THE INFLUENCE OF COAL MINING ACTIVITY ON THE WATER QUALITY OF THE LOVETT RIVER

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1990

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OVERVIEW

This report describes the water quality and benthic invertebrate communities in the Lovett River upstream and downstream of the Coal Valley mine, owned by Luscar Ltd. and Alberta Energy Corp. and operated by Luscar Sterco (1977) Ltd. The evaluations are based on field investigations conducted in 1984 by the former Water Quality Control Branch, Pollution Control Division, Alberta Environment.

Statistically significant changes in river water quality occurred as a result of point or non-point source discharges from within the lease area. The concentration of particulate material, as measured by turbidity, non-filterable residue, and suspended sediments, increased in a downstream direction during wet and dry weather. The concentration of various dissolved materials also increased downstream. Discharges from impoundments increased river concentrations of major ions, and caused a shift in ionic dominance. Seven metals and trace elements (i.e., aluminum, molybdenum, manganese, arsenic, zinc, chromium and selenium) increased significantly downstream of the impoundments. Plant nutrients (forms of nitrogen and phosphorus) also increased significantly downstream.

Most water quality changes were interpreted with reference to the Alberta Surface Water Quality Objectives (ASWQO) and Canadian Water Quality Guidelines (CWQG), where suitable numeric limits existed. In general, the most frequent exceedances of either ASWQO or CWQG were for non-filterable residue, total nitrogen, total phosphorus, and certain metals (iron, aluminum and chromium). Other elements which occasionally exceeded the guidelines were manganese, arsenic, and selenium. Concentrations of certain substances (iron, aluminum, copper, chromium and phenolics) were naturally high at the background sites and on occasion also exceeded the Alberta Surface Water Quality Objectives or Canadian Water Quality Guidelines.

These changes in water quality were reflected by changes in the two biological communities that were monitored in the Lovett River. Benthic algal growth was stimulated below the mine as a result of nutrient enrichment. In addition to the influence of changes in water quality, sedimentation of the river bottom and changes in the food base induced a shift in benthic invertebrate community composition whereby the importance of pollution-intolerant taxa (e.g., mayflies, stoneflies) declined and that of pollution-tolerant taxa (e.g., worms, some Diptera larvae) increased in the downstream direction. Such a change in river zoobenthos was not evident in benthic collections of 1976, before the coal mine operation started.

The Lovett River discharges into the Pembina River. The effects on the latter system were measurable at one site 13.5 km downstream. Statistically significant increases were found for some major ions, all nitrogen forms, soluble reactive phosphorus, total organic carbon, molybdenum, manganese and arsenic.

Although the study on the Lovett River was limited in time to one year (1984), the general value of its findings is strengthened by studies on certain other western Canadian coal mines which have also identified significant increases in sediment flux and nitrogen loading. Because of the high levels of inorganic nitrogen below the mine, any further increases in phosphorus loadings could result in accelerated eutrophication, as has been observed below similar mine settings in the Elk River watershed, British Columbia.

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ACKNOWLEDGEMENTS

The authors are grateful to Luscar Sterco (1977) Ltd. for facilitating the access to the sampling sites within the active mining area.

The help of individuals and services within Alberta Environment is also gratefully acknowledged.

John Willis, Colleen Campbell, Leslie Hicks and Dave Allan (Environmental Assessment Division and Pollution Control Division) provided field assistance for the water quality and invertebrate sampling. A. Gac assisted in the processing of benthic invertebrate samples. The Water Survey Section (Technical Services Division) conducted instantaneous stream velocity measurements. The River Engineering Branch (Technical Services Division) conducted sediment sampling and provided support in the preparation of the report. The Hydrology Branch (Technical Services Division) provided mean monthly discharge estimates for the Lovett River sites. Water chemistry samples were analyzed at the Alberta Environmental Centre, under supervision of Fred Dieken and phosphorus and chlorophyll 'a' analyses were performed at the Millwoods facility (Environmental Assessment Division). Figures were prepared by Terry Zenith and staff (Design and Construction Division).

L. Lockhart (Environmental Quality Monitoring Branch) and L. Godin (Pollution Control Division) typed the manuscript.

1.0 INTRODUCTION

This report describes the water quality and benthic community in the Lovett River upstream and downstream of the Coal Valley mine, owned by Luscar Ltd. and Alberta Energy Corporation and operated by Luscar Sterco (1977) Ltd. The evaluations are based on field investigations conducted in 1984 by the former Water Quality Control Branch, Pollution Control Division, Alberta Environment.

1.1 BACKGROUND

Mining in the vicinity of Coal Valley, Alberta dates back to 1910. At present, three coal mines operate in the region (Luscar Sterco (1977) Ltd. at Coal Valley, Cardinal River Coals at Luscar, and Gregg River Resources at Gregg River) with six others in various stages of planning. Most of the leases are located in the mountain and foothills biomes within the headwaters of McLeod River drainage, while the Luscar Sterco mine predominantly lies in the Pembina River drainage.

Although each mine is unique in terms of its location and mining plan, certain inherent operational features and their effects on adjacent watercourses are of common concern. Stream water quality impacts may result from uncontrolled erosion from roads, stream crossings and cleared slopes. Streams also receive controlled discharges from settling ponds which collect pit water and surface runoff from the mine site. The primary function of these ponds is to reduce the load of inert mineral sediments in the discharges to surface waters. The magnitude and locations of these inputs are in a state of flux through the life of the mine as old pits are abandoned and new ones created.

To address perceived water quality concerns, the Water Quality Control Branch initiated a study on the Lovett River during the open-water season of 1984. The principal purpose of the study was to determine the extent of any upstream to downstream changes in the aquatic environment due principally to the coal mining operations of Luscar Sterco (1977) Ltd., and to provide a preliminary evaluation of the underlying causes for these changes. It was impossible to prepare a formal impact assessment because the historical data base for the water quality variables of major interest was frequently inadequate. The secondary objective of the study was to apply this knowledge in developing a water quality management plan for the region as part of a river basin planning program for the McLeod River.

1.2 OBJECTIVES

The study objectives were as follows:

1. to describe the spatial and temporal changes in water quality and the benthic community in the Lovett River upstream, within and downstream of the Luscar Sterco (1977) Ltd. Coal Valley mine area;
2. to provide a preliminary assessment of the changes as they relate to the hydrologic regime, precipitation, surface runoff and pit water discharges, other mine activities, groundwater discharges, and other land uses in the study area; and

3. to assess the implications of the water quality changes to the aquatic life in the Lovett and Pembina rivers.

1.3 STUDY AREA

The study area encompasses portions of the Lovett and Pembina rivers, and extends from the old town of Foothills, Alberta, in the Lovett River Valley, to the Highway No. 40 bridge on the Pembina River (Figure 1). The Lovett River originates approximately 8 km west of Foothills, flows southeasterly and enters the Pembina River about 34 km downstream.

The Luscar Sterco (1977) Ltd. coal mine is located approximately 80 km south of Edson, Alberta. The coal is extracted with the use of dragline and shovel-truck operations, cleaned and processed, and transported to markets by unit trains. The mine plan involves four distinct mining zones: Mynheer "A", Mynheer "B", Val D'Or, and Silkstone (Figure 1). Each mining zone consists of numerous pits. During the study period of May to October 1984, mining activities were mainly limited to pits 12 and 13 (Mynheer "A"), pit 42 (Mynheer "B"), and pits 21 and 24 in the Val D'Or zone which were mined occasionally for "make-up" coal (R. Kusters, pers. comm.).

Pit water and surface runoff are diverted into impoundments prior to release to the river. Pits 12 and 13 drained into the Mynheer "A" (pit 15) impoundment, Pit 42 discharged into the Mynheer "B" impoundment, and pits 21 and 24 drained into the Val D'Or south-east impoundment. Surface runoff from the plant site and discharge from the

