ECOLOGICAL CHARACTERISTICS OF THE HIGHWOOD RIVER (1983 - 1985)

by:

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SUMMARY

During 1984 and 1985 Alberta Environment conducted studies on the Highwood River to define water quality conditions above and below the town of High River, and to determine the environmental conditions that contribute to fish mortality. This report summarizes the water chemistry and biological databases collected.

During the period of observation the reaches of the Highwood River below High River were classified as highly eutrophic. This was the direct result of low river flows and excessive nutrient additions from the effluent discharged from the town of High River sewage treatment plant. Eutrophication was evident from high nutrient and epilithic algal concentrations, as well as large accumulations of aquatic macrophytes, which may have contributed to excessive diurnal fluctuations in dissolved oxygen. Fish kills were correlated with periods of extremely high air temperatures (>30°C) and low river flows (<10 cms). The numbers of total and fecal coliform bacteria exceeded the limits recommended by the Alberta Surface Water Quality Objectives for direct contact recreation and irrigation immediately below the townsite.

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ACKNOWLEDGEMENTS

This study was planned, conducted and jointly funded by Planning Division and the Water Quality Control Branch (WQCB) of Pollution Control Division. The original draft was prepared by Dr. S.E.D. Charlton and K.A. Brennan in 1986 and subsequently finalized by staff of the Environmental Quality Monitoring Branch (EQMB) in 1990. The authors wish to thank L. Forbes, D. Lawrence, H. Wong, D. Jarrett, J. Button and Dr. G. Trump of Mount Royal College for their assistance with the sampling program.

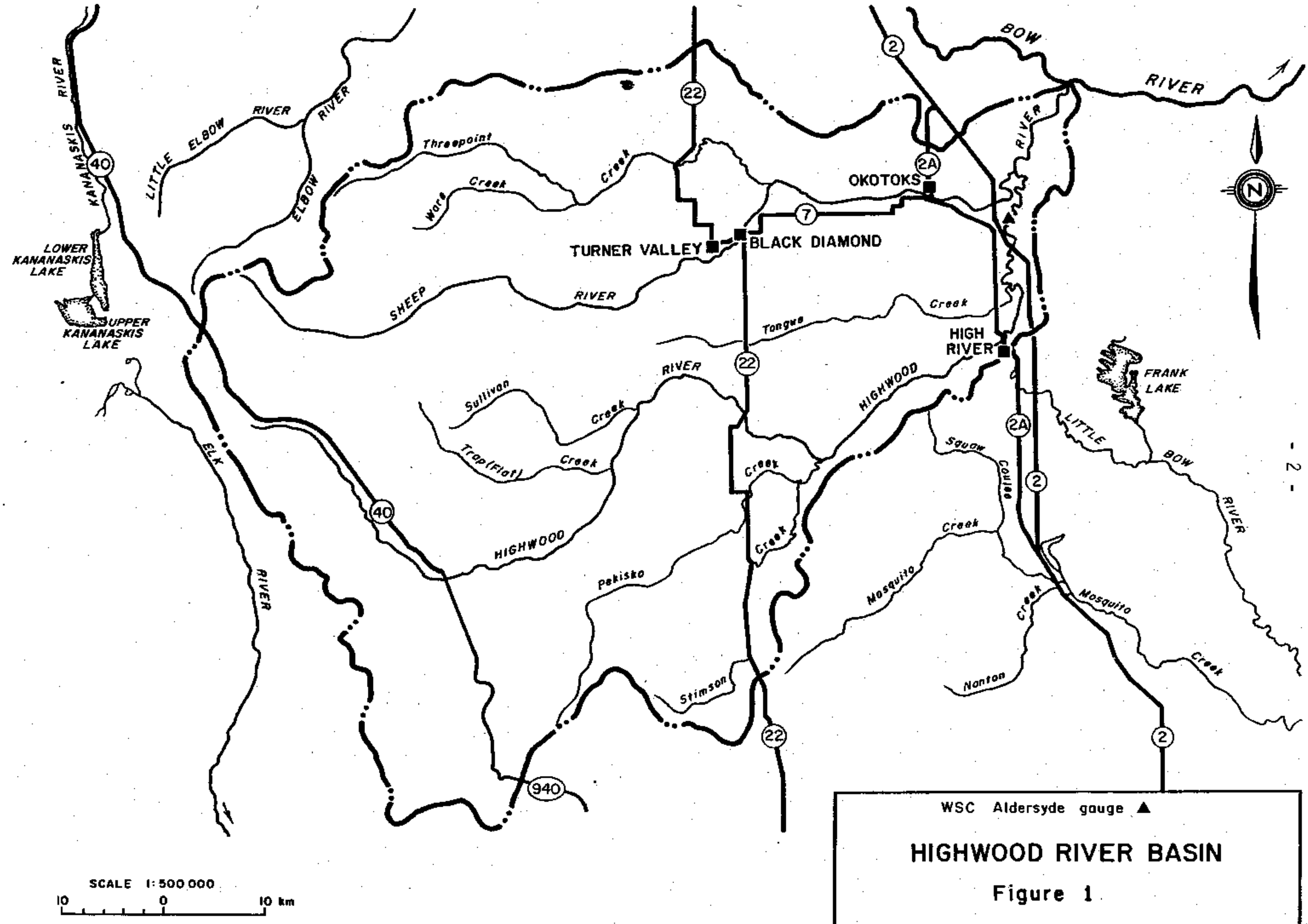
1.0 INTRODUCTION

During 1984 and 1985 Alberta Environment conducted studies on the Highwood River to determine environmental factors that contribute to mid-summer fish mortality. The study was part of a cooperative project to assess instream flow needs of the lower Highwood River; participating agencies included Planning, Pollution Control and Technical Services divisions of Alberta Environment and Fish and Wildlife Division of Alberta Forestry, Lands and Wildlife. The following report provides a description of the longitudinal and seasonal characteristics of the lower Highwood River between one of its tributaries, Pekisko Creek, and the confluence of the Highwood with the Bow River. Also included in the study was one site on the Sheep River, which is the major tributary to the lower Highwood River.

1.1 STUDY AREA

The Highwood River, which drains 3990 km², is ecologically a very important tributary of the Bow River. The Highwood River flows in the south-easterly direction from the Rocky Mountains and is joined by a number of tributary streams, including Pekisko, Sullivan and Flat creeks and the Sheep River (Figure 1). The Highwood River provides major spawning and rearing areas for Bow River rainbow trout (*Oncorhynchus mykiss*) and mountain whitefish (*Prosopium williamsoni*) (Stelfox 1981, Wiebe 1979), and thereby contributes to the excellent recreational fishing opportunities in the area (IEC Beak 1984).

The Highwood River is an important source of water for irrigation and domestic water use. Two diversions, Squaw Coulee (capacity 1.7 cubic meters per second (cms) and the Little Bow Canal



WSC Aldersyde gauge ▲

HIGHWOOD RIVER BASIN

Figure 1

(capacity 2.8 cms) direct water into the Little Bow River (Figure 2). The amount of water diverted at a particular time is a function of demand throughout the Little Bow River drainage basin. Demands usually peak during the months of July and August due to the semi-arid nature of southern Alberta. Specific operational guidelines are presented in Brassard (1986).

In addition to the uses already outlined, the Highwood River was formerly used to dilute domestic sewage effluent from the town of High River. Between 1978 and 1983 the monthly sewage effluent discharge averaged about 0.028 cms (Hamilton 1984). The mean monthly volume of river water that received the effluent was highly variable, but was generally below average between late 1981 and 1985 (Figure 3). Sewage treatment plant output monthly averages were 0.0272 cms in 1984 and 0.0292 cms in 1985 (Dave Fisher, Alberta Environment, Lethbridge, Alberta, personal communication).

2.0 METHODS AND MATERIALS

Although the Highwood River has been sampled in the vicinity of High River since 1978, frequent samples were not collected until the present study, which began in 1983. During 1984-85 biotic and abiotic variables were examined every two weeks during the summer months and at least monthly during the spring and fall at the sites indicated in Figure 2. Winter samples were not routinely collected. Variables examined and their respective NAQUADAT codes appear in Table 1. Relevant variables were also monitored in the treated effluent from the High River sewage treatment plant during 1985.

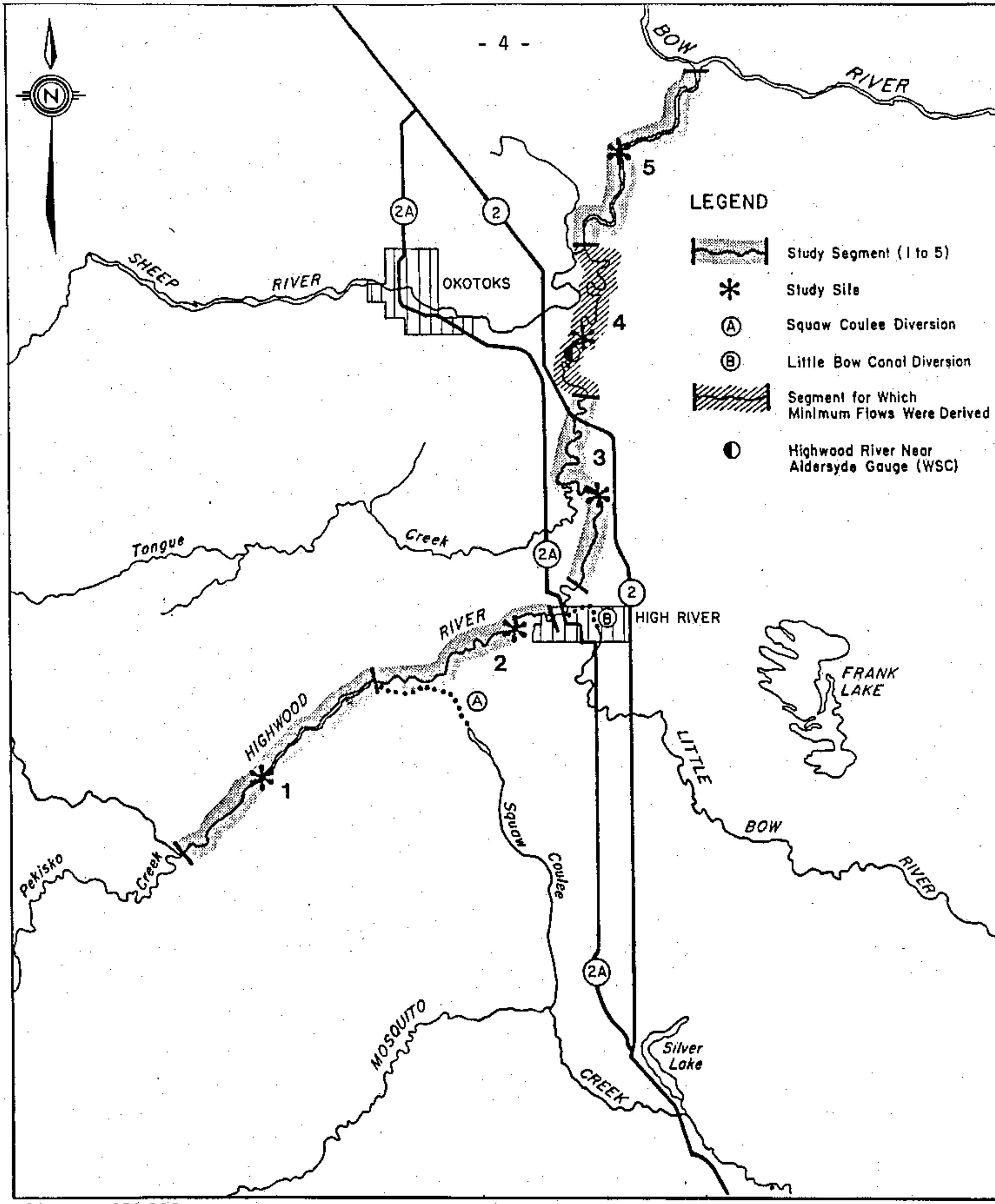


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FIGURE 2
MAP OF THE STUDY AREA
SHOWING LOCATION OF SEGMENT BOUNDARIES
AND STUDY SITES ON THE HIGHWOOD RIVER

