60	55	290
	80	75	85	60	60	285
	75	65	91	60	70	280
	100	90	80	65	65	320
	90	75	85	65	65	335
	115	90	80	65	345	360
x̄(S.D	92 (12)	79 (9)	94 (33)	66 (6)	111 (93)	322 (30)
95% limit	82-101	73-86	69-119	61-70	41-181	299-344

APPENDIX II(c): COMPARISON OF SEQUENTIAL AND REPLICATE SAMPLES COLLECTED OVER AN IDENTICAL SAMPLE PERIOD ON THE COWICHAN RIVER - AMMONIA

REPLICATE SAMPLING STATION 1

	1979 - NH_3 (ug/l)				1980 - NH_3 (ug/l)	
	June 19-20	July 10-11	July 31-August 1	September 4-5	June 16-17	August 19-20
	6.0	2.0	8.0	6.0	6.0	175
	5.0	3.0	4.0	5.0	7.0	213
	18.0	2.0	6.0	8.0	7.0	227
	5.0	2.0	8.0	34.0	6.0	225
	9.0	2.0	7.0	8.0	6.0	218
	10.0	3.0	7.0	9.0	6.0	196
	9.0	2.0	2.0	8.0	6.0	206
	4.0	2.0	16.0	5.0	6.0	216
	8.0	2.0	9.0	34.0	6.0	180
	10.0	2.0	7.0	8.0	6.0	173
	6.0	2.0	12.0	6.0	6.0	193
	4.0	3.0	11.0	4.0	6.0	-
$\bar{x}$(S.D)	7.8 (3.9)	2.2 (0.4)	8.1 (3.7)	11.2 (10.7)	6.2 (0.4)	202 (19.8)
95% limit	5.4-10.3	2.0-2.5	5.8-10.4	4.5-18	5.9-6.4	189-215

REPLICATE SAMPLING STATION 2

	1979 - NH_3 (ug/l)				1980 - NH_3 (ug/l)	
	June 19-20	July 10-11	July 31-August 1	September 4-5	June 16-17	August 19-20
	7.0	2.0	4.0	2.0	8.0	234
	13.0	2.0	6.0	2.0	2.0	232
	9.0	2.0	18.0	2.0	5.0	237
	11.0	6.0	5.0	2.0	8.0	190
	7.0	3.0	6.0	2.0	6.0	193
	8.0	2.0	10.0	2.0	6.0	194
	10.0	6.0	4.0	3.0	4.0	217
	13.0	2.0	4.0	3.0	5.0	226
	10.0	4.0	4.0	3.0	2.0	217
$\bar{x}$(S.D)	9.8 (2.3)	3.2 (1.7)	6.8 (4.6)	2.3 (0.5)	5.1 (2.2)	216 (187)
95% limit	8.1-11.5	1.9-4.5	3.3-10.3	2.0-2.7	3.4-6.8	201-230

APPENDIX II(d): COMPARISON OF SEQUENTIAL AND REPLICATE SAMPLES COLLECTED OVER AN IDENTICAL SAMPLE PERIOD ON THE COWICHAN RIVER - NITRATE - NITRITE

SEQUENTIAL SAMPLING STATION 2

	1979 - NO_3-NO_2 (ug/l)				1980 - NO_3-NO_2 (ug/l)	
	June 19-20	July 10-11	July 31-August 1	September 4-5	June 16-17	August 19-20
	6.0	3.0	< 2.0	2.0	6.0	20
	7.0	2.0	< 2.0	2.0	7.0	22
	7.0	3.0	3.0	2.0	7.0	12
	5.0	5.0	< 2.0	3.0	6.0	20
	6.0	3.0	4.0	4.0	6.0	21
	7.0	5.0	< 2.0	4.0	6.0	19
	6.0	4.0	3.0	4.0	6.0	3.0
	7.0	5.0	4.0	3.0	6.0	13
	6.0	5.0	3.0	3.0	6.0	3.0
	6.0	6.0	2.0	2.0	6.0	2.0
	7.0	4.0	3.0	2.0	6.0	2.0
	6.0	4.0	3.0	2.0	6.0	-
$\bar{x}$(S.D)	6.3 (0.6)	4.1 (1.2)	2.7 (0.7)	2.7 (0.9)	6.2 (0.4)	12.4 (8.5)
95% limit	5.9-6.7	3.3-4.8	2.3-3.2	2.2-3.3	5.9-6.4	6.8-18.1

REPLICATE SAMPLING STATION 2

	1979 - NO_3-NO_2 (ug/l)				1980 - NO_3-NO_2 (ug/l)	
	June 19-20	July 10-11	July 31-August 1	September 4-5	June 16-17	August 19-20
	8.0	3.0	< 2.0	< 2.0	4.0	<2.0
	9.0	3.0	< 2.0	< 2.0	3.0	<2.0
	9.0	3.0	4.0	< 2.0	3.0	<2.0
	9.0	3.0	< 2.0	2.0	5.0	<2.0
	7.0	3.0	< 2.0	2.0	6.0	<2.0
	8.0	<2.0	< 2.0	2.0	6.0	<2.0
	14.0	6.0	< 2.0	2.0	5.0	<2.0
	8.0	4.0	< 2.0	2.0	5.0	<2.0
	14.0	6.0	<2.0	2.0	5.0	<2.0
$\bar{x}$(S.D)	9.6 (2.6)	3.7 (1.4)	2.2 (0.7)	2.0 (0.0)	4.7 (1.1)	2.0 (0.0)
95% limit	7.6-11.5	2.6-4.7	1.7-2.7	2.0-2.0	3.8-5.5	2.0-2.0