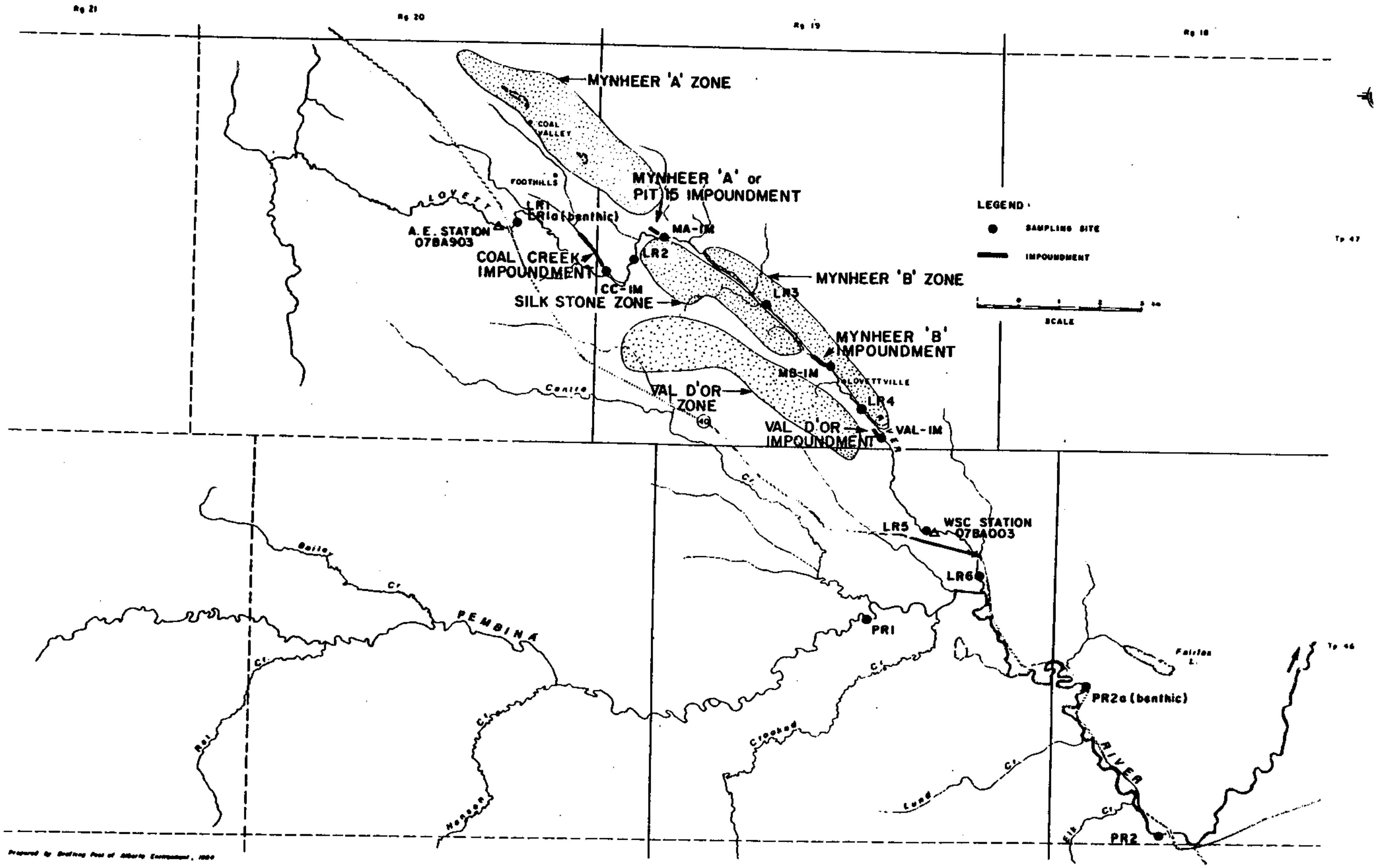

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FIGURE I. LOVETT RIVER – SAMPLING SITES.

sewage lagoons drained into the Coal Creek impoundment. Discharge rates from the various impoundments fluctuated during the study period.

2.0 DRAINAGE BASIN CHARACTERISTICS

This section provides a general description of the climate, physiography, surficial geology and soils, hydrogeology, major habitat types, and land uses in the study area. The information presented in this section focuses on factors that have important effects on determining water quality in streams; it was obtained mainly from EPEC Consulting Western Ltd. (1976).

2.1 CLIMATE

The study area lies within the Boreal climate zone which is characterized by long cold winters, short cool summers and moderate amounts of precipitation. EPEC Consulting Western Ltd. (1976) reported that highest and lowest mean monthly temperatures at Robb, Alberta occur in July (13°C) and January (-17°C), respectively. Average annual precipitation is approximately 64 cm, of which over one-half is rain. Vogwill (1983) reported that for the Edson region the potential evapotranspiration exceeds the mean precipitation during the growing season; this results in an annual soil moisture deficit of about 50 mm. Local patches with positive moisture index have been reported in the Edson region. In the Coal Valley, for example, precipitation exceeds evapotranspiration (EPEC Consulting Western Ltd. 1976, Alberta Soils Advisory Committee 1987).

2.2 PHYSIOGRAPHY AND GEOLOGY

The study area is located within the Rocky Mountain Foothills subdivision of the Western Cordillera region. The region is characterized by undulating topography with long forested ridges aligned in a northwest-southeast direction separated by steep-sided, eroded valleys. The relief varies from approximately 1524 m above sea level near the Lovett Lookout to about 1326 m at the confluence of the Pembina and Lovett rivers.

The intensely folded bedrock of Cretaceous and Tertiary ages is overlain by Pleistocene deposits of till and colluvial Holocene material (Dumanski et al. 1972). The main bedrock structure is the Paskapoo Formation (Vogwill 1983), consisting of calcareous sandstone, siltstone and mudstone.

2.3 SURFICIAL GEOLOGY AND SOILS

Surficial materials in the study area vary from alluvial sand and gravel, and glacial till to colluvium associated with eroded slopes and historical mine discard (EPEC Consulting Western Ltd. 1976). Sand and gravel deposits are found in the valley bottom and muskeg on upland areas; till is the principal surficial deposit (Vogwill 1983). Soils are predominantly of the Robb association, which is characteristic of well drained, steeply sloping ridges, and consist of Gray Luvisols and Eutric and Dystric Brunisols.

Erosion by water is the dominant form of soil erosion in the study area. The Luvisolic and Brunisolic topsoils have a moderate erosion potential, while the parent material of the Robb association, which is primarily a stoney till, is generally considered to have a low erosion potential. However, bedrock parent material which is blasted and removed from the Coal Valley weathers and breaks down very quickly. This material is commonly used on haulroads and weathering of these roads may represent a significant source of suspended sediment to the Lovett River.

2.4 HYDROGEOLOGY

The groundwater regime varies from complex to relatively well defined because of tectonic activity and previous coal mining operations (EPEC Consulting Western Ltd. 1976). Groundwater anomalies resulting from previous surface and underground mining are most evident in the Mynheer "B" Zone. Vogwill (1983) reported that the Paskapoo Formation is the main bedrock aquifer in the area with groundwater yield dependent on the degree of fracturing. He also indicated that groundwater obtained from wells in the Lovett River valley is mainly of the sodium bicarbonate type with probable yields of 0.4 to 2.0 $L \cdot s^{-1}$; water from an artesian well at Lovettville is of the calcium bicarbonate type.

Groundwater in the Mynheer "A" zone generally flows to the southwest direction from the northwest to southeast trending ridge which forms the local surface and groundwater divide. The groundwater table in this zone coincides with water levels in the abandoned pits and in Coal Creek, southwest of the mining area.

In the Mynheer "B" zone, important groundwater bearing zones are present above and below the Mynheer Coal Seam. Groundwater in the lower aquifer is under artesian pressure. The groundwater table in this region is approximately 9.1 m below surface. In the Val D'Or Zone, groundwater flow is generally downslope and follows the general dip of the underlying bedrock strata which is away from the mine.

2.5 HABITAT TYPES

In 1976, the main terrestrial habitat in the study area (Lovett River valley) was dominated by a coniferous forest (61.5%), followed by mixedwood (17.7%), marsh-muskeg (14.7%), deciduous (4.2%); and disturbed land (1.0%) (EPEC Consulting Western Ltd. 1976). In the coniferous forest, white spruce (*Picea glauca*) is the climax species, while lodgepole pine (*Pinus contrata*) is the dominant upland tree type. The mixedwood forest consists of poplar (*Populus tremuloides*) and lodgepole pine, and to a lesser extent, white and black spruce (*Picea mariana*). The mixedwood communities primarily occupy the valley bottoms.

The marsh and muskeg habitat type includes both the riparian communities associated with the streams and the muskegs located in poorly drained, depressional areas. The riparian communities are dominated by willows and dwarf birch *Betula glandulosa*. Stream margins exhibit extensive growth of hydrophilic herbs and sedges. Extensive muskegs occur in the lowland areas including those adjacent to the Lovett River. Stunted black spruce and tamarack *Larix laricina* along with dwarf birch are prevalent. The deciduous forest comprises mainly aspen poplar, which is abundant on the well drained southerly and southwesterly facing slopes. Balsam poplar *Populus balsamifera* and white birch *Betula* papyrifera were also present.

A study conducted in the Edson, Alberta region revealed that based on an average infiltration capacity of each forest cover type, Lodgepole pine, spruce-fir and aspen forests have a low, very high and moderate erosion susceptibilities, respectively (Singh 1983).

2.6 LAND USE

The history of man's activities in the area goes back over 8,000 years, a time when native people maintained relatively large encampments on the banks of the Lovett River (EPEC Consulting Western Ltd. 1976). With the coming of the steam engine to the West, coal became a valuable commodity. Although there were Indian tales from the region about "stones that burn", coal was not discovered by Europeans until Jack Gregg, an explorer and buffalo hunter, discovered coal between 1895 and 1900. Subsequent finds were made by others including P.A. Robb, after whom the Coal Branch town was named. Coal production varied during the years but reached its highest level during World War II. Recent demands for metallurgical and thermal grade coals have resulted in renewed activity in the area.

Within the Lovett River drainage system, energy resources comprise the most important component of the non-renewable resource base. Much of the region is under coal leases held by Luscar Ltd.

Oil and gas exploration has not occurred in recent years (K. Wheat, Alberta Forest Service, pers. comm.). Although forest (mainly pulpwood) is the most important renewable resource in the area, there has been no harvesting in the Lovett River drainage in the previous five years (K. Wheat, pers. comm.).

EPEC Consulting Western Ltd. (1976) reported that the Lovett River valley constitutes an important recreational area. They also indicated that historical pursuits (sightseeing of former mine workings and weathered remains of the town of Lovettville), fishing and hunting are the main recreational uses. The Lovett River and its tributary, Coal Creek, are the main streams located in the Lovett River basin; no lakes are found in the basin. Generally, streams in the region have low to moderate fishing potential; the Lovett River provides only marginal habitat for cold water species. Additional fisheries information is provided (Energy and Natural Resources, Fish & Wildlife Division, 1984).

3.0 METHODS AND PROCEDURES

The study programs were designed to evaluate the water quality and the benthic community components throughout the open-water season.

3.1 WATER QUALITY

3.1.1 Field Methods

The water quality program was designed to characterize specific physical, chemical and biological variables of the watercourses within the study area. Eleven sampling stations were established. Five stations were located on the Lovett River (above, within and below the mine), two on the Pembina River (above and below the Lovett River confluence), and one on each of the four outlets associated with the impoundments (Figure 1 and Table 1). Sampling commenced on 27 April 1984, continued at two week intervals and was completed on 23 October 1984.

Discrete samples from the river were collected with a stainless steel sampling vessel approximately 200 m downstream of tributaries and impoundment discharges, to allow for complete mixing of the receiving water. Because the Lovett River is small, shallow, and relatively swift it was assumed that vertically integrated samples were unnecessary (Environment Canada 1983). At each station, samples from 5 to 10 locations across the river were combined in a nalgene carbuoy and transported to the vehicle. Subsequently, the contents were mixed, subsamples obtained and preserved according to the following procedures:

Variable Group	Bottle Type	Preservative
Routine	500 mL polyethylene	none
Metals	500 mL polyethylene	5 mL 1:1 HNO_3
Phenols	1000 mL glass with teflon liner	5 mL 1:1 H_2SO_4
Oil and Grease	1000 mL glass with teflon liner	5 mL 1:1 H_2SO_4
Mercury	125 mL polypropylene	2 mL $K_2Cr_2O_7$-HNO_3
Nutrients	125 mL polyethylene	2 mL 5% H_2SO_4
Carbon	125 mL polyethylene	none
B.O.D.	2000 mL glass with teflon liner	none

Samples were stored in coolers and transported to the Alberta Environmental Centre at Vegreville, Alberta, for chemical analysis.