SOURCE ENGLERT, BRASSARD & MIDDLETON 1987

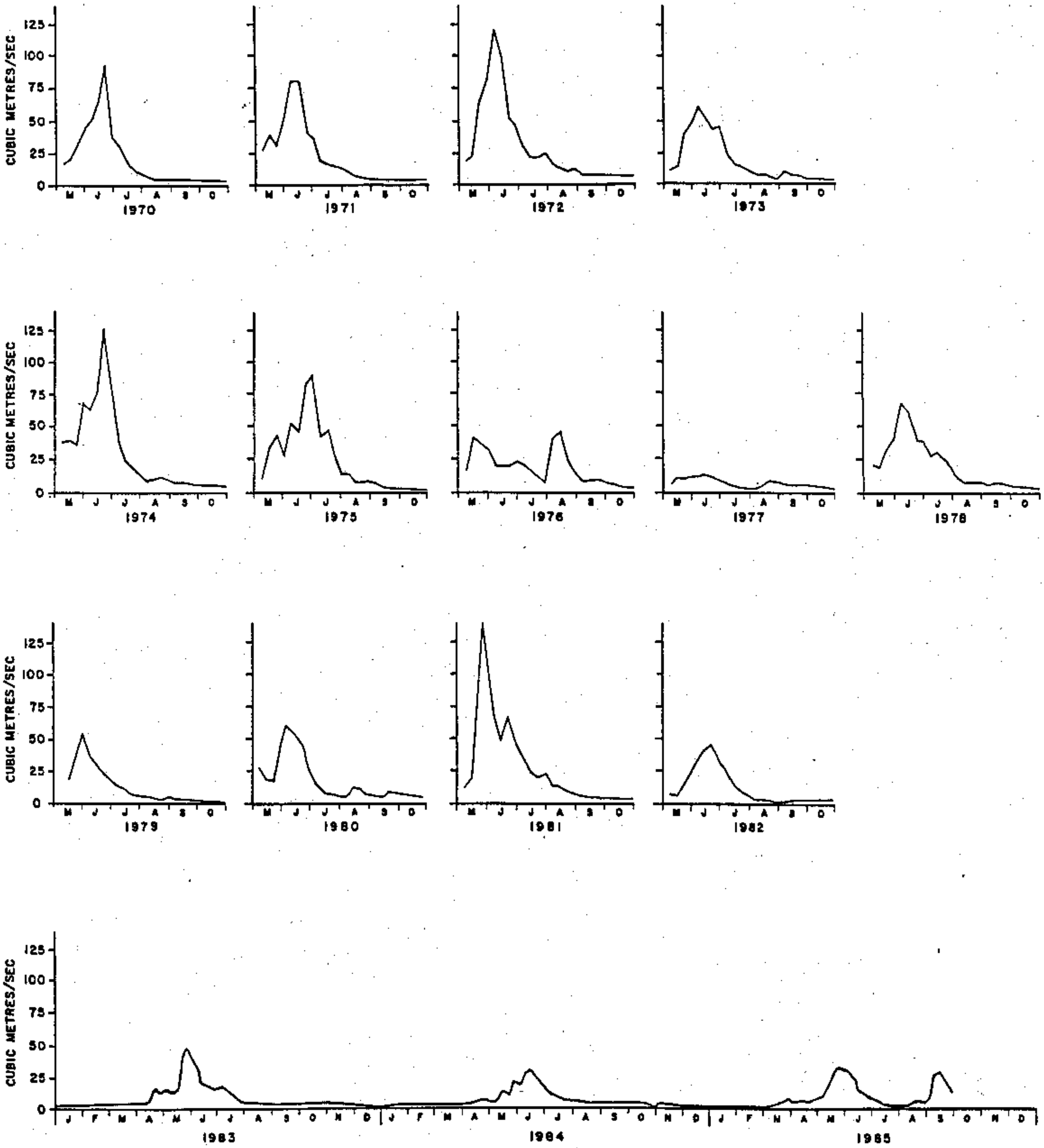

Figure 3 Weekly mean Highwood River flows (1970-1985).

TABLE 1. List of variables and their respective NAQUADAT codes.

VARIABLE	NAQUADAT CODE
Calcium	20103L
Magnesium	12102L
Sodium	11103L
Potassium	19103L
Chloride	17203L
Sulphate	16306L
PP Alkalinity as $CaCO_3$	10151L
Total Alkalinity as $CaCO_3$	10101L
pH	10301L
Bicarbonate	06201L
Total Hardness as $CaCO_3$	10602L
Fluoride	09105L
Silica	14101L
Specific Conductance	02041L
Colour	02021L
Turbidity	02073L
Total Filterable Residue	10451L
Total Non-Filterable Residue	10401L
Total Non-Filterable Residue Fixed	10501L
Biochemical Oxygen Demand	08202L
Nitrite Nitrogen as N	07206L
Nitrate & Nitrite Nitrogen as N	07110L
Total Kjeldahl Nitrogen	07015L
Total Ammonia Nitrogen	07505L
Total Phosphorus as P	15406L
Total Organic Carbon	06005L
Total Inorganic Carbon	06052L
Phenol	06537L
Ortho Phosphorus as P	15256L

VARIABLE	NAQUADAT CODE
Arsenic	33104L
Selenium	34102L
Cadmium	48302L
Copper	29305L
Iron	26302L
Chromium	24302
Manganese	25304L
Zinc	30305L
Aluminum	13302L
Lead	82302L
Nickel	28302L
Cobalt	27302L
Mercury	80011L
Water Temperature	02061F
Air Temperature	02066F
Field pH	10301F
Dissolved Oxygen	08101F
Specific Conductance	02041F
Bicarbonate Alkalinity	10122F
Chlorophyll a (mg/m^2) epilithic	06721L
Chlorophyll a (mg/m^3) planktonic	06720L
Total Coliforms/100 mL	36002L
Fecal Coliforms/100 mL	36012L

2.1 PHYSICAL FACTORS

River velocity was measured at .20, .60, and .80 m depths, using a Teledyne Gurley Flow Meter. Insolation (surface, subsurface, bottom) was measured with a Protomatic light meter. River discharge data were provided by the Water Survey of Canada. Dissolved oxygen concentrations were determined using the Winkler technique. Field measurements of pH, specific conductance and temperature were routinely determined using a Model 4041 Hydrolab Surveyor.

2.2 WATER CHEMISTRY

Water samples were collected from about 0.15 m below the river surface, preserved and/or placed on ice and delivered as soon as possible to Chemex Labs, Calgary, Alberta for analysis.

2.3 ALGAE

Whole water samples for phytoplanktonic chlorophyll a were collected (1 litre) and field filtered through Whatman GF/C filters. The filters were covered with anhydrous magnesium carbonate, wrapped in aluminum foil and placed on dry ice for chlorophyll a analysis. Epilithic algal chlorophyll a concentrations were estimated by removing the entire attached community from a known area of rock and treating the sample as indicated above. Pigments of both the suspended and attached algal communities were homogenized and extracted into 90% acetone at -4°C for 24 hours in the dark. The spectrophotometric method and equations of Moss (1967a, 1967b) were used to determine the quantity of chlorophyll a present.

2.4 AQUATIC MACROPHYTES

Aquatic macrophytes were monitored quantitatively using a quadrat collection technique. Representative transects from shore to a maximum possible wading depth were sampled. Quadrats were defined and the plants within the perimeter removed down to a substrate depth of 0.2 m. A net (3 mm mesh) attached to the downstream side of the quadrat was used to collect dislodged plant material. Twigs, terrestrial leaves and non-macrophytic matter were removed. Upon return to the laboratory the plant material was centrifuged for two minutes, wet weight determined, then oven dried at 105°C for 20-48 hours (Westlake 1965) and weighed again to determine dry weight.

3.0 RESULTS

3.1 DISCHARGE

In rivers, the annual pattern of stream discharge determines many physical and biological properties. The volume of discharge is dependent upon rainfall, catchment geology, bed slope, area and flow restriction factors such as vegetation, beaver dams and human activity. River discharge also plays a particularly important role in affecting the distribution, abundance and deposition of suspended material. Phosphorus and most metals are generally transported and associated with particles, hence discharge directly influences the trophic state of rivers. Figure 3 presents weekly mean discharge for the Highwood River from 1970 until 1985.

The upper region of the drainage basin receives higher average annual precipitation (356 mm), while the town of High River area receives 305 mm (12 in.). During past years (i.e. 1970 to 1975 and 1981) the river underwent a period of flood, usually in June, principally due to mountain runoff. Hence, during June of those years the river was subjected to scouring and erosion which presumably was deleterious to the biological (attached) communities. However, during more recent years (i.e., 1976, 1977, 1982-1985) the spring spate was less significant, and the biological community in the Highwood River was likely not scoured and/or stressed to the same degree. Moreover the reduced spring spate was followed by very hot dry summers and high demands of river water for agricultural use. The combined effects of these factors therefore contributed to the maintenance of below average discharge in the Highwood River during this study period.

3.2 DISSOLVED OXYGEN AND TEMPERATURE

Dissolved oxygen is essential to the metabolism of all aquatic organisms that possess aerobic respiratory biochemistry. Its solubility is affected by pressure, temperature, meteorological conditions and salinity. Oxygen solubility in particular is affected nonlinearly by temperature and increases considerably in cold water (Wetzel 1975). River temperatures are influenced by topography of the drainage basin, meteorological conditions, flow regime, groundwater, turbidity and color.

In the Highwood River temperatures are lower upstream of High River than downstream, generally below 20°C during the summer period. Air temperatures in the vicinity of High River average 22.2°C. During

July and August the area may have as many as 35 days of temperatures above 26.7°C or 80°F (Atlas of Alberta). The period of maximum river temperature occurs in July through early August.

Figure 4 presents the mean, maximum and minimum daily water temperatures recorded at sites 1, 2 and 3. Daily temperatures fluctuate widely in response to the diurnal changes of insolation. Daily temperature in the river peaks during July and slowly decreases during the remainder of the summer.