APPENDIX III

DAILY BACTERIOLOGICAL RESULTS FOR COWICHAN SEWAGE TREATMENT LAGOONS AND COWICHAN RIVER

DAILY BACTERIOLOGICAL RESULTS FOR COWICHAN SEWAGE TREATMENT LAGOONS AND COWICHAN RIVER

Sample Station	Date	Count/100 ml TC	FC	FS	35°C SPC/ml
L1	Sept. 15	$2.5x10^6$	$2.0x10^6$	$3.8x10^5$	
	16	$1.1x10^7$	$2.5x10^6$	$4.9x10^5$	
	17	$4.3x10^7$	$4.6x10^5$	$6.1x10^5$	
	18	$2.5x10^7$	$6.1x10^6$	$1.5x10^6$	
Mean		$2.0x10^7$	$2.8x10^6$	$7.4x10^5$	
L2	Sept. 15	$2.9x10^5$	$2.1x10^4$		
	16	$1.1x10^5$	$2.7x10^4$		
	17	-	$1.9x10^4$		
	18	$3.3x10^5$	$2.7x10^4$		
Mean		$2.43x10^5$	$2.35x10^4$		
L3	Sept. 15	$2.8x10^5$	$2.0x10^3$		
	16	$1.4x10^5$	$2.0x10^3$		
	17	$1.6x10^5$	$3.2x10^3$		
	18	$6.7x10^5$	$4.3x10^3$		
Mean		$3.11x10^5$	$2.87x10^3$		

(continued)

Sample Station	Date	Count/100 ml TC	FC	FS	35°C SPC/ml
L4	Sept. 15	$2.1x10^5$	$6.9x10^4$		
	16	$7.9x10^4$	$1.9x10^4$		
	17	-	$5.8x10^4$		
	18	$5.3x10^5$	$3.2x10^4$		
Mean		$2.7x10^5$	$4.5x10^4$		
L5	Sept. 15	$2.1x10^4$	L1000		
	16	-	$1.3x10^5$		
	17	$1.7x10^5$	$1.6x10^3$		
	18	$1.6x10^5$	$2.8x10^3$		
Mean		$1.21x10^5$	$4.48x10^4$		
L6	Sept. 15	$1.8x10^4$	L100		
	16	-	40		
	17	$9.8x10^4$	450		
	18	$7.0x10^3$	20		
Mean		$4.1x10^4$	170		

(continued)

Sample Station	Date	Count/100 ml TC	FC	FS	35°C SPC/ml
L7	Sept. 15	6000	100		$6.2x10^5$
	16	7000	100		$4.8x10^5$
	17	-	20		$6.7x10^5$
	18	$5.7x10^4$	40		$3.1x10^5$
Mean		$2.3x10^4$	65		$5.2x10^5$
L8	Sept. 15	-	L100		$5.9x10^4$
Mean		-	L100		$5.9x10^5$
	Sept. 16				
L8	0800	-	10	$2.7x10^3$	$4.0x10^5$
	0900	-	10	$2.1x10^3$	$6.4x10^5$
	1000	$1.6x10^4$	10	$4.4x10^3$	$4.5x10^5$
	1100	-	L10	$1.3x10^3$	$4.9x10^5$
	1200	-	10	$1.0x10^3$	$4.2x10^5$
	1300	-	10	$7.4x10^2$	$2.7x10^5$
	1400	$1.5x10^4$	L10	$4.2x10^3$	$3.7x10^5$
Mean		$1.52x10^4$	10	$2.35x10^3$	$4.34x10^5$

(continued)

Sample Station	Date	Count/100 ml TC	FC	FS	35°C SPC/ml
	Sept. 17				
L8	0800	$10.1x10^4$	L10	$4.1x10^3$	$5.4x10^5$
	0900	-	10	$2.1x10^3$	$6.4x10^5$
	1000	$1.3x10^4$	L10	$4.8x10^3$	$4.8x10^5$
	1100	$1.5x10^4$	10	$4.9x10^3$	$5.4x10^5$
	1200	-	20	$3.3x10^3$	$4.0x10^5$
	1300	$1.2x10^4$	10	$3.5x10^3$	$2.7x10^5$
	1400	$4.8x10^4$	10	$5.7x10^3$	$4.5x10^5$
Mean		$3.8x10^4$	8.57	$4.0x10^3$	$4.7x10^5$
	Sept. 18				
L8	0800	$8.4x10^4$	20	$4.3x10^3$	$3.9x10^5$
	0900	$6.1x10^4$	10	$3.1x10^3$	$3.5x10^5$
	1000	$5.3x10^4$	20	$2.3x10^3$	$4.9x10^5$
	1100	$2.8x10^4$	40	$1.8x10^3$	$4.8x10^5$
	1200	$1.5x10^4$	20	$3.1x10^3$	$3.9x10^5$
	1300	$3.1x10^4$	40	$4.5x10^3$	$3.5x10^5$
	1400	-		-	-
Mean		$4.53x10^4$	25	$3.18x10^3$	$4.08x10^5$

(continued)

Sample Station	Date	Count/100 ml TC	FC	FS	35°C SPC/ml
Cowichan River					
1	Sept. 15		10	10	
	16		10	30	
	17		60	150	
	18		60	120	
Mean			46.7	77.5	
2	Sept. 15		L10	10	
	16		50	70	
	17		180	250	
	18		60	90	
Mean			96.7	105	
3	Sept. 15		40	10	
	16		20	160	
	17		120	140	
	18		80	90	
Mean			65	100	

(continued)

Sample Station	Date	Count/100 ml TC	FC	FS	35°C SPC/ml
4	Sept. 15		L10	20	
	16		20	40	
	17		150	190	
	18		90	90	
Mean			86.7	85	
5	Sept. 15		-	-	
	16		10	60	
	17		30	180	
	18		50	150	
Mean			30	190	