Table 1 Summary of sampling station locations on the Lovett River, Pembina River, and coal mine impoundments, 1984.

Sampling Station	Station Code	Location	Description	Distance (river km) from Lovett River/ Pembina River confluence
LR1 & LR1a	00AL07AF6050	Lat. 53°3'50" Long. 116°48'50"	Lovett River upstream of Coal Creek confluence.	20.5
CC-IM	20AL07AF3006	Lat. 53°3'32" Long. 116°46'47"	Lower Coal Creek impoundment outlet.	16.4
LR2	00AL07AF6075	Lat. 53°3'10" Long. 116°46'20"	Lovett River downstream of station CC-IM.	15.1
MA-IM	20AL07AF3011	Lat. 53°3'45" Long. 116°46'0"	Mynheer "A" (pit 15) impoundment outlet.	13.6
LR3	00AL07AF7000	Lat. 53°3'42" Long. 116°45'0"	Lovett River downstream of station MA-IM.	10.4
MB-IM	20AL07AF3009	Lat. 53°2'31" Long. 116°42'19"	Mynheer "B" impoundment outlet.	8.1
LR4	00AL07BA0350	Lat.53°01'58" Long. 116°41'25"	Lovett River at Lovettville.	7.6
VAL-IM	20AL07AF3008	Lat. 53°4'10" Long. 116°47'20"	Val D'Or east impoundment outlet.	6.8
LR5	00AL07BA0400	Lat. 53°0'55" Long. 116°40'15"	Lovett River at WSC gauging station downstream of Lovettville.	2.7
LR6	None	Lat.52°59'25" Long. 116°38'20"	Lovett River downstream of station LR5	0.5
PR1	00AL07BA0300	Lat.52°58'35" Long. 116°40'24"	Pembina River upstream of Centre Creek confluence.	-4.2
PR2a	00AL07BA0575	Lat.52°57'54" Long. 116°36'0"	Pembina River downstream of Lovett River Confluence	+7.5
PR2	00AL07BA4500	Lat. 52°56'0" Long. 116°34'5"	Pembina River at Highway No. 40 bridge.	+13.5

Recordings of temperature (by thermometer) and dissolved oxygen (Winkler technique - Alberta Environment 1977) were conducted in the field. Analyses for all other variables were conducted in the laboratory.

An automatic sampler, (ISCO-model 2100, Lincoln, Nebraska) was located at stations LR1 and LR5, to obtain water samples for non-filterable residue analysis. An ISCO sampler is a portable device designed to collect up to 24 separate, sequential samples of a predetermined volume from a liquid source. During this study the sampler was set to collect 60 mL of water once every three hours; these samples subsequently were combined over a 24 hour period into one container.

3.1.1.1 Epilithic and potomo-phytoplanktonic algae

Samples for epilithic (benthic) algal standing crop (as chlorophyll 'a') were taken at stations LR1, LR4 and LR5 (Figure 1) according to the methods reported in Hickman et. al. (1982). This was accomplished by randomly picking five rocks at each site from water less than one meter deep. The rocks were then transported to the vehicle where the attached algae were removed by brushing with a bristle brush. The resultant slurry was measured for volume and three subsamples removed. Each subsample was filtered through a Whatman GFC filter at a vacuum of 380 mm of mercury. The filter was placed in a screw-top test tube and 25 mL of 90% buffered acetone added. Each tube was placed in a cool, dark container prior to shipment to Edmonton where it was analyzed using the spectrophotometric technique outlined in Moss (1967 a, b). The surface area of each rock was estimated by outlining its area onto an acetate sheet and measuring the latter with a planimeter.

Potomo-phytoplanktonic chlorophyll 'a' was also sampled at the corresponding three stations. After the water for chemical analysis was removed, the carboy was shaken well and three subsamples were taken. Each subsample was filtered through a glass fiber filter at a vacuum of 380 mm of mercury. The filter was placed into 25 mL of 90% buffered acetone. Each tube was placed in a cool, dark container for shipment to Edmonton where chlorophyll 'a' was measured using the fluorometric technique of Yentsch and Menzel (1963) as modified by Holm-Hansen et al. (1965).

3.1.2 Laboratory Procedures

Since historical water quality data for the study area were sparse, a wide range of variables was selected for analysis to fully characterize the water quality in the drainage. These constituents included major ions and related variables, nutrients, metals and trace elements, suspended solids (non-filterable residue), oil and grease, BOD and COD. The selected variables and their respective analytical procedures are summarized by NAQUADAT code in Table 2.

3.1.3 Chemical Data Analysis

In order to conduct comparative analyses and difference testing, it was necessary to reduce the measurements for each variable to a measure of central tendency. Three statistics commonly employed for this purpose are the mean, the median, and the mode. In a perfectly normal distribution, mean, median, and mode coincide, but normal distributions are seldom encountered in water quality data sets due to the variable

Table 2 Summary of analytical methods.

Variable	NAQUADAT Code	Detection Limit
pH	10301L	
Specific Conductance $uS \cdot cm^{-1}$	02041L	
Turbidity N.T.U.	02074L	0.1
Non-Filterable Residue	10407L	2.0
Total Dissolved Solids	00205L	
Alkalinity, T. as $CaCO_3$	10101L	5.0
Hardness, T. as $CaCO_3$	10605L	5.0
Bicarbonate	06201L	5.0
Carbonate	06301L	5.0
Calcium	20110L	1.0
Magnesium	12102L	1.0
Sodium	11103L	1.0
Chloride	17203L	1.0
Sulphate	16306L	5.0
Potassium	19103L	0.2
Fluoride	09107L	0.05
Nitrogen, T. as N	07601L	0.05
Nitrogen Ammonia, Diss. as N	07562L	0.05
Nitrogen $NO_3 + NO_2$, Diss. as N	07105L	0.05
Nitrogen NO_2, Diss. as N	07205L	0.001
Nitrogen T. Kjeldahl as N	07021L	0.05
Nitrogen T. Partic. as N	07906L	0.01
Phosphorus, T. as P	15421L	0.006
Phosphorus Ortho., Diss. as P	15256L	0.002
Silica Reactive	14102L	0.5
Carbon Inorganic, Diss.	06154L	1.0
Carbon Organic, Diss.	06107L	0.4
Carbon	06905L	0.01
Phenolics	06537L	0.002
Mercury, T.	80015L	0.0001
Cadmium, T.	48009L	0.001
Arsenic, T.	33005L	0.0002
Copper, T.	29009L	0.001
Lead, Ext.	82302L	0.003
Manganese, T.	25003L	0.008
Nickel, T.	28009L	0.001
Zinc, T.	30009L	0.001
Selenium, T.	34005L	0.0002
Molybdenum, T.	42009L	0.001
Chromium, T.	24009L	0.001
Cobalt, T.	27009L	0.001
Aluminum, Ext.	13306L	0.02
Beryllium, Ext.	04304L	0.001
Vanadium, T.	23009L	0.002
Iron, Ext.	26304L	0.002
Epilithic Chlorophyll 'a'	06711L	0.001
Planktonic Chlorophyll 'a'	06715L	0.001
Threshold Odor Number	02001L	
Chemical Oxygen Demand	08304L	5.0
Biochemical Oxygen Demand	08202L	1.0
Oil and Grease	06524L	0.2
Chromium Hexavalent	24101L	0.001

Note: All values are reported in $mg \cdot L^{-1}$ unless otherwise stated.

influences of hydrological and biological forces with time (Helsel 1983). Because concentration medians may be more representative of central tendency than the means in skewed distributions, and because several non-parametric tests can be used to test the differences between the medians of non-normal data sets (Elliott 1977), the 1984 data for different stations were summarized as median concentrations (i.e. 50th percentile: Zar 1974).

All variables were described in terms of spatial and temporal variations between the control station and stations downstream of the mine. Where possible, the water quality description included relationships with hydrology, precipitation, effluent drainage, substrate characteristics, sediment transport, groundwater discharge, and land uses. The water quality data were summarized in tables (see Table 6 in section 4.2) showing maximum, median, and minimum values. All data are stored on NAQUADAT.

The Wilcoxon Signed-Rank Matched-Pairs test (a non-parametric test for the comparison of median values) was used to identify the significant spatial differences of selected variables. The level of confidence for the 2-tailed test was set at 95%; "P" values $\leq$ 0.05 were considered significant (Siegel 1956). This means that there is 95% confidence that the concentration of the tested variables at the downstream station is different than at the upstream station. Tests were performed with the aid of the SPSS INC. (1983) package run through the government of Alberta computing center.

To aid in differentiating between point and non-point sources of specific materials to the Lovett River, a mass balance analysis was conducted at one site (above and below the Coal Creek Impoundment). A comparison of predicted concentrations at LR2 with observed concentrations provided some indication on the importance of non-point sources. The predicted downstream concentrations were developed using the mass balance equation:

$$C = \frac{Q_L C_L + Q_E C_E}{Q_L + Q_E}$$

where Q_L and C_L represent the flow and concentration, respectively, of the Lovett River upstream; Q_E and C_E represent the flow and concentration, respectively, of the effluent at station CC-IM. Ideally, sampling progression is to be determined by the time of travel of water in the river and water chemistry sampling is to occur simultaneously to discharge measurement. As these requirements were not always met, the accuracy of the estimates may be inconsistent.

The implications of water quality changes were interpreted according to their possible effects on recreation and the propagation of aquatic life, which are the main water uses of the streams in the study area. Where appropriate, implications are described in terms of the Alberta Surface Water Quality Objectives (ASWQO; Alberta Environment 1977) and the multiple use guidelines described in the Environment Canada - Water Quality Sourcebook (McNeely et al. 1979).