Figure 5 presents temporal variation of discharge, minimum weekly dissolved oxygen (% saturation), daily maximum air temperature and daily maximum water temperature for 1984 and 1985. All data were collected in the vicinity of High River except 1985 air temperatures which were taken at Calgary.

During July of both 1984 and 1985 fish mortality was reported for the Highwood River. Fish mortality always followed a period when air temperatures exceeded 30°C for more than two consecutive days. During the same period river discharge was decreasing and below 10 cms. Daily maximum water temperatures during these periods of fish mortality in 1984 and 1985 exceeded 20°C. Minimum weekly dissolved oxygen (% saturation) decreased during the periods of fish mortality to a low of 6% saturation on July 29, 1984 and 33% saturation on July 11, 1985. Fish mortality coincided with 6% saturation (dissolved oxygen) or less. Thus it would appear that meteorological conditions play a particularly important role governing river water temperature, discharge, air temperature and the dissolved oxygen concentration of the Highwood River. The accumulation

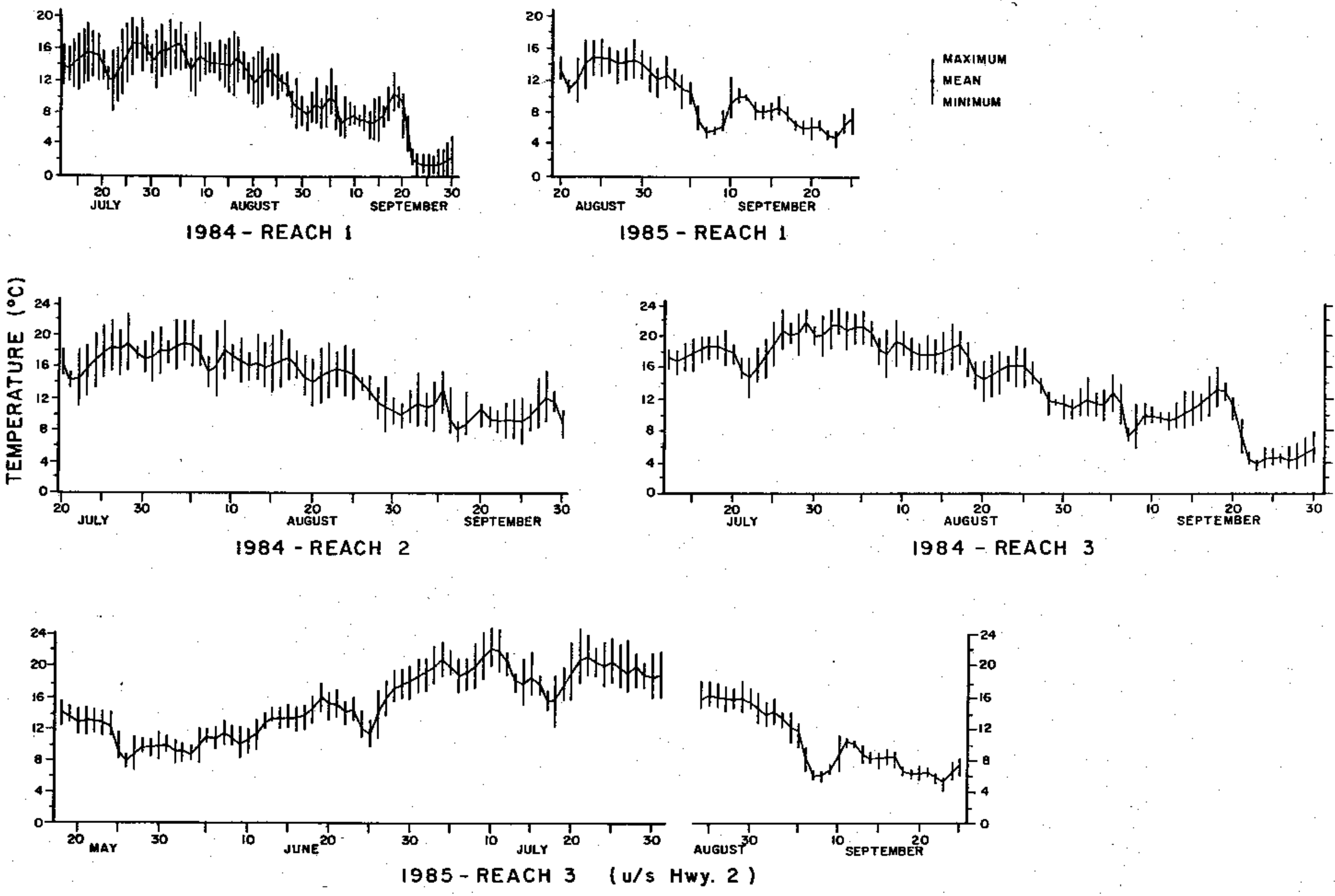

Figure 4. Daily Temperatures for the Highwood River.

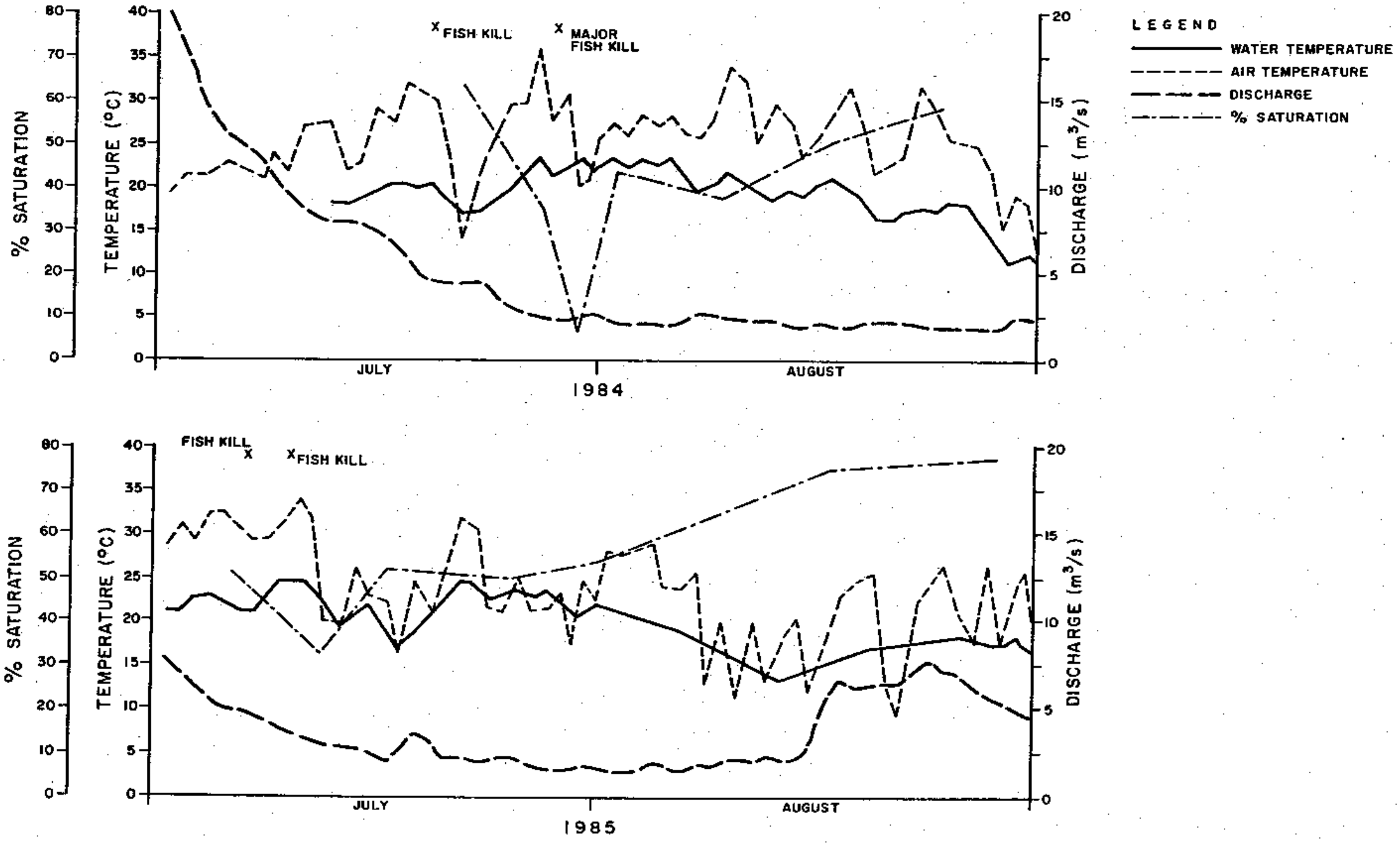

Figure 5. Highwood River air and water temperatures, discharge and % saturation for July and August 1984-85.

of submerged aquatic plant biomass (Section 3.4.2) also affects the diurnal pattern of oxygen and carbon dioxide concentration directly, and alters the flow regime of lotic systems.

3.3 WATER CHEMISTRY

Tables 2 and 3 present the mean and range of a number of variables examined between 1983 and 1985 for the Highwood River; sites listed are shown in Figure 2. These variables will be discussed with special reference to the Alberta Surface Water Quality Objectives (1977) (A.S.W.Q.O.).

3.3.1 Major Ions

Sodium concentrations in the Highwood River ranged from 2 to 8 mg/L between 1983 and 1985. Average values were 3 mg/L at sites S1 and S2 upstream of High River, 4 mg/L at sites S3 and S4 downstream of High River and 6 mg/L at Site S5. Sodium concentrations in the Highwood River remain well below the recommended limit for Alberta.

Magnesium concentrations for the Highwood River ranged between 7 mg/L (S1, S2, S3) and 15 mg/L (S4, S5). The average concentration however, was the same among all sites, i.e., 12 mg/L (Table 2).

Calcium concentrations in the Highwood River ranged between 31 and 54 mg/L during the study. Values decreased in a downstream direction from a mean of 46 mg/L at sites S1 and S2 to 41 mg/L at sites S4 and S5. At sites S3 and S4 concentrations declined during early to mid-August.

Potassium concentrations in the Highwood River ranged from 0.5 mg/L to 1.1 mg/L between 1983 and 1985. The mean concentration of

TABLE 2. The mean and range of values for selected inorganic variables in the Highwood River during fall 1983 through fall 1985, open water period. Units are mg/L unless indicated otherwise, n = approximately 26.