3.2 BENTHIC COMMUNITY

3.2.1 Field Sampling

Zoobenthic surveys were conducted twice in the Lovett and

Pembina rivers: in late spring (24 to 25 May, 1984) and early autumn (9 to 11 October, 1984).

3.2.1.1 Spring Sampling

Zoobenthic samples were collected at five locations on the Lovett River (stations LR1, LR2, LR3, LR5, and LR6) and at two locations on the Pembina River (stations PR1 and PR2) (Figure 1 and Table 1). Sampling was restricted to erosional habitats (i.e. riffles) and was performed with a Neill cylinder sampler which had a sampling surface area of 0.1 m^2 and a collecting net mesh size of 0.210 mm (Neill 1938). Five replicate samples were collected at each station. In as far as field conditions permitted (snow and ice cover precluded the access to some areas in the Lovett River), samples were collected in a manner that minimizes differences in substrate characteristics, flow velocity and depth among stations.

At most stations (LR1, LR5, PR1 and PR2) the substrate consisted of pebbles mixed with gravel and sand, and a few cobbles. Cobbles were not found at LR2 and LR6. Station LR3, where boulders were predominant, differed most from other stations.

Samples were collected at a water depth ranging from 20 to 40 cm and were preserved in 4% formaldehyde solution immediately after collection. Macroscopic algal growth was absent from all stations except station PR2 which had extensive mats of the colonial diatom Didymosphenia geminata in association with other sessile algae (R.S. Anderson, pers. comm.).

3.2.1.2 Autumn Sampling

3.2.1.2.1 Erosional Habitats

The number and location of stations sampled in the spring was modified for the autumn survey (Figure 1). Two control stations (LR1 and LR1a) were sampled on the Lovett River. Station LR3, which in spring had a substrate type very dissimilar from the other stations, was moved approximately 200 m upstream in autumn where a more comparable type of substrate was sampled. In order to match sites monitored for zoobenthos and water chemistry, sampling at station LR6 was discontinued in the autumn program; another station (LR4), was sampled instead. An additional station (PR2a) was sampled on the Pembina River, approximately halfway between station PR2 and the confluence of the Lovett River with the Fembina River.

The two control stations (LR1 and LR1a) represented the two types of substrate which were predominant in erosional areas of the Lovett River. LR1 samples were taken from a substrate where small cobble and pebble mixed with sand and gravel was predominant. LR1a samples were taken from a finer grained, more compact substrate consisting primarily of coarse gravel and sand. At all remaining stations on the Lovett River, the substrate was more similar to that of LR1 than LR1a.

Stations on the Pembina River exhibited a coarser substrate than the Lovett River: large cobble-pebble with boulders and some sand and gravel were predominant. At station PR2a a silt deposit was present despite a strong water current. All stations had a light algal cover; station LR2 also had light, scattered patches of filamentous algae.

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3.2.1.2.2 Depositional Habitats

Slow flowing areas with soft sediments (i.e. depositional zones) were also sampled in the autumn in the Lovett River (LR1, LR2, LR3, LR4 and LR5), but not in the Pembina River. Depending upon accessibility of the stations (i.e. sampling depth, consistency of substrate), samples were collected from a small inflatable boat or by wading into the river.

The samples were collected with an Ekman dredge (15.5 cm x 15.5 cm), which was slowly lowered into the water and pushed into the sediment with the aid of a rod before activating the release mechanism. This procedure, which is only possible in shallow waters, ensured the sampling of deeper layers in compact sediment than would ordinarily be collected with an Ekman dredge and should increase the sampling efficiency. The Ekman dredge was carefully lifted and emptied into a sieving pail (mesh aperture: 1.0 mm). Six replicate samples were collected at each station and at water depths ranging between 0.6 and 1.2 m. The samples contained mostly sand and silt, and sometimes included quantities of gravel (some samples from LR2 and LR6).

3.2.2 Laboratory Methods

Zoobenthic samples were stained with Rose Bengal (Mason and Yevich 1967) upon return to the laboratory. Samples were screened and the residue on the finest sieve (0.213 mm) was extracted with a solution of Ludox AM, a commercial preparation of silica sol. Ludox has been used successfully in the separation of marine zoobenthos (Jonge and Bauman 1977). The residue remaining after three extractions was examined and specimens which were not extracted were removed manually. Coarse, and

Ludox-extracted fine fractions of each sample were sorted under a dissecting microscope (magnification 10 x 6 to 10 x 25).

Specimens were counted and identified according to Bauman et al. (1977), Edmunds et al. (1976), Merritt and Cummins (1979), Pennak (1953), and Wiggins (1977).

Because Chironomidae and Oligochaeta were frequently the only invertebrate taxa in the Ekman samples, a more detailed level of identification for these two taxa was desirable. Up to 120 chironomid larvae were mounted from each sample. Small specimens were mounted directly in CMCP 9/9 AF mounting medium (Beckett and Lewis 1982). Better results were obtained when large specimens were cleared in 10% potassium hydroxide prior to mounting. Identifications followed the keys in Wiederholm (1983), Oliver et al. (1978) and Oliver and Roussel (1983). Chironomid identifications were confirmed by D.W. Mayhood, Freshwater Research Limited, Calgary.

Tubificid worms (up to 30 per sample) were mounted in CMCP 9/9 AF. A number of mature specimens were also dissected to expose genital organs which are key features. Identifications were made according to Brinkhurst and Jamieson (1972).

3.2.3 Zoobenthic Data Analysis

3.2.3.1 Preliminary Data Analysis (Major Zoobenthic Variables)

Consistent changes in zoobenthic community composition, such as changes in the density of major taxonomic groups, total invertebrate numbers, or total number of invertebrate taxa, could be indicative of an identifiable impact. A one-way analysis of variance (ANOVA) (Sokal and

Rohlf 1969) was performed on the density of major taxonomic groups, total invertebrate numbers, and total number of invertebrate taxa to determine whether these variables differed significantly in their means between stations. If significant differences were found, the Student-Newman-Keuls test (SNK) (Sokal and Rohlf 1969) was performed to determine which stations were different. Before performing these tests, data were tested for normality with the Kolmogorov-Smirnov test (Siegel 1956). Normality was achieved after log (x+1) transformation of the data. Statistical tests were performed with the aid of the SPSS INC. (1983) package.

3.2.3.2 Detailed Data Analysis (Multivariate Analysis)

Two multivariate techniques, cluster analysis (CA) and principal component analysis (PCA), were also used in the analysis of zoobenthic data. Some theoretical considerations and practical applications of these techniques are discussed in Gauch and Whittaker (1972), Sinhai (1977), Sprules (1977), Green (1979) and Gauch (1982).

Both CA and PCA provide a means of comparing samples using all information contained in these samples (i.e. numerical abundance data for each taxon). Cluster analysis is a technique whereby sampling sites are grouped according to similarities among the zoobenthic taxa (i.e. qualitative and quantitative). The similarity index used in the present analysis was the Squared Euclidean Distance. A variety of techniques can be applied to the resulting similarity matrix for the fusion of similar clusters. The Ward (1963) method was used here. Results can be presented graphically in the form of a dendrogram. Sampling sites with similar zoobenthic associations cluster together, and the difference in similarity coefficient between clusters at their fusion points can be used as a relative measure of the degree of similarity (or dissimilarity) between clusters.

The basic effect of PCA is to change the original samples-by-invertebrate taxa matrix into a samples-by-components matrix where the number of components is much smaller than the number of invertebrate taxa. Each component, a simple linear compound of the transformed proportionate abundances, has an associated eigenvalue giving the amount of variation in invertebrate taxa accounted for by the component, and an eigenvector of component coefficients giving the weighting of each invertebrate taxon in the linear compound. Successive components account for unique, progressively smaller portions of the total variation in invertebrate taxa, the first two or three usually accounting for most of the variation. Eigenvector values provide, for each component, a measure of the importance of individual taxa. Therefore, taxa with high positive or negative eigenvector values can be used to characterize each component. The benthic invertebrate taxa which typify a sample or a cluster of samples can be derived from the position of this sample or sample cluster on the ordination graph.

Inter-site differences in score values are primarily related to inter-site differences in the density of taxa with high loading values. Ideally it is possible to give an ecological interpretation to these inter-site differences on the basis of the knowledge of the requirements or preferences of these taxa. Taxa with an erratic occurrence and with low densities were excluded from the analyses.

3.3 HYDROLOGY

The hydrologic description, which is limited to the Lovett River, is based on continuous discharge data obtained from Water Survey of Canada for station 07BA003, located near the mouth of the Lovett River. In addition, the Water Survey Section, Alberta Environment conducted instantaneous stream velocity measurements at hydrometric station 07BA903, located immediately downstream of Highway No. 40 bridge (near LR1). Measurements were recorded approximately weekly from 26 April to 23 October 1984, using a Gurley 622 current meter. Selection of metering locations was determined by accessibility, uniformity of substrate, absence of weeds and obstructions, consistent flow pattern, and convenient depth. Discharges were then determined using procedures outlined in Hydrometric Field Procedures Manual III (Water Survey of Canada 1977).

The remaining daily discharges at 07BA903 were estimated through the use of a regression equation between upstream and downstream flows (Alberta Environment 1985):

$$Q_{U/S} = 0.4571\ Q_{D/S}^{\ 1.5181}$$

where $Q_{U/S}$ was the measured discharge for the Lovett River at 07BA903 ($m^3 \cdot s^{-1}$) and $Q_{D/S}$ was the recorded discharge for the Lovett River at the mouth (station 07BA003). The analysis indicated that 92 percent of the variance could be explained by the above relationship (n=27).

Subsequently, mean monthly discharges at stations LR2, LR3 and LR4 were calculated. Mean monthly flows calculated for the Lovett

River at Highway No. 40 were subtracted from the mean monthly flows recorded for the Lovett River near the mouth. A drainage area ratio was then used to calculate the downstream discharge component of each intermediate station. Finally, mean monthly flows were derived by adding the upstream and downstream discharge components, as shown by the following calculations:

$$Q_{Station} = Q_{Hwy40} + (Q_{Mouth} - Q_{Hwy40}) \frac{(A_{Station} - A_{Hwy40})}{(A_{Mouth} - A_{Hwy40})}$$

Where:	$Q_{Station}$	is the mean monthly flow for the area in question ($m^3 \cdot s^{-1}$)
	Q_{Mouth}	is the mean monthly flow for the Lovett River at the Mouth ($m^3 \cdot s^{-1}$)
	Q_{Hwy40}	is the mean monthly flow for the Lovett River at Highway No. 40 ($m^3 \cdot s^{-1}$)
	$A_{Station}$	is the drainage area upstream of the station in question (km^2)
	A_{Hwy40}	is the drainage area upstream of the Lovett River at Highway No. 40 (km^2)
	A_{Mouth}	is the drainage area upstream of the Lovett River near the mouth (km^2)

3.4 PRECIPITATION

The 1984 daily precipitation data were obtained from the Luscar Sterco (1977) Ltd. plant station and from the Lovett Forestry Tower (Alberta Forest Service; see Figure 1).

3.5 SUSPENDED SEDIMENT

3.5.1 Field Methods

Measurements of suspended sediment loads in Canadian rivers are normally made by the Water Survey of Canada. The standard sampling approach is to take a vertically integrated sample in order to account for the vertical gradient in suspended material that often characterizes large rivers. Although discrete (i.e. NFR) samples were employed in this study (discussed in Section 3.1.1), it was seen advantageous to generate a suspended sediment data base using standard integrated samples for comparison with sediment loading data for other nearby rivers. Accordingly, suspended sediment and discharge measurements were conducted at two hydrometric stations on the Lovett River: one at Highway 40 (station 07BA903), the second at the Water Survey of Canada (WSC) gauging station (07BA003) near the mouth of the Lovett (Figure 1).

Sediment sampling was conducted approximately weekly at both stations by the River Engineering Branch, Alberta Environment. Samples were collected from 10 May to 9 October at station 07BA903 and from 5 June to 9 October at station 07BA003. During each sampling period, individual depth-integrated samples were obtained at either two or three locations across the stream channel, depending on discharge.

Suspended sediment concentration was determined for each sample at the WSC Sediment Laboratory in Regina, Saskatchewan. Size analysis was conducted only on those samples obtained from station 07BA003 on 7 September; suspended sediment concentrations at station 07BA903 were too low to determine particle size. During all other sampling events at both stations low suspended sediment concentrations prevented particle size analysis.

It should be noted also that slight methodological discrepancies further weaken the direct comparability of suspended sediment and NFR data. The NFR measurement represents the solid material that was suspended in the river water and that was removed from a discrete sample by 0.4 μm polycarbonate membrane filtration and measured. The suspended sediment measurement represents solid material greater than 2.0 μm from an integrated sample (R. Drury, River Engineering Branch, pers. comm.).

3.5.2 Sediment Load Analysis

Relationships between measured discharges and measured suspended sediment concentrations were developed for each station using regression techniques. There was little variability in suspended sediment concentrations between sample units taken at various locations at each station. Therefore, an average concentration per station was developed for each sampling event. Using the mean daily discharge sequence, and the relationship between discharges and concentrations, daily suspended sediment loads were estimated for the period 1 May to 31 October, 1984. These daily loads were then added in order to obtain seasonal and total suspended sediment loads.

There was one anomaly in the analysis. Suspended sediment concentrations measured at station 07BA003 on 6 September and 10 September were relatively high, and were not adequately described by the regression analysis. Therefore, for the period 1 September to 10 September, suspended sediment loads were estimated by interpolation using the measured data of station 07BA003 only (R. Drury, River Engineering Branch, pers. comm.).

4.0 RESULTS - HYDROLOGIC, PHYSICAL, AND CHEMICAL VARIABLES

4.1 HYDROLOGY

The Lovett River drainage basin discharges into the Pembina River which enters the Athabasca River near Tieland, Alberta. EPEC Consulting Western Ltd. (1976) reported that the Lovett River has a drainage of 10 100 ha, a stream length of 34 km and a mean gradient of 4.8 $m \cdot km^{-1}$. The upper reaches of the Lovett River watershed are characterized by a large marsh and muskeg area and by numerous springs. Above the Coal Creek confluence, the river width varies between 4.5 and 7.5 m and the river bottom is predominantly rocky with extensive riffle areas. Below Coal Creek the channel widens to nearly 10 m, its configuration becomes U-shaped, and there are fewer riffles.

4.1.1 Precipitation

Based upon the long term (1951-80) precipitation record for the Lovett Forestry Tower, the average total precipitation between May 1 and October 31 is 485.4 mm. The maximum monthly rate usually occurs in June, but monthly precipitation can be relatively constant between May and August (Figure 2). Precipitation usually declines during September and October.

The 1984 total monthly precipitation rate was highest in September and lowest in October with values of approximately 155 and 15 mm, respectively (Figures 2 and 3). The data also indicate that the total monthly precipitation in the area during 1984 was notably less than the long-term mean monthly values, except in September.

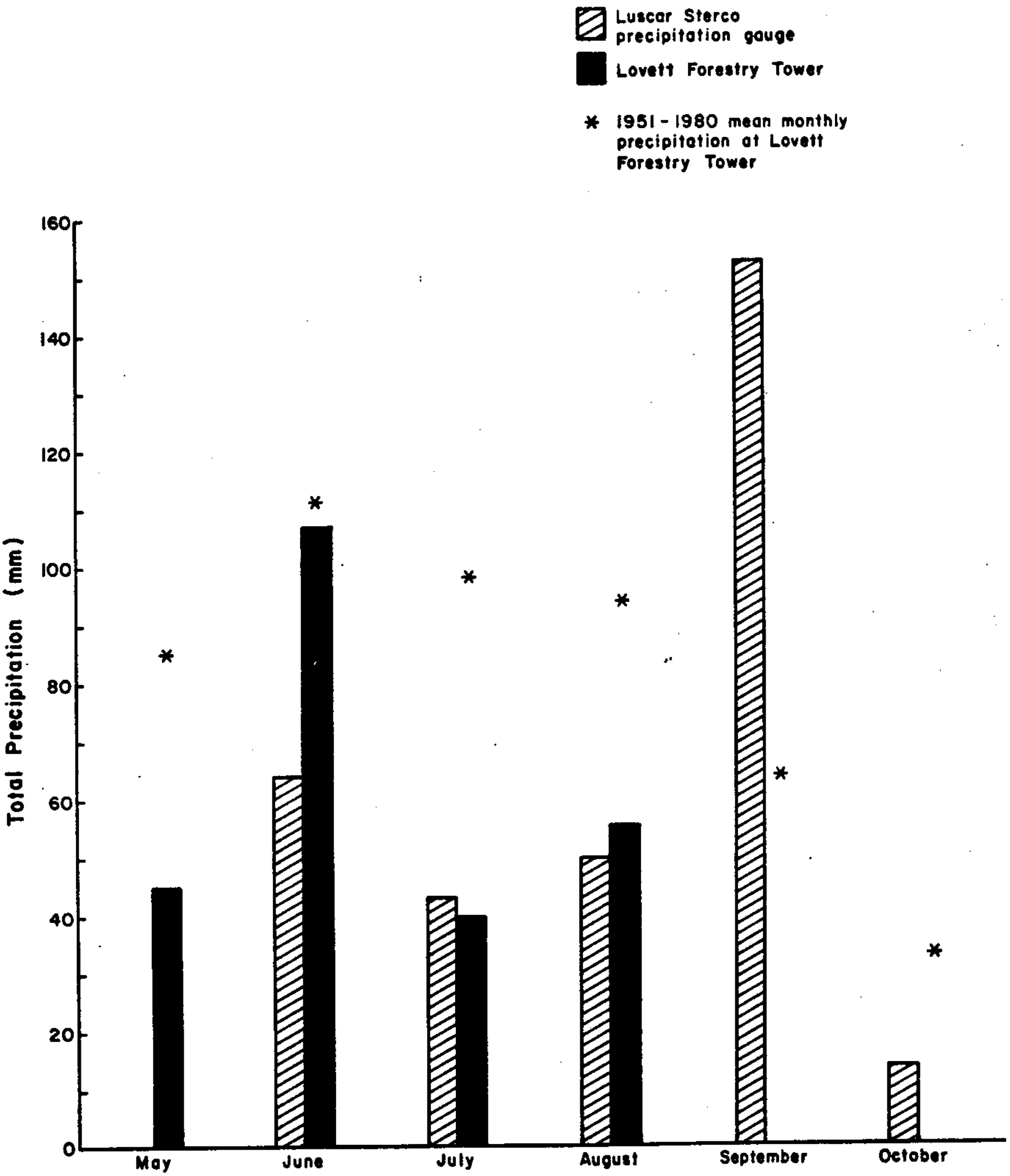


Figure 2 Total monthly precipitation recorded at the Lovett Forestry Tower and Luscar Sterco precipitation gauge, 1984.