	Site S1 $\bar{x}$ & Range	Site S2 $\bar{x}$ & Range	Site S3 $\bar{x}$ & Range	Site S4 $\bar{x}$ & Range	Site S5 $\bar{x}$ & Range
pH	8.2 7.4-8.6	8.2 7.4-8.7	8.3 7.4-9.1	8.3 7.4-9.1	8.4 7.3-9.0
Na	3 2-5	3 2-5	4 2-6	4 2-7	6 3-8
Mg	12 7-14	12 7-14	12 7-14	12 8-15	12 8-15
Ca	46 36-54	46 36-54	44 36-54	41 31-53	41 31-54
K	0.6 0.5-0.8	0.6 0.5-0.8	0.7 0.5-1.0	0.7 0.5-1.0	0.9 0.6-1.1
Cl	0.6 0.1-1.4	0.6 0.1-1.4	1.3 0.3-4.0	1.2 0.4-2.5	1.7 0.6-4.0
SO_4	37 18-70	37 19-70	38 19-76	39 19-70	43 23-75
HCO_3	164 140-189	165 135-188	157 120.5-193	151 94-188	153 96-189
Hardness (as $CaCO_3$)	162 122-190	161 123-192	159 124-192	152 122-191	154 128-196
Alkalinity (as $CaCO_3$)	138 115-156	137 118-154	136 115-158	128 101-158	129 98-158
Conductance (μS/cm)	320 245-389	320 249-386	321 249-378	308 242-390	321 270-402
TSS (NFR)	6.2 0.4-40	7.0 0.4-61	7.6 0.4-85	8.0 0.4-82	10.0 0.4-110
Color (rel. units)	9.0 4.9-45	10.2 4.9-55	10 4.9-45	10.2 4.9-45	10 4.9-45
Si	4.15 3.3-5.7	4.18 3.2-6.3	2.61 0.22-5.7	1.92 0.18-5.4	2.25 0.39-6.5
F	0.15 0.03-0.27	0.14 0.04-0.27	0.15 0.03-0.29	0.15 0.03-0.27	0.14 0.03-0.27

TABLE 3. The mean and range of values for selected organic and nutrient variables at five sites on the Highwood River, August 1983 – September 1985. Units are mg/L unless indicated otherwise; n = approx. 24.

	Site S1 $\bar{x}$ & Range	Site S2 $\bar{x}$ & Range	Site S3 $\bar{x}$ & Range	Site S4 $\bar{x}$ & Range	Site S5 $\bar{x}$ & Range
Phenols	0.005 0.001-0.028	0.007 0.001-0.073	0.012 0.001-0.170	0.005 0.001-0.034	0.003 0.001-0.019
BOD	0.8 0.2-2.3	0.8 0.2-2.1	1.2 0.7-2.3	1.3 0.3-2.7	1.2 0.3-2.0
TOC	1.6 0.7-4.5	1.6 0.7-4.5	1.9 0.8-4.0	1.9 1.1-2.8	1.9 1.0-3.0
TIC	30.1 23-35	30.3 23-35	29.1 22.5-36	26.9 20-34	27.5 19-36
TP	0.011 <0.003-0.046	0.011 <0.003-0.067	0.040 0.015-0.097	0.037 0.007-0.280	0.053 0.006-0.620
TKN	0.35 0.14-0.78	0.36 0.08-0.62	0.50 0.20-2.4	0.41 <0.02-0.72	0.45 0.14-1.20
OP	<0.005 <0.003-0.019	<0.004 <0.003-0.020	0.018 <0.003-0.064	<0.007 <0.003-0.030	<0.005 <0.003-0.028
NO_2+NO_3-N	0.006 <0.003-0.031	0.007 <0.003-0.021	0.012 <0.003-0.074	0.005 <0.003-0.020	0.010 <0.003-0.042
NH_3-N	0.02 <0.01-0.05	0.02 <0.01-0.05	0.03 <0.01-0.08	0.02 <0.01-0.10	0.02 <0.01-0.09

potassium increased in a downstream direction, averaging 0.6 mg/L at sites S1 and S2, 0.7 mg/L at sites S3 and S4 and 0.9 mg/L at Site S5.

Mean chloride concentrations also increase in a downstream direction from 0.6 mg/L at sites S1 and S2 to 1.7 mg/L at Site S5. Throughout the entire study chloride ranged from a minimum of 0.1 mg/L at sites S1 and S2 to a maximum of 4 mg/L at sites S3 and S5.

Sulphate concentrations ranged from 18 mg/L at Site S1 to a maximum of 76 mg/L at site S3 downstream of the town of High River. Mean values however were less variable with a trend toward increases at each successive site. Mean values ranged from 37 mg/L at Site S1 to 43 mg/L at Site S5.

The Alberta Surface Water Quality Objectives (1977) do not recommend limits for any of the major ions due to their generally low concentrations and innocuous nature in surface waters.

3.3.2 pH, Total Alkalinity and Related Variables

Between 1984 and 1985 pH ranged from 7.3 at the mouth of the Highwood (S5) to 9.1 at sites S3 and S4. Mean values generally increased in a downstream direction, averaging 8.2 at site S1 and 8.4 at Site S5. Mean values remained within the reccmmended range of 6.5 to 8.5 (Alberta Surface Water Quality Objectives, 1977).

Total alkalinity decreased in a downstream direction in the Highwood River. Mean values decreased from 138 mg/L at site S1 to 129 mg/L at Site S5. Bicarbonate alkalinity was highest at Site S2 (i.e., 165 mg/L). Mean values among the remaining sites ranged from 150.6 mg/L at Site S4 to 163.8 mg/L at Site S1. These values indicate that the Highwood River is well buffered.

Specific conductance provides some indication of the amount of dissolved electrolyte in water. It ranged from a mean of 308 μS/cm at Site S4 to 321 μS/cm at sites S3 and S5.

3.3.3 Total Suspended Solids (TSS)

Suspended solids (nonfilterable residue) increased from a mean of 6.2 mg/L at Site S1 to 10.1 mg/L at Site S5 (Table 2). The widest range of values were found for Site S5, e.g. 0.4 - 110 mg/L. This variable provided evidence of the capacity of the Highwood River to carry increasing loads of suspended material derived from both allochthonous and autochthonous sources.

3.3.4 Colour

Colour in the Highwood River changed little throughout the five sites sampled. Values increased from 9.0 colour units at Site S1 to 10.2 colour units at Site S2. Both nonfilterable residue and colour affect the heat absorbing quality of water.

3.3.5 Dissolved Silica

Dissolved silica is the primary element essential for the formation of algal cell walls in diatoms. This element can become limiting to some species at concentrations of less than 3 mg/L. Mean silica concentrations in the Highwood River were below this algal requirement at sites S3, S4 and S5. Mean concentrations among these sites ranged between 1.92 mg/L and 2.61 mg/L. Hence it would appear that sites S3, S4 and S5 may provide a selective advantage to species not requiring silica. Silica values declined annually during the spring spate and again during the fall when diatoms are generally more abundant.

3.3.6 Fluoride

Fluoride concentrations were always below the A.S.W.Q.O. in the Highwood River. Mean values ranged from 0.14 mg/L to 0.15 mg/L, and fluoride did not display a longitudinal trend (Table 2).

3.3.7 Phenols

Phenols are particularly important with regard to water use. At minute concentrations they impart a taste to water which is intensified by chlorination, and they may also taint fish flesh. The Alberta Surface Water Quality Objectives recommend a limit of 0.005 mg/L. In the Highwood River 0.005 mg/L phenol was detected at sites S1 and S4. The highest phenol concentration was recorded for Site S3 downstream of High River, (i.e., 0.170 mg/L) (Table 3).

3.3.8 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand is indicative of the oxygen required to degrade ambient organic materials. Mean values in the Highwood River were low and ranged from 0.8 mg/L to 1.3 mg/L (Table 3). The sites located downstream of the town of High River had higher values than the sites located upstream of the town.

3.3.9 Nutrients

Total Organic Carbon (TOC): Wetzel (1975) indicates that the total organic carbon content of natural waters varies from approximately 1 to 30 mg/L. Values for the Highwood River (Table 3) provide evidence of the comparatively low quantity of organic carbon present in this system, which is typical of streams originating on the east slope of the Rocky Mountains. Mean values, although higher downstream of High River, ranged only between 1.6 m/L and 1.9 mg/L.

Total Inorganic Carbon: The total inorganic carbon content of river water is the sum of all carbon present as CO_2, HCO_3^- and $CO_3^=$. It is particularly important for evaluating the inorganic carbon available for photosynthesis. The concentration of total inorganic carbon depends on the pH, which is governed largely by the buffering reactions of carbonic acid, and the amount of bicarbonate and carbonate derived from the weathering of rocks.

In the Highwood River mean total inorganic carbon concentrations decrease at successive downstream sites. Mean values ranged from 30.3 mg/L upstream of High River to 26.9 mg/L at Site S4 (Table 3). Hence it would appear that some factor (probably the photosynthetic activity of the primary producers) at site S3 and S4 contributed to a reduction of the total inorganic carbon concentrations within these Highwood River reaches.

Total Phosphorus: Wetzel (1975) indicates that total phosphorus is a very important variable in view of the metabolic characteristics of aquatic systems. Most uncontaminated surface waters have concentrations ranging between 0.010 and 0.050 mg/L. However, variation is high in accordance with the geochemical structure of the drainage basin. Mean total phosphorus concentrations in the Highwood River occasionally exceeded 0.050 mg/L at all sites except S1 (Figure 6). Exceedance may be related to phosphorus inputs from domestic sewage effluent, urban and agricultural inputs and other allochthonous sources within the drainage basin.

In the Highwood River, total phosphorus ranged from <0.003 mg/L upstream of High River to 0.620 mg/L at Site S5 downstream of the town of High River. Mean values ranged from 0.011 mg/L at sites S1 and S2 to 0.053 at Site S5 (Table 3). Total phosphorus generally reached higher concentrations during low flow periods, as in early June prior to the spate and again during the fall prior to ice formation. Highest concentrations occurred in late July, 1984 at stations downstream of High River (Figure 4), which coincided with sewage treatment plant operational problems and the output of sewage having 14.6 mg/L TP. Immediately following the event, phosphorus concentrations decreased significantly. Throughout 1985 total phosphorus was consistently higher at sites S3, S4 and S5 than at site S1 and S2 upstream of High River.

The sewage effluent contributed large quantities of phosphorus to the river. Hamilton (1984) reported that between 1978 and 1983 mean annual average sewage discharge ranged between 0.0236 cms in 1982 and 0.0309 cms in 1983. The following formula was employed to calculate the mean monthly theoretical range of total phosphorus in the river downstream of the STP discharge (Site S3).

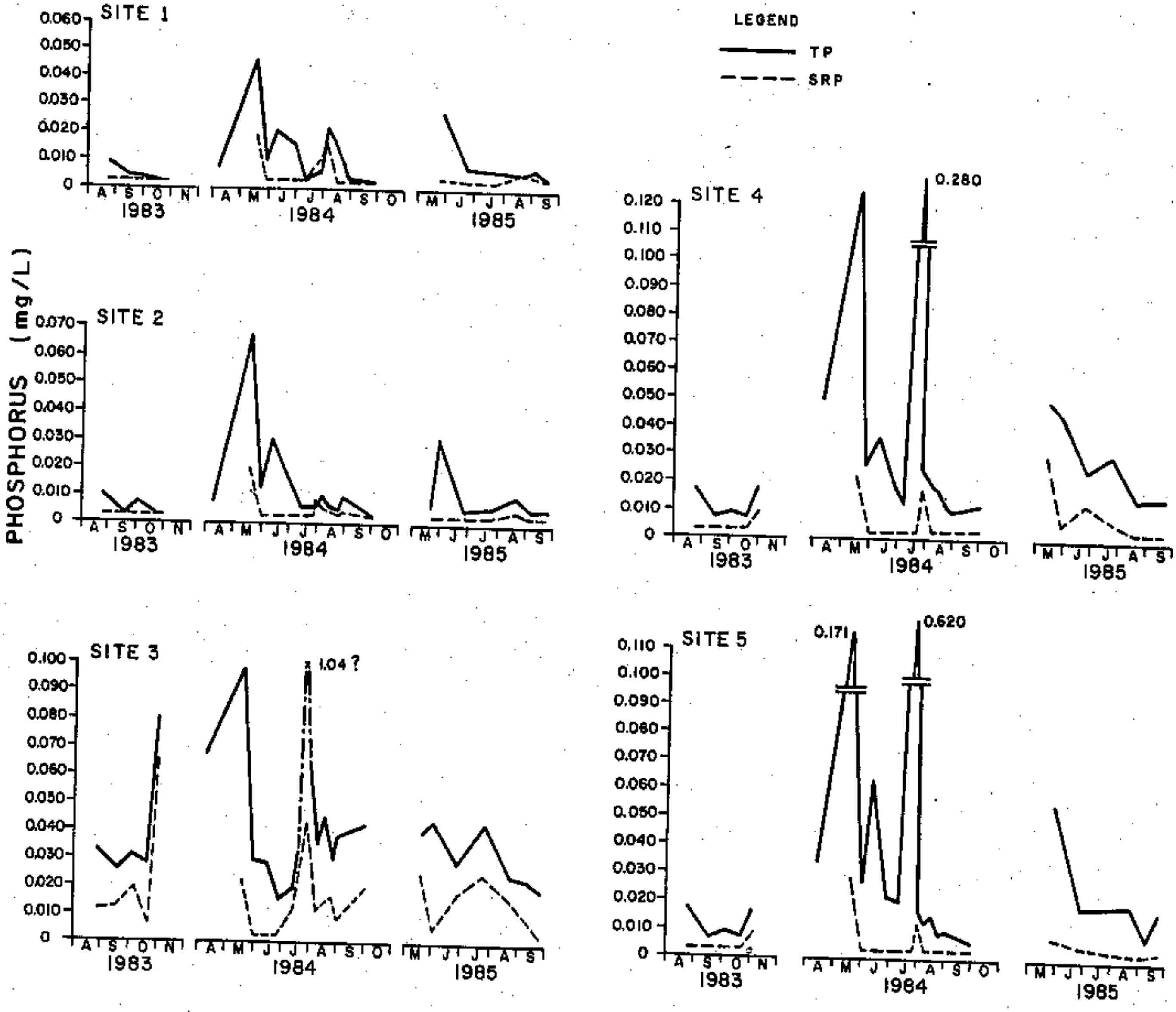

Figure 6. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) in the Highwood River 1983-1985.

$$[TP] = (C_R \times F_R) + (C_S \times F_S)/(F_R + F_S)$$

where:

C_R = Concentration of total phosphorus (TP) in river upstream of the sewage treatment plant

F_R = Flow in river at the Aldersyde Water Survey Station adjusted for flow in Little Bow Canal (cms)

C_S = Concentration of total phosphorus in sewage effluent

F_S = Discharge of sewage (cms)

Table 4 presents the predicted range of values and the actual river water concentrations at Site S3. The observed concentrations of total phosphorus in the Highwood River were often less than the values predicted by the preceeding formula. Losses may relate to biological uptake; hence aquatic primary producers exert an important controlling influence upon ambient phosphorus concentrations. Moreover, the availability of this important nutrient contributes to the abundance of primary producers observed and their secondary effects upon river water quality.

Soluble Reactive Phosphorus: Aquatic plants primarily take up orthophosphate from the river water and sediments. They also take up "excess" quantities and store it as polyphosphates for utilization during periods when external phosphate concentrations are low. The specific requirement depends upon species composition, their physiological state and the amount and rate at which phosphorus is being cycled in the aquatic system.

In the Highwood River soluble reactive phosphorus (≃ orthophosphate) concentrations ranged from a mean of <0.004 mg/L at Site S2 to 0.018 mg/L at Site S3 (Table 3). Values declined during early June

TABLE 4 Predicted and observed concentrations (mg/L) of total phosphorus in the Highwood River downstream of High River (Site S3), Sewage Treatment Plant (STP) effluent and river flow (cms), 1984 and 1985.

	1984				1985			
	TP		Flow		TP		Flow	
	Predicted*	Observed	STP	River	Predicted	Observed	STP	River
Apr	0.073	0.068	0.026	2.93	0.039	0.040	0.029	5.19
May	0.064	0.064	0.025	7.53	0.031	0.042	0.032	16.6
Jun	0.033	0.024	0.034	24.4	0.018	0.029	0.036	18.2
Jul	0.068	0.055	0.028	6.70	0.057	0.044	0.026	3.07
Aug	0.085	0.037	0.025	2.39	0.048	0.025	0.027	4.19
Sep	0.096	0.038	0.027	2.26	0.015	0.022	(0.027)	18.1
Oct	0.091	0.043	0.027	2.21	**	**	**	**

** not available
* Assumes TP in sewage effluent = 7.33 mg/L 1984 and 5.96 mg/L 1985

(1984 and 1985) with the onset of the spring spate (Figure 6). After early July levels again increased, particularly at sites S3 and S4. Similar seasonal patterns were detected during both 1984 and 1985 although soluble reactive phosphorus concentrations were higher at Site S3 during 1984. High late July values at Site S3 coincided with operational problems at the High River Sewage Treatment Plant (Brassard 1986).

<u>Total Kjeldahl Nitrogen</u> (TKN): Total Kjeldahl nitrogen is the sum of organic nitrogen and ammonia nitrogen. Organic nitrogen may include such natural materials as proteins and peptides, nucleic acids and urea. Ammonia is produced largely by the deamination of organic nitrogen-containing compounds and by the hydrolysis of urea. Ammonia may also be produced naturally by the reduction of nitrate under anaerobic conditions.

The greatest range in total Kjeldahl nitrogen was observed at Site S3 (0.02 mg/L to 2.4 mg/L). Site S3 also had the highest mean concentration, i.e., 0.50 mg/L (Table 3). Figure 7 presents the seasonal changes of TKN at sites S2, S3 and S4. Total kjeldahl nitrogen fluctuated widely, peaking in 1984 during the June spate and again during early August. A late August peak also occurred at Site S2, upstream of High River. During 1985, concentrations declined at sites S2 and S4 following the spring spate and increased again in late July. Values decreased more slowly at Site S3 following the spring spate but thereafter declined to 0.3 mg/L in late July. After the late July minimum total kjeldahl nitrogen dramatically increased as discharge in the Highwood River reached the mid-summer minimum.

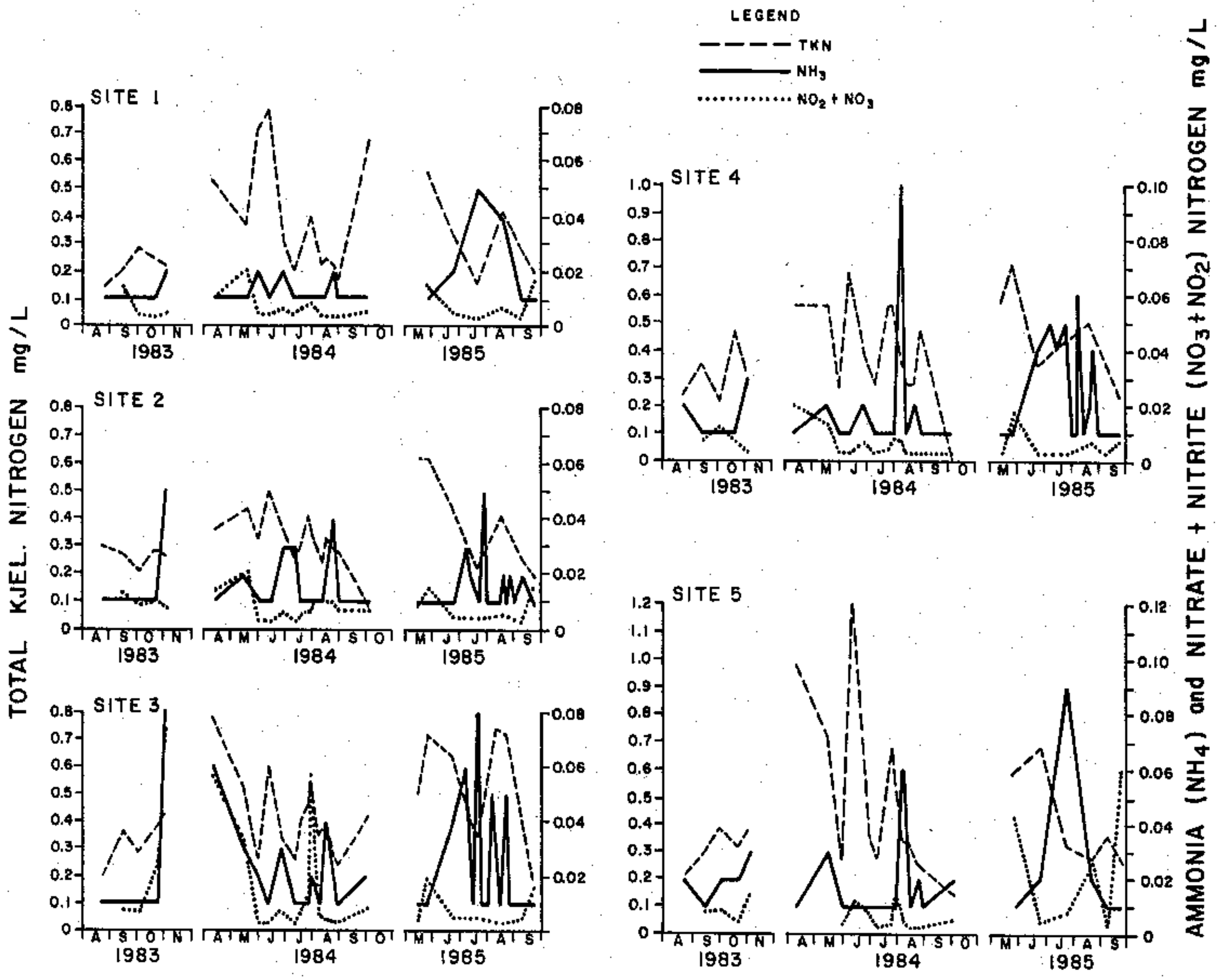

Figure 7. Concentrations of total kjeldahl nitrogen (TKN), ammonia-nitrogen (NH) and nitrate + nitrite - nitrogen (NO + NO) in the Highwood River.