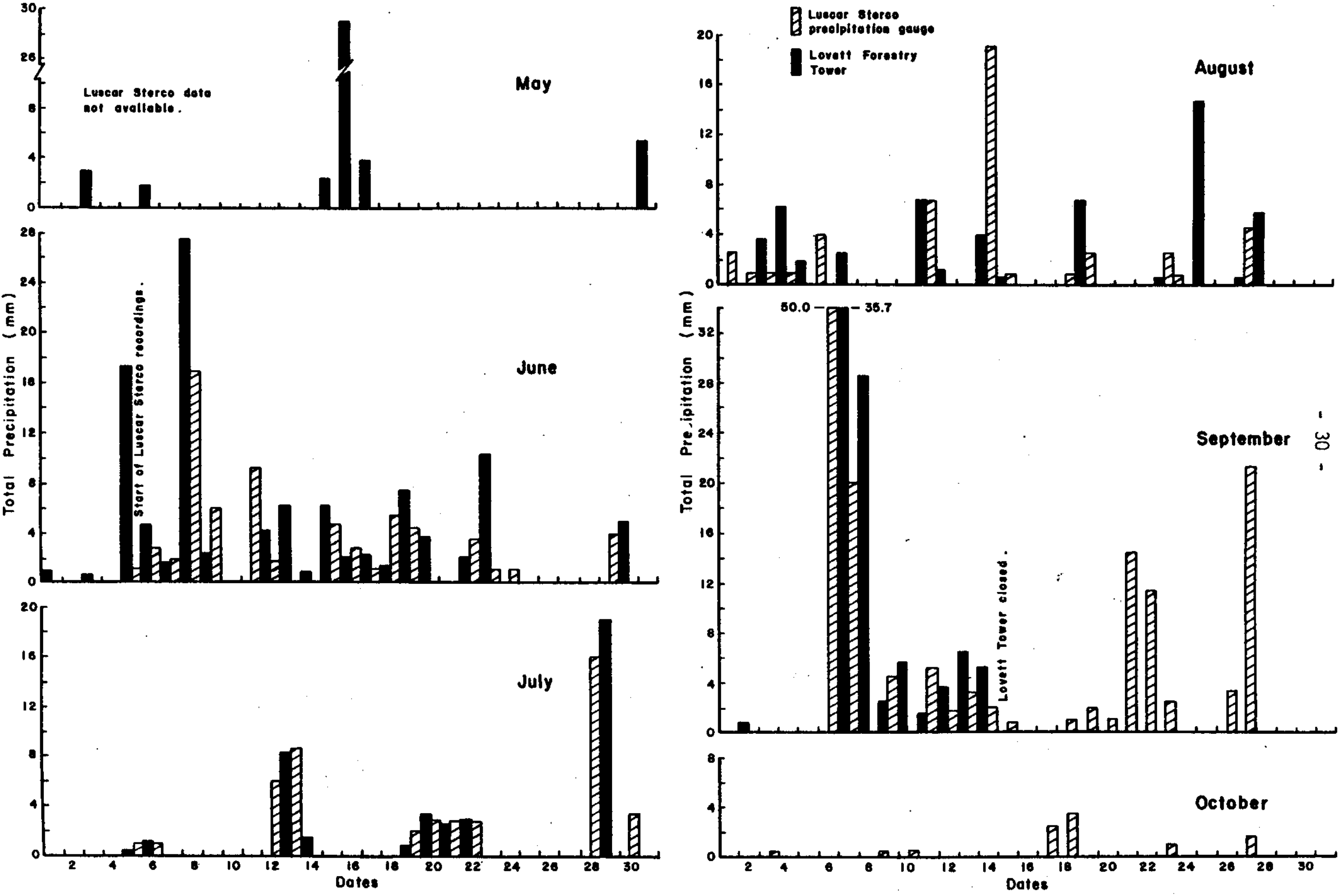


Figure 3 Total daily precipitation recorded at the Lovett Forestry Tower and Luscar Sterco precipitation gauge, 1984

Intensive rainfall is common to this area. The maximum daily precipitation event during 1984 occurred between 5-7 September when 64.3 mm of rainfall was reported at the Lovett Forestry Tower. Based on the rainfall frequency analysis (24 hr. maximum precipitation) reported in EPEC Consulting Western Ltd. (1976), the 5 September 1984 storm constituted a 1 in 6 yr. return period. Within the study area such a storm event has an 18% probability of occurring. All other rain storms had a less than 1 in 5 yr. return period.

Because of microclimates, the precipitation in the Lovett River valley varies spatially as indicated by differences within the precipitation events recorded at the Lovett Forestry Tower and Luscar Sterco (1977) Ltd. precipitation gauges (Figure 3).

4.1.2 Discharges

The long-term hydrograph (Figure 4) for the Lovett River downstream from Lovettville (WSC station 07BA003) reveals a pattern similar to that defined by the long-term precipitation record. The highest median daily flows usually occur between early May and mid-July, corresponding to the period of maximum precipitation. Peak flows usually occur in June, and decline progressively through late summer and autumn.

During the 1984 study period, flows in May only occasionally exceeded the long-term median discharge, whereas in June the flows frequently exceeded the median values. During July and August flows were quite low and usually below the lower quartile (Figure 4, Table 3). Flows in September and October were high and generally exceeded the long-term median discharge. Thus, the study year was characterized by

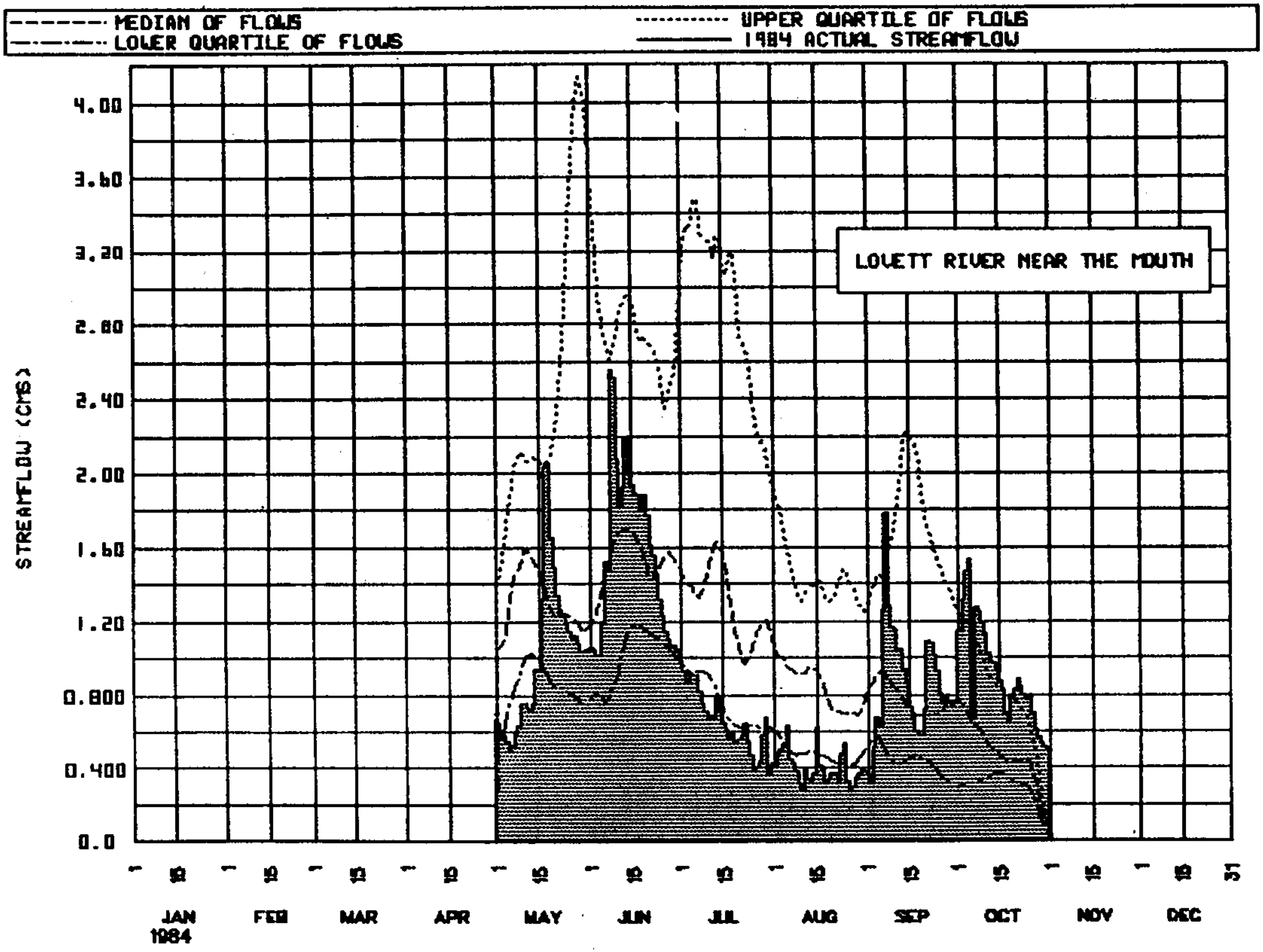


Figure 4 Lovett River hydrograph based on 1975 to 1984 data recorded by Water Survey of Canada at station 07BA003 (Alberta Environment, 1984).

Table 3 Daily discharge data ($m^3 \cdot s^{-1}$), for the Lovett River near the mouth (station 07BA003), 1984.

Date	Apr.	May	June	July	Aug.	Sept.	Oct.
1		0.641	1.060	0.983	0.415	0.365	1.040
2		0.595	1.040	0.929	0.485	0.314	1.140
3		0.575	1.010	0.871	0.502	0.518	1.320
4		0.549	1.010	0.916	0.529	0.675	1.470
5		0.499	1.200	0.904	0.637	0.632	1.530
6		0.528	1.520	0.900	0.446	1.260	0.660
7		0.591	1.480	0.815	0.428	1.780	1.270
8		0.835	2.550	0.755	0.385	1.280	1.250
9		0.755	2.510	0.712	0.317	1.160	1.190
10		0.747	2.080	0.679	0.287	1.150	1.130
11		0.730	1.830	0.685	0.395	1.050	1.020
12		0.718	1.920	0.673	0.344	1.050	0.980
13		0.758	2.190	0.784	0.326	0.940	0.972
14		0.933	2.000	0.713	0.375	0.870	0.931
15		0.923	1.940	0.644	0.623	0.729	0.871
16		1.320	1.890	0.616	0.412	0.675	0.828
17		2.030	1.880	0.570	0.392	0.604	0.694
18		2.050	1.790	0.596	0.316	0.578	0.654
19		1.650	1.880	0.541	0.339	0.582	0.789
20		1.490	1.770	0.561	0.371	0.715	0.833
21		1.340	1.610	0.583	0.377	1.090	0.880
22		1.260	1.560	0.643	0.316	1.080	0.839
23		1.230	1.460	0.541	0.481	1.010	0.801
24		1.190	1.320	0.468	0.539	0.924	0.774
25		1.140	1.230	0.391	0.327	0.802	0.794
26	0.439	1.110	1.140	0.406	0.278	0.749	0.693
27	0.371	1.120	1.100	0.439	0.300	0.797	0.615
28	0.357	1.080	1.070	0.576	0.347	0.768	0.566
29	0.388	1.030	1.070	0.680	0.373	0.742	0.534
30	0.524	1.030	1.040	0.370	0.397	0.760	0.518
31		1.050		0.424	0.384		0.502
Mean		1.010	1.570	0.657	0.397	0.855	0.978

Note: Taken from Alberta Environment (1985).

variable flow during spring, low flows during summer, and high flows during autumn.

The maximum daily discharge at the mouth occurred on June 8, 1984 (2.550 $m^3 \bullet s^{-1}$), the result of five consecutive days of precipitation. The second highest discharge occurred on September 7, 1984 and was associated with the peak rainfall event described in Section 4.1.1. The low flow date during the study period was August 26, 1984 (0.278 $m^3 \bullet s^{-1}$).

The calculated and measured discharge rates above the minesite (WSC station 07BA903) (Table 4) indicate that in 1984 the daily flows ranged from approximately one-third to one-half of those at the mouth. A summary of mean monthly discharges at various stations in the Lovett River is shown in Table 5.

Although deforestation has been implicated with altered peak flows and increased basin water yields in the Tri-Creeks study area (Alberta Environment 1986), no evidence for altered regimes in the Lovett River basin could be found. The initial hydrologic changes due to clearing of the minesite may be masked by the use of artificial impoundments to trap and regulate runoff (R. Bothe, pers comm., Hydrology Branch).

4.2 TEMPERATURE

All physical, chemical, and biological data for the Lovett River, Pembina River, and Luscar Sterco 1977 (Ltd.) impoundments have been summarized in Table 6. The data are expressed as the minimum, median, and maximum concentration for each variable.

Table 4 Calculated and recorded daily discharges ($m^3 \cdot s^{-1}$) for the Lovett River at Highway No.40 (station 07BA903), 1984.

Date	Apr.	May	June	July	Aug.	Sept.	Oct.
1		0.189	0.499 E	0.445 E	0.120 E	0.099 E	0.485 E
2		0.208 E	0.485 E	0.409 E	0.152 E	0.079 E	0.491
3		0.197 E	0.464 E	0.371 E	0.161 E	0.168 E	0.697 E
4		0.184 E	0.464 E	0.357	0.174 E	0.252 E	0.820 E
5		0.159 E	0.651	0.391 E	0.231 E	0.228 E	0.872 E
6		0.173 E	0.863 E	0.390 E	0.134 E	0.649 E	0.248 E
7		0.206 E	0.829 E	0.335 E	0.117	0.662	0.657 E
8		0.229 E	1.893 E	0.298 E	0.107 E	0.665 E	0.641 E
9		0.513	1.848 E	0.253	0.080 E	0.573 E	0.713
10		0.266	1.390 E	0.254 E	0.069 E	0.610	0.550 E
11		0.283 E	1.070	0.257 E	0.112 E	0.492 E	0.471 E
12		0.276 E	1.231 E	0.251 E	0.090 E	0.492 E	0.447 E
13		0.300 E	1.503 E	0.316 E	0.083 E	0.4416 E	0.438 E
14		0.411 E	1.309 E	0.274 E	0.129	0.370 E	0.410 E
15		0.405 E	1.250 E	0.234 E	0.223 E	0.283 E	0.371 E
16		0.697 E	1.201 E	0.219 E	0.119 E	0.252 E	0.343 E
17		1.339 E	1.192 E	0.196	0.110 E	0.225	0.263 E
18		1.590	0.951	0.208 E	0.080 E	0.119 E	0.240 E
19		0.978 E	1.192 E	0.180 E	0.088 E	0.201 E	0.319 E
20		0.837 E	1.088 E	0.190 E	0.101 E	0.275 E	0.346 E
21		0.713 E	0.942 E	0.201 E	0.074	0.521 E	0.376 E
22		0.649 E	0.898 E	0.234 E	0.080 E	0.514 E	0.350 E
23		1.010	0.812 E	0.152	0.150 E	0.464 E	0.372
24		0.595 E	0.697 E	0.144 E	0.179 E	0.405 E	0.310 E
25		0.558 E	0.626 E	0.110 E	0.084 E	0.248	0.322 E
26	0.131 E	0.536 E	0.496	0.116 E	0.065 E	0.295 E	0.262 E
27	0.102 E	0.543 E	0.528 E	0.131 E	0.073 E	0.324 E	0.219 E
28	0.096 E	0.514 E	0.507 E	0.198 E	0.092 E	0.306 E	0.193 E
29	0.109 E	0.478 E	0.507 E	0.255 E	0.082	0.291 E	0.176 E
30	0.171 E	0.586	0.485 E	0.101 E	0.112 E	0.301 E	0.168 E
31		0.492 E		0.137	0.107 E		0.161 E
Mean		0.519	0.929	0.245	0.115	0.361	0.410

Notes: E - estimated daily discharge.
Taken from Alberta Environment (1985).

Table 5 Drainage areas and mean monthly discharges for the Lovett River at stations 07BA903, LR2, LR3, LR4, and 07BA003 (1984).

Station	Drainage Area (km^2)	Mean Monthly Discharge (m^3•s^{-1})					
		May	June	July	Aug.	Sept.	Oct.
Lovett River at station 07BA903	48.6	0.519	0.929	0.245	0.115	0.362	0.410
LR2	70.6	0.726	1.200	0.418	0.233	0.569	0.628
LR3	85.6	0.866	1.380	0.536	0.314	0.710	0.776
LR4	94.8	0.952	1.490	0.608	0.364	0.797	0.867
Lovett River at station 07BA003	101.0	1.010	1.570	0.657	0.397	0.855	0.928

Note: Taken from Alberta Environment (1985).

Table 6 Summary of water quality data for the Lovett River, Pembina River and effluent discharges April to October, 1984.

Parameter / Station	LR1			CC-IM			LR2			MA-IM		
	max.	med.	min.	max.	med.	min.	max.	med.	min.	max.	med.	min.
Temperature °C	17.2	5.9	0.0									
pH	8.2	7.7	7.3	8.5	8.4	8.2	8.5	8.2	7.6	8.4	8.1	7.8
Specific Conductance uS•cm^{-1}	168.0	106.0	77.0	847.0	527.0	414.0	442.0	183.5	138.0	728.0	536.0	442.0
Dissolved Oxygen	12.3	10.2	8.3									
Oxygen % Saturation	125	80	57									
Turbidity N.T.U.	2.5	2.0	1.0	50.0	22.0	3.0	20.0	5.5	2.0	177.5	18.0	2.6
Non-Filterable Residue	9.0	5.9	L2.0	80.4	27.5	10.6	91.2	11.0	7.0	311.2	30.4	8.6
Total Dissolved Solids	89.0	59.0	41.0	525.0	317.0	224.0	250.0	100.0	74.0	461.0	324.0	229.0
Alkalinity, T. as $CaCO_3$	86.9	50.7	36.2	357.2	234.4	182.3	196.2	87.8	62.7	208.7	175.7	159.5
Hardness, T. as $CaCO_3$	56.0	46.5	33.0	90.0	62.0	16.0	70.0	54.0	38.0	63.0	44.0	31.0
Bicarbonate	106.0	62.0	44.0	260.0	241.0	222.0	228.0	107.0	76.0	205.0	201.0	197.0
Carbonate	0	0	0	7	3	0	0	0	0	0	0	0
Calcium	19.00	10.00	5.00	31.00	20.00	3.00	23.00	14.50	9.00	25.00	16.00	9.00
Magnesium	3.00	2.00	L1.00	4.00	3.00	2.00	3.00	2.00	2.00	3.00	2.00	L1.00
Sodium	10.00	7.00	5.00	177.00	96.00	68.00	72.00	20.50	14.00	146.00	98.00	73.0
Chloride	L1.00	L1.00	L1.00	20.00	11.00	6.00	7.00	1.50	L1.00	16.00	15.00	6.00
Sulphate	L5.0	L5.0	L5.0	76.0	41.0	15.0	26.0	10.0	L5.0	74.0	42.0	24.0
Potassium	0.90	0.50	0.40	2.90	1.70	1.30	1.10	0.80	0.60	1.60	1.50	1.10
Fluoride	0.12	0.09	0.08	0.89	0.63	0.45	0..34	0.17	0.12	0.47	0.36	0.26
Nitrogen, T. as N	0.393	0.203	0.127	4.080	3.068	2.240	1.150	0.595	0.227	10.500	8.020	6.705
Nitrogen Ammonia, Diss. as N	0.024	0.006	L0.002	0.270	0.118	0.018	0.104	0.025	0.007	0.095	0.024	0.010
Nitrogen NO_3 + NO_2 Diss. as N	0.013	0.006	0.003	2.536	2.180	1.790	1.455	0.319	0.027	7.170	6.296	5.780
Nitrogen NO_2, Diss. as N	L0.050	L0.001	L0.001	0.192	0.100	0.035	L0.050	L0.027	0.002	0.061	0.050	0.009
Nitrogen T. Kjeldahl as N	0.380	0.180	0.120	0.740	0.445	0.320	0.380	0.300	0.200	0.800	0.530	0.340
Nitrogen T. Partic. as N	0.140	0.020	L0.010	0.340	0.100	L0.010	0.300	0.075	L0.010	0.480	L0.120	L0.010
Phosphorus, T. as P	0.026	0.012	0.008	0.062	0.031	0.017	0.100	0.021	0.010	0.120	0.031	L0.006
SRP	0.014	0.009	L0.002	0.084	0.008	L0.002	0.049	0.008	L0.002	0.010	0.005	L0.002
Silica Reactive	8.80	7.40	6.20	6.90	5.20	4.60	7.80	6.65	5.30	6.20	4.70	3.60
Carbon Inorganic, Diss.	36.40	12.20	8.70	414.00	59.55	46.00	46.60	20.90	15.10	50.20	45.00	38.30
Carbon Organic, Diss.	9.00	4.70	2.30	3.90	3.30	2.20	24.70	4.65	2.10	5.30	3.10	2.50
Phenolics	0.018	0.007	L0.002	0.021	L0.002	L0.002	0.016	0.004	L0.002	0.009	L0.002	L0.002
Mercury, T.	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001
Cadmium, T.	0.0020	L0.0010	L0.0010	L0.0001	L0.0001	L0.0010	0.0020	L0.0010	L0.0010	0.0030	L0.0010	L0.0010
Arsenic, T.	0.0011	0.0006	0.0004	0.0470	0.0137	0.0090	0.0532	0.0029	0.0013	0.0090	0.0034	0.0015
Copper, T.	0.0040	L0.0010	L0.0010	0.0070	0.0020	L0.0010	0.0050	L0.0010	L0.0010	0.0110	0.0030	L0.0010
Lead, Ext.	L0.003	L0.003	L0.003	0.004	L0.003	L0.003	0.004	L0.003	L0.003	0.006	L0.003	L0.003
Manganese, T.	0.025	0.016	0.010	0.085	0.054	0.028	0.089	0.027	0.016	0.245	0.140	0.086
Nickel, T.	0.010	L0.001	L0.001	0.014	0.004	L0.001	0.010	L0.001	L0.001	0.014	0.004	L0.001
Zinc, T.	0.012	0.004	L0.001	0.018	0.007	0.002	0.015	0.005	0.002	0.167	0.057	0.022
Selenium, T.	0.0004	L0.0002	L0.0002	0.0220	0.0014	0.0009	0.0007	L0.0002	L0.0002	0.0026	0.0014	0.0006
Molybdenum, T.	0.0060	L0.0010	L0.0010	0.1230	0.0680	0.0380	0.0380	0.0090	L0.0010	0.1700	0.0860	0.0660
Chromium, T.	0.0050	L0.0010	L0.0010	0.0070	L0.0010	L0.0010	0.0070	L0.0010	L0.0010	0.0150	0.0030	L0.0010
Cobalt, T.	0.0040	L0.0010	L0.0010	0.0030	L0.0010	L0.0010	0.0030	L0.0010	L0.0010	0.0080	L0.0010	L0.0010
Aluminum, Ext.	0.2140	0.0540	L0.0200	1.1400	0.4010	0.0430	3.1800	0.1380	0.0400	2.2400	0.2110	0.0360
Beryllium, Ext.	L0.0010	L0.0010	L0.0010	L0.0010	L0.0010	L0.0010	0.0020	L0.0010	L0.0010	0.0020	L0.0010	L0.0010
Vanadium, T.	0.0060	L0.0020	L0.0020	0.00600	L0.0030	L0.0020	0.006	L0.0020	L0.0020	0.0200	0.0040	L0.0020
Iron, Ext.	0.390	0.220	L0.020	2.990	0.510	0.120	2.100	0.255	0.150	10.900	0.700	0.180
Chlorophyll 'a' Epilithon mg•m^{-2}	22.8	7.8	0.4									
Chlorophyll 'a' ug•L^{-1}	1.9	0.5	0.1									
Threshold Odor Number				2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Biochemical Oxygen Demand				1.9	1.5	1.1				1.9	1.2	L1.0
Chemical Oxygen Demand				25.2	L11.3	L5.0				58.4	11.9	5.3
Oil and Grease				0.50	L0.20	L0.20				1.80	0.40	L0.23
Chromium Hexavalent				L0.0010	L0.0010	L0.0010				L0.0010	L0.0010	L0.0010
Discharge m^3·s^{-1}				0.21	0.10	0.01	1.22	0.54	0.24			