Ammonia Nitrogen (NH_3): Ammonia concentrations in the Highwood River ranged from detection limit values (<0.01 mg/L) at all sites to a maximum of 0.10 mg/L at Site S4 during early August, 1984 (Figure 7). The highest mean concentration was detected at Site S3, e.g., 0.03 mg/L. Ammonia generally remained within a narrow range of concentration in the Highwood River upstream of the town of High River. Seasonally, the ammonia concentrations declined during the spring spate and again during late July, 1984. Although ammonia concentrations increased sooner at sites S3 and S4 than Site S2, levels peaked during late July at all sites. Ammonia appeared to increase during the fall of both 1984 and 1985.

Nitrate+Nitrite Nitrogen (NO_2^- + NO_3^-): Nitrate (NO_3^-) generally occurs in trace quantities in surface waters but may attain high levels in some groundwaters. It is an essential nutrient for many photosynthetic autotrophs. Nitrite (NO_2^-) is an intermediate state of nitrogen, both in the oxidation of ammonia to nitrate and in the reduction of nitrate. Concentrations in the Highwood of either form did not exceed the recommended Alberta Surface Water Quality Objective of 1.0 mg/L.

In the Highwood River, nitrite+nitrate nitrogen concentrations ranged between a minimum of <0.003 mg/L at all sites to a maximum of 0.074 mg/L at Site S3 downstream of High River (Table 3). Site S3 also had the highest mean 1983-1985 concentration, 0.012 mg/L. Figure 7 presents the seasonal changes of nitrite+nitrate concentrations. In 1984 NO_2^-+NO_3^- declined to lowest values during the June spate and remained low until late July. A dramatic increase was detected at Site S3 during early August, when problems arose at the High River Sewage Treatment Plant and river flow was minimal. Hence, it would appear that domestic effluent may have contributed to the higher values detected at Site S3. During 1985, NO_2^-+NO_3^- remained low before and after the spring spate at all Highwood River sites.

3.3.10 Metals

Metals were sampled on three occasions during 1983 (August/October/November) twice during 1984 (April/August) and once during 1985 (August). Table 5 presents the mean concentrations detected during the three year period.

Metal compounds occur naturally in watershed soils and rocks, and therefore appear in the river due to leaching and weathering. Metals also occur in surface waters as a result of human activity. Numerous metals were detected in the Highwood River, but all were found below the limits defined by the Alberta Surface Water Quality Objectives during 1983-1985.

3.4 BIOLOGICAL CHARACTERISTICS

3.4.1 Algae

Epilithic (attached) and phytoplanktonic (suspended) algal standing crops were estimated by means of chlorophyll a. Table 6 presents the mean and range of phytoplanktonic and epilithic algal standing crops for 1984, 1985 and 1984/1985 combined.

Mean epilithic algal standing crops generally increased in a downstream direction and were higher during 1984 than 1985. Epilithic

TABLE 5. Mean concentrations of metals in the Highwood River, 1983-85. Units are mg/L.

	Site S1	Site S2	Site S3	Site S4	Site S5	A.S.W.Q.O.
Al	0.017	0.038	0.009	0.011	0.009	-*
Cd	0.0009	0.0009	0.0009	0.0009	0.0009	0.01
Co	0.0013	0.0011	0.0013	0.0013	0.0012	-*
Cu	0.0009	0.0009	0.0009	0.0009	0.0014	0.02
Cr	0.0013	0.0014	0.0012	0.0011	0.0011	0.05
Fe	0.042	0.063	0.035	0.037	0.029	0.3
Pb	0.0021	0.0024	0.0023	0.0026	0.0021	0.05
Mn	0.0070	0.0113	0.0098	0.0070	0.0070	0.05
Hg	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001
Ni	0.0013	0.0011	0.0011	0.0009	0.0011	-*
Se	0.00019	0.00019	0.00019	0.00022	0.00022	0.01
Zn	0.0009	0.0094	0.0038	0.0015	0.0016	0.05
As	0.0003	0.0003	0.0003	0.0005	0.0004	0.01

* A.S.W.Q.O. not defined

TABLE 6. The mean and range of phytoplanktonic chlorophyll *a* (mg/m^3) and epilithic chlorophyll *a* (mg/m^2) for the Highwood River in 1984 and 1985.

	PHYTOPLANKTON (mg Chl *a*/m^3)		EPILITHON (mg Chl *a*/m^2)	
	MEAN	RANGE	MEAN	RANGE
1984				
Site S1	0.8	0.3-1.6	110.1	28.9-200.9
S2	0.9	0.1-1.3	59.1	17.8-126.0
S3	2.6	1.8-3.5	No Data	No Data
S4	2.6	1.8-3.4	182.9	51.6-265.4
S5	3.1	1.7-5.4	185.4	47.2-389.3
1985				
Site S1	0.5	0.0-1.9	42.0	4.7-86.5
S2	0.3	0.0-1.1	31.2	6.7-60.7
S3	2.6	0.8-6.6	186.7	85.0-287.0
S4	2.2	0.0-4.5	160.1	24.6-290.6
S5	2.2	0.0-5.8	165.8	9.6-306.5
Sheep R.	2.2	0.0-5.7	199.4	6.9-334.7

algal standing crops ranged from 59.1 mg Chl a m^{-2} at Site S2 to 185.4 mg Chl a m^{-2} at Site S5 during 1984 and from 31.2 mg/m^2 at Site S2 to 186.7 mg/m^2 at Site S3 during 1985. The mean epilithic algal standing crop in the Sheep River was higher than any site sampled in the Highwood River. Phytoplankton standing crops in the Highwood River increased somewhat in a downstream direction, likely due to nutrient enrichment, inputs of algae from municipal discharges, and scouring of the epilithic community. However, mean values remained low, ranging between 0.3 mg Chl a m^{-3} at Site S2 and 3.1 mg Chl a m^{-3} at Site S5 during the two years.

Although the seasonal dynamics of phytoplankton and epilithic algal standing crops were generally similar, the timing of each often differed (Figure 8). Peaks of phytoplankton chlorophyll a generally followed a peak of epilithic standing crop, presumably due to detachment and entrainment of the latter into the flowing water. During both years epilithic algal standing crops increased after the spring spate and peaked during late July or early August. It appears that river discharges exceeding 10 cms, i.e., spring spate, contribute significantly to the abrasion of the epilithic communities. In 1985, the Sheep River exhibited a similar pattern, but the standing crops of epilithon were higher than those found for the Highwood River.

3.4.2 Submerged Aquatic Macrophytes

Aquatic macrophyte biomass accumulated during the summer months at all sites (Figure 9). Site S3 reached a mean macrophyte biomass of 424 g/m^2 dry weight (dwt) in 1984 and 298 g/m^2 in 1985. At Site S4 the mean biomass reached was 477 g/m^2 during 1984 and 648 g/m^2 in 1985.

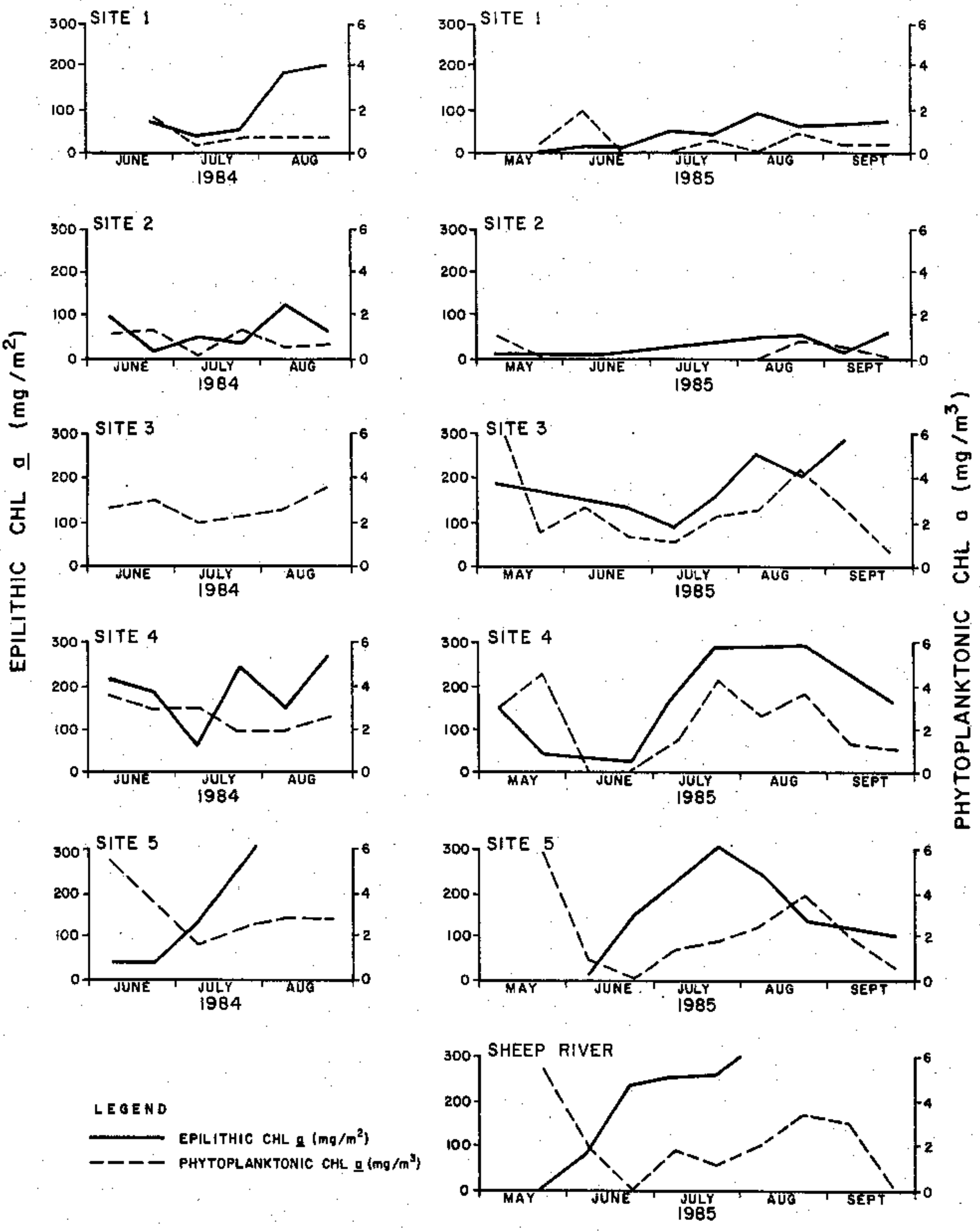

Figure 8. Highwood River epilithic and phytoplanktonic chlorophyll a concentrations 1984 - 1985.

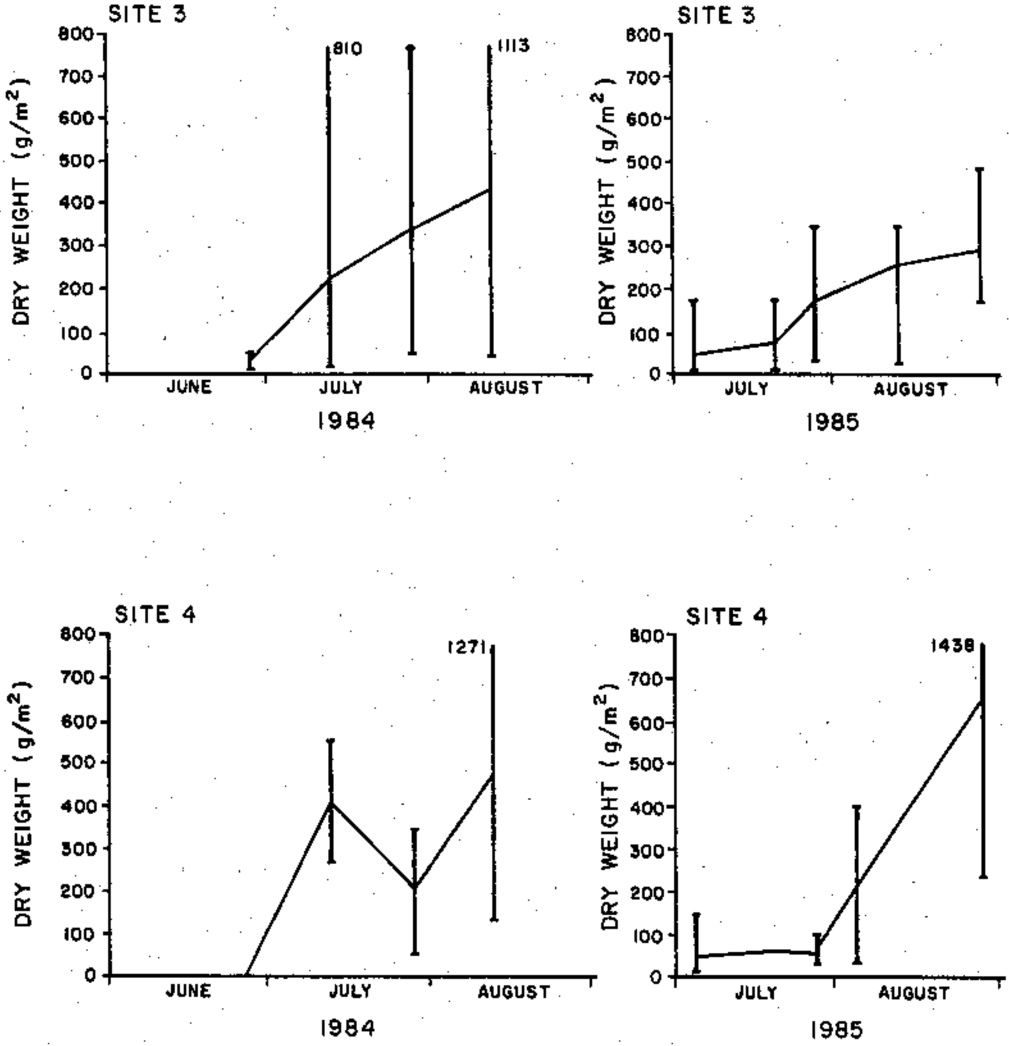

Figure 9. Highwood River Average Dry Weight Biomass of Aquatic Macrophytes at sites S3 and S4, 1984-1985.

Submerged aquatic macrophtyes were monitored at sites S3 and S4 downstream of the town of High River during both 1984 and 1985. At Site S3 the biomass accumulated during July and August of both years. Standing crops were particularly heterogenous during 1985 hence the wide range of biomass estimates indicated by Figure 9. At Site S4 biomass increased rapidly during 1984 but fell during late July. Thereafter it increased to a maximum of 1271 g/m^2 dry weight. During 1985 macrophyte biomass accumulated less slowly at Site S4 than Site S3 but again Site S4 supported a higher standing crop than Site S3, i.e., 1438 g/m^2 dry weight.

3.4.3 Bacterial Counts

Total and fecal coliform bacteria were sampled fortnightly at three sites in the Highwood River in addition to the High River sewage treatment plant effluent and 50 meters downstream of the effluent outfall. The numbers of total and fecal coliform bacteria exceeded the limits recommended by the Alberta Surface Water Quality Objectives for direct contact recreation and irrigation at Site S3, and 50 meters downstream of the sewage treatment plant outfall (Table 7). Numbers were highest during September and October at Site S3.

4.0 DISCUSSION

4.1 ENVIRONMENTAL CONDITIONS IN THE HIGHWOOD RIVER

During the 1983-85 study period, below average precipitation and above normal temperatures contributed significantly to water-supply problems throughout southern Alberta (Grace and Johnson 1985). The

TABLE 7. Mean monthly total and fecal coliform bacteria in the Highwood River and the High River Sewage Treatment Plant effluent (1985) (counts/100 mL).

MONTH	SITE S2		SITE S3		SITE S4		STP EFFLUENT		50 METERS DOWNSTREAM OF STP	
	TOTAL	FECAL	TOTAL	FECAL	TOTAL	FECAL	TOTAL	FECAL	TOTAL	FECAL
May	130	36	410	76	700	180				
June	28	1	550	45	*150	18				
July	118	38	2	2	40	14				
August	66	16	640	149	185	30	900,000	100,000	38,000	5,000
September	25	10	6,800	400	635	82	1,350,000	190,000	257,500	36,100
October	20	12	5,800	750	2,100	180	2,500,000	703,000	42,000	9,200
November	6	2	2,000	200	410	10	850,000	20,000	46,000	3,300
December	20	0	5,000	380	1,000	180	400,000	260,000	50,000	2,300

d/s STP (50 yards downstream of the High River Sewage Treatment Outlet, Right Bank) amplitude of the spring spate was below normal in 1976, 1977, 1982, and 1983-85. Spring spates play an important role ecologically by scouring the river substratum and removing silt accumulations and by relocating and transporting organic material. The spring spate "resets" the chemical and physical state of lotic systems: It counteracts the physical and chemical changes brought about by factors which impede or alter river regimes during the winter and warm water seasons.

The Highwood River is an important resource from fisheries, recreation, water supply and agricultural perspectives. As in many Alberta rivers, the middle reaches are particularly important ecologically (Charlton 1985). The middle reach of the Highwood River was also the most highly impacted by human activity.

The impact of anthropogenic nutrient additions was most evident downstream of the town of High River (Sites S3, S4 and S5). This river region supported the highest standing crops of aquatic plants which depend upon the river water for all their physical and chemical needs. The macrophytes in particular also altered the river regime downstream of the town by impeding water flow, hence accelerating sedimentation and the amount of heat absorbed by the river water. Through the process of photosynthesis they also liberate dissolved oxygen and metabolic by-products by daylight, then deplete the dissolved oxygen during night-time respiration. Site S3 in particular was characterized by thick (30 cm) accumulations of anaerobic sediment and high concentrations of sulphate, phenol, total phosphorus, orthophosphate, total Kjeldahl nitrogen, ammonia, nitrate-nitrite nitrogen, total organic and total inorganic carbon.

As a result of the biotic and abiotic interactions occurring at Site 3, extending periodically (i.e., July) to Site 4, these river reaches were subject to periodic fish kills. Aiken and Atherton (1970) indicated that climatic and physical factors which elevate river temperatures above 21°C increase gut efficiency and energy demand, hence reduce specific growth rates of cold water fish. Roberts and Hughes (1970) found that high river temperatures increase the ventilation rate of fish. Sylbester (1971) found that high temperature increases fish vulnerability to predation. Wedemeyer (1973) showed that elevated temperatures increase hyperglycalmia, hypocholesterolaemia and blood haemoglobin while decreasing blood-sugar regulatory precision. Thus, elevated river temperature, which also limits the capacity of river water to retain dissolved oxygen, is very detrimental to cold water fish species.

While macrophytes play an important role chemically and physically they also offer fish shade, cover, and an ideal habitat for many invertebrates, an important fish food source. Consequently, fish may prefer river reaches that offer food and cover during the day, but which become lethal during the early morning hours when dissolved oxygen concentrations decrease.

The Highwood River at sites 3 and 4 support high standing crop of macrophytes. Site 4, for example, supported an average dry weight biomass of 477 g/m^2 in 1984 and 648 g/m^2 in 1985. Epilithic algal standing crops are, however, higher at other sites downstream of major nutrient additions. This finding suggests that macrophytes exhibit a competitive advantage over epilithic algae. Moreover, epilithic algae are extremely opportunistic and capable of responding very quickly to lotic regimes, due to their relatively short lifespan. Nostoc commune and numerous other cyanophycean (blue-green) algae observed in epilithic samples are also capable of fixing elemental nitrogen, thus they flourish in the lower reaches of the Highwood River where inorganic nitrogen concentrations were relatively low.

Macrophytes accumulate biomass during the open water period faster than epilithic algae. At Site 4 epilithic biomass averaged 8 g/m^2 compared to 648 g/m^2 for macrophytes. Thus macrophytes exert the most profound influence upon the Highwood River regime both directly (photosynthesis and respiration) and indirectly when they decompose during early fall and winter.

4.2 EFFECTS OF THE HIGH RIVER SEWAGE TREATMENT PLANT EFFLUENT

The High River Sewage Treatment Plant played an important role with respect to the nutrient status of the Highwood River. Its effluent contributed significant quantities of total phosphorus, ammonia and biochemical oxygen demand at downstream sites. Moreover, when there were technical problems at the treatment plant, large quantities of total phosphorus were discharged to the river, which probably stimulated the aquatic plants. Low levels of dissolved oxygen in the effluent may have been hazardous to river biota that required high oxygen concentrations. Dilution of the effluent during 1984 and 1985 was also highly variable, but very low at times. The volume of flow in the Highwood River was, therefore, a critical factor governing the impacts of the High River sewage effluent upon the biotic resources and potential recreational use. Dilution was particularly important, in light of the evidence for very high bacterial counts found not only in the sewage treatment plant effluent but also extending to Site 3. The river region extending from the outlet of the High River sewage treatment plant throughout Site 3 was not suitable for direct contact recreation or irrigation because bacterial counts often exceeded levels considered safe.

In conclusion, the Highwood River was highly eutrophic during 1984-85, as a direct result of low river flows and excessive nutrient additions, particularly from the effluent discharged from the town of High River sewage treatment plant. The continued success of macrophytes as a result of nutrient additions and their capacity to modify river regimes is further rendering the Highwood River below High River of limited use as a fisheries, recreational and agricultural resource.

5.0 REFERENCES

Aiken, A., W.D. Atherton. 1970. Growth, nitrogen metabolism and fat metabolism in Salmo gairdneri. Rich. comp. Biochem. Physiol. 36:719-747.

Alberta Surface Water Quality Objectives. 1977. Standards and Approvals Division, Water Quality Branch. 17 pp.

Atlas of Alberta. 1969. University of Alberta Press. 158 pp.

Brassard, B. 1986. A summary of biological and environmental information pertaining to fisheries in the Highwood River system. Alberta Environment, Planning Division, Calgary.

Brown, A.V., M.L. Armstrong. 1985. Propensity to drift downstream among various species of fish. J. Freshwat. Ecology. 3(1): 3-17.

Charlton, S.E.D. 1985. The ecology of five rivers. Ph. D. thesis, Department of Botany, University of Alberta, Edmonton, Alberta. 290 pp.

Charlton, S.E.D., M. Hickman. 1982. Longitudinal physio-chemical and algal surveys of rivers flowing through the Oil Sands region of northeastern Alberta, Canada. Nova Hedwigia 465-522.

Englert, J., B. Brassard and R. Middleton. 1987. Highwood River instream flow needs study. Alberta Environment, Planning Division, Edmonton.

Grace, G., D.L. Johnson. 1985. The drought of 1984 in southern Alberta: Its severity and effects. Canadian Water Resources Journal. 10(2): 28-38.

Hamilton, H.R. 1984. Working paper on the need for advanced phosphorus removal at the town of High River. Alberta Environment, Planning Division, Calgary.

Hynes, H.B. 1970. The ecology of running waters. Univ. Toronto Press, Toronto. 555 pp.

I.E.C. Beak Consultants Ltd. 1984. Highwood River instream flow needs study. Prepared for Alberta Environment, Planning Division, Edmonton, Alberta. 92 pp.

Moss, B. 1967 (a). A spectrophotometric method for the estimation of percentage degradation of chlorophylls to pheopigments in extracts of algae. Limnol. Oceanogr. 12:335-340.

Moss, B. 1967 (b). A note on the estimation of chlorophyll a in freshwater algal communities. Limnol. Oceanogr. 12:340-342.

Stelfox, J.D. 1981. Rainbow trout spawning in Pekisko Creek and the Sheep River watershed, May, 1980. Alberta Energy and Natural Resources, Fish and Wildlife Division. 38 pp.

Roberts, J.L., G.M. Hughes. 1970. A study of the effect of temperature changes on the respiratory pumps of the rainbow trout. J. Exp. Biol. 52:117-192.

Sylbester, J.R. 1971. Some effects of thermal stress on the predator-prey interaction of two salmonids. Thesis, University of Washington, 115 pp.

Wedemeyer, G. 1973. Some physiological aspects of sub-lethal heat stress in the juvenile steelhead trout (Salmo gairdneri) and coho salmon (Oncorhynchus kisutch). J. Fish. Res. Bd. Can. 30:831-834.

Westlake, D.F. 1965. Theoretical aspects of the comparability of productivity data. Mem. Ist Ital. Hydrobiol. 18 Suppl. 313-322.

Wiebe, A.P. 1979. Kananaskis Country - spring spawning survey. Alberta Energy and Natural Resources, Fish and Wildlife Division, Calgary. 21 pp.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Toronto. 743 pp.

APPENDICES

APPENDIX I
HIGHWOOD RIVER MACROPHYTE BIOMASS (g/m²)

DATE	QUADRAT A	B	C	D	E	F	G	H	I	J	x BIOMASS
1984											
Site 3 Dry Weights											
June 27	41.72	13.82	--	--	--	--	--	--	--	--	27.77
July 12	60.11	44.30	201.67	23.44	62.80	350.64	58.54	532.04	810.32	--	238
July 25	40.54	145.77	334.41	518.39	636.67	776.63	146.40	134.40	431.34	99.25	326
Aug. 10	107.42	934.52	130.75	713.44	1115.91	541.61	327.36	33.98	27.10	312.04	424
Site 4 Dry Weights											
June 28	--	--	--	--	--	--	--	--	--	--	0.0
July 12	--	--	--	--	--	549.57	263.98	--	--	--	406.8
July 26	--	--	51.51	327.1	--	132.80	150.11	--	286.45	--	189.6
Aug. 10	--	--	257.96	129.46	261.83	1271.08	574.4	364.09	--	--	476.5
1985											
Site 3 Dry Weights											
July 12	176.12	91.07	60.48	10.16	1.08	12.15	17.90	18.50	59.36	6.66	45.35
July 16	28.28	52.69	179.46	71.40	48.06	26.34	124.57	1.08	83.12	118.71	73.4
July 29	177.63	205.59	352.47	73.55	145.70	169.09	67.80	34.03	340.27	188.28	175
Aug. 12	125.05	180.32	56.54	262.7	230.6	156.8	395.5	269.8	121.0	296.3	260
Aug. 26	291.5	238.7	246.99	215.5	169.9	311.5	410.1	198.1	410.9	490.1	298
Site 4 Dry Weights											
July 3	146.9	12.5	47.5	--	32.8	5.8	--	--	--	--	49
July 17	63.98	--	--	--	--	--	--	--	--	--	63.98
July 30	86.88	39.8	98.5	34.2	--	51.6	--	--	--	--	62
Aug. 13	402.4	333.2	90.75	--	29.35	--	--	--	--	--	214
Aug. 27	276.13	229.6	--	--	--	1438.2	--	--	--	--	647.9

APPENDIX II

MEAN MONTHLY CONCENTRATIONS OF AMMONIA, BIOCHEMICAL OXYGEN DEMAND (BOD), DISSOLVED OXYGEN AND TEMPERATURE (°C) IN THE HIGH RIVER SEWAGE TREATMENT PLANT EFFLUENT DURING 1985.

DATE	AMMONIA(mg/L)	BOD (mg/L)	DISSOLVED OXYGEN (mg/L)	TEMPERATURE (°C)
July	16.3	38.9	4.8	18.1
August	14.2	23.6	7.0	15.9
September	12.0	9.4	7.6	11.0
October	17.8	17.1	N/A	6.0
November	12.6	18.5	7.0	4.0

N/A - Data not available

MEAN MONTHLY DISCHARGES (cms) AND THE DILUTION FACTORS FOR DOMESTIC EFFLUENT ENTERING THE HIGHWOOD RIVER @ THE TOWN OF HIGH RIVER IN 1984 AND 1985.

	HIGHWOOD R. @ ALDERSYDE	STP DISCHARGE	DILUTION FACTOR
Jan. 84	1.15E	.0277	41.5
Feb. 84	1.15E	.0278	41.4
Mar. 84	1.77	.0264	67.0
Apr. 84	3.54	.0251	135.6
May 84	8.09	.0254	318.5
June 84	25.0	.0336	744.0
July 84	7.78	.0283	274.9
Aug. 84	2.30	.0254	90.6
Sept. 84	2.25	.0266	84.6
Oct. 84	2.00	.0266	75.2
Nov. 84	.287E	.0256	11.2
Dec. 84	.287E	N/A	N/A
Jan. 85	.0600E	.0271	2.2
Feb. 85	.0600E	.0282	2.1
Mar. 85	2.29	.0283	80.9
Apr. 85	7.97	.0291	273.9
May 85	16.4	.0325	504.6
June 85	19.0	.0356	533.7
July 85	3.30	.0264	125.0
Aug. 85	4.14	.0267	155.1
Sept. 85	16.2	N/A	N/A
Oct. 85	10.4	N/A	N/A
Nov. 85	9.05E	N/A	N/A
Dec. 85	9.05E	N/A	N/A

STP = High River Sewage Treatment Plant, E = Estimated, N/A = Data Not Available

APPENDIX III

MAXIMUM, MINIMUM AND MEAN CONCENTRATIONS* OF TOTAL PHOSPHORUS (TP) IN THE HIGH RIVER SEWAGE TREATMENT PLANT LAGOON EFFLUENT

	TP (mg/L) MINIMUM	TP (mg/L) MAXIMUM	TP (mg/L) MEAN
1983	4.25	4.30	4.28
1984	5.40	8.50	7.33
1985	4.60	7.50	5.96

* Data provided by D. Fisher, Municipal Engineering Branch, Alberta Environment, November 20, 1985.

APPENDIX IV
BACTERIAL COUNTS (mpn/100 mL) 1985

SITE S2			SITE S3			SITE S4		
DATE	TOTAL COLIFORMS	FECAL COLIFORMS	DATE	TOTAL COLIFORMS	FECAL COLIFORMS	DATE	TOTAL COLIFORMS	FECAL COLIFORMS
May 27	130	36	May 27	410	76	May 28	700	180
June 10	20	0	June 10	800	40	June 11	150	16
June 24	36	2	June 24	300	50	June 25	150	20
$\bar{x}$ June	28	1	$\bar{x}$ June	550	45	$\bar{x}$ June	150	18
GM June	27	2	GM June	490	45	GM June	150	18
July 8	56	16	July 8	0	0	July 9	20	8
July 22	180	60	July 22	4	4	July 23	60	20
$\bar{x}$ July	118	38	$\bar{x}$ July	2	2	$\bar{x}$ July	40	14
GM July	100	31	GM July	2	2	GM July	35	13
Aug. 6	36	20	Aug. 6	100	8	Aug. 7	180	40
Aug. 19	96	12	Aug. 19	1,200	290	Aug. 20	190	20
$\bar{x}$ Aug.	66	16	$\bar{x}$ Aug.	650	149	$\bar{x}$ Aug.	185	30
GM Aug.	59	16	GM Aug.	346	48	GM Aug.	185	28
Sept. 9	36	14	Sept. 9	5,400	880	Sept. 10	170	64
Sept. 23	14	6	Sept. 17	3,000	500	Sept. 24	1,100	100
$\bar{x}$ Sept	25	10	Sept. 23	700	20	$\bar{x}$ Sept	635	82
GM Sept.	22	9	Sept. 26	18,000	2,000	GM Sept.	432	80
			$\bar{x}$ Sept	6,800	400			
			GM Sept.	3,774	205			
Oct. 16	20	12	Oct. 1	5,000	1,800	Oct. 16	2,100	180
			Oct. 15	2,400	250			
			Oct. 16	10,000	200			
			$\bar{x}$ Oct.	5,800	750			
			GM Oct.	4,932	448			
Nov. 6	6	2	Nov. 5	2,000	220	Nov. 6	410	10
Dec. 10	20	0	Dec. 10	5,000	380	Dec. 10	1,000	180
HIGH RIVER STP			50 YARDS D/S STP					
Aug. 1	900,000	110,000	Aug. 1	38,000	5,000			
Sept. 17	1,900,000	300,000	Sept. 17	500,000	70,000			
Sept. 26	800,000	80,000	Sept. 26	15,000	2,200			
$\bar{x}$ Sept	1,350,000	190,000	$\bar{x}$ Sept	257,500	36,100			
GM Sept.	1,233,233	154,898	GM Sept.	86,605	12,408			
Oct. 1	3,500,000	1,800,000	Oct. 1	47,000	18,000			
Oct. 15	2,500,000	100,000	Oct. 15	32,000	1,500			
Oct. 16	1,600,000	210,000	Oct. 16	49,000	8,000			
$\bar{x}$ Oct.	2,500,000	703,000	$\bar{x}$ Oct.	42,000	9,200			
GM Oct.	2,410,127	335,536	GM Oct.	41,918	5,998			
Nov. 5	850,000	20,000	Nov. 5	46,000	3,300			
Dec. 10	400,000	260,000	Dec. 10	50,000	2,300			