Notes: All values are reported in mg.L^{-1} unless otherwise stated. N - Nitrogen; P - Phosphorus; T. - Total; L - Less than; Diss. - Dissolved; Ext. - Extractable.

continued...

Table 6 Summary of water quality data for the Lovett River, Pembina River and effluent discharges April to October, 1984.

Parameter / Station	LR3 max.	LR3 med.	LR3 min.	MB-IM max.	MB-IM med.	MB-IM min.	LR4 max.	LR4 med.	LR4 min.	VAL-IM max.	VAL-IM med.	VAL-IM min.
Temperature °C												
pH	8.6	8.2	7.7	8.7	8.7	8.5	8.6	8.1	7.8	9.0	8.5	8.2
Specific Conductance $uS\cdot cm^{-1}$	370.0	191.0	147.0	855.0	700.0	654.0	369.0	192.0	65.0	913.0	492.0	318.0
Dissolved Oxygen												
Oxygen % Saturation												
Turbidity N.T.U.	25.0	12.0	6.0	20.0	15.0	8.0	15.0	7.0	3.5	20.0	3.5	2.0
Non-Filterable Residue	98.0	20.0	5.0	22.8	22.6	15.0	29.4	13.2	8.6	30.0	11.2	4.0
Total Dissolved Solids	216.0	109.0	79.0	549.0	415.0	281.0	209.0	103.0	77.0	577.0	303.0	169.0
Alkalinity, T. as $CaCO_3$	167.9	92.0	68.0	242.9	218.3	185.6	167.4	93.3	69.2	315.6	206.9	125.0
Hardness, T. as $CaCO_3$	70.0	53.0	38.0	31.0	25.0	22.0	67.0	60.0	45.0	118.0	92.0	46.0
Bicarbonate	195.0	112.0	83.0	265.1	239.8	212.1	194.0	114.0	84.0	369.0	213.0	152.0
Carbonate	7	L5	L5	15	13	7	7	5	L5	21	7	L5
Calcium	23.00	15.00	9.00	9.00	7.00	7.00	22.00	15.50	11.00	35.00	21.50	12.00
Magnesium	3.00	2.00	2.00	2.00	L1.00	L1.00	4.00	2.50	L1.00	8.00	4.00	3.00
Sodium	57.00	22.00	15.00	181.00	142.00	138.00	57.00	20.00	11.00	169.0	94.50	46.00
Chloride	5.00	2.00	L1.00	14.00	10.00	9.00	5.00	L1.00	L1.00	5.00	L3.00	L1.00
Sulphate	23.0	10.0	6.0	31.0	30.0	8.0	21.0	8.0	L5.0	158.0	44.5	19.0
Potassium	1.00	0.80	0.60	2.00	1.90	1.60	1.00	0.75	0.50	4.00	2.05	1.40
Fluoride	0.31	0.16	0.13	0.99	0.85	0.68	0.31	0.15	0.12	0.57	0.41	0.22
Nitrogen, T. as N	0.891	0.575	0.379	48.480	45.040	41.600	1.400	0.730	0.232	6.060	2.900	0.920
Nitrogen Ammonia, Diss. as N	0.044	0.014	0.006	5.600	4.400	1.560	0.072	0.014	0.003	0.100	0.054	L0.002
Nitrogen NO_3 + NO_2 Diss. as N	0.791	0.392	0.156	35.30*	35.30*	35.30*	1.126	0.431	0.032	0.550	0.517	0.483
Nitrogen NO_2, Diss. as N	L0.050	L0.010	0.002	1.320	1.070	0.520	L0.050	L0.010	L0.001	0.430	0.065	0.015
Nitrogen T. Kjeldahl as N	0.390	0.270	0.180	10.480	8.390	6.300	0.460	0.270	0.170	1.020	0.430	0.051
Nitrogen T. Partic. as N	0.560	0.080	L0.010	0.300	0.270	0.180	0.200	0.090	L0.010	1.010	0.150	0.020
Phosphorus, T. as P	0.058	0.029	0.013	0.188	0.108	0.028	0.048	0.020	0.010	0.028	0.010	0.007
SRP	0.034	0.007	L0.002				0.010	0.008	L0.002	0.010	0.006	L0.002
Silica Reactive	7.70	6.60	5.30	3.40	3.30	3.00	7.80	6.60	5.00	6.60	5.95	4.50
Carbon Inorganic, Diss.	38.80	22.00	14.80	57.00	50.60	46.00	38.80	21.95	15.90	75.70	46.80	31.50
Carbon Organic, Diss.	7.00	4.70	2.10	4.10	2.70	2.60	6.90	3.85	0.72	4.50	3.50	2.60
Phenolics	0.050	0.006	L0.002	L0.002	L0.002	L0.002	0.007	0.004	L0.002	0.010	L0.002	L0.002
Mercury, T.	0.0002	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	0.0002	L0.0001	L0.0001
Cadmium, T.	L0.0010	L0.0010	L0.0010	0.0020	L0.0010	L0.0010	0.0040	L0.0010	L0.0010	0.0020	L0.0010	L0.0010
Arsenic, T.	0.0485	0.0021	0.0015	0.0210	0.0200	0.0058	0.0038	0.0019	0.0007	0.0034	0.0024	0.0007
Copper, T.	0.0050	L0.0010	L0.0010	0.0040	0.0030	L0.0010	0.0030	L0.0010	L0.0010	0.0060	L0.0010	L0.0010
Lead, Ext.	0.004	L0.003	L0.003	0.010	0.004	L0.003	L0.003	L0.003	L0.003	0.011	L0.003	L0.003
Manganese, T.	0.057	0.041	0.017	0.018	L0.008	L0.008	0.088	0.025	0.014	0.063	0.039	L0.003
Nickel, T.	0.010	0.003	L0.001	0.006	L0.001	L0.001	0.005	0.002	L0.001	0.012	0.004	L0.001
Zinc, T.	0.017	0.007	0.002	0.024	0.003	L0.001	0.015	0.005	L0.001	0.023	0.004	0.002
Selenium, T.	0.0012	L0.0002	L0.0002	0.0031	0.0019	0.0006	0.0007	L0.0002	L0.0002	0.0023	0.0014	L0.0002
Molybdenum, T.	0.0320	0.0100	L0.001	0.1120	0.1050	0.0360	0.0420	L0.0075	L0.0010	0.2100	0.0235	0.0100
Chromium, T.	0.0120	0.0030	L0.0010	0.0170	L0.0010	L0.0010	0.011	L0.0010	L0.0010	0.0250	0.0020	L0.0010
Cobalt, T.	0.0030	L0.0010	L0.0010	0.0040	L0.0010	L0.0010	0.0050	L0.0010	L0.0010	0.0030	L0.0010	L0.0010
Aluminum, Ext.	2.3400	0.1590	0.0580	0.1900	0.1060	0.0730	0.3750	0.1560	0.0750	1.0800	0.0495	L0.0200
Beryllium, Ext.	L0.0010	L0.0010	L0.0010	0.0020	L0.0010	L0.0010	L0.0010	L0.0010	L0.0010	L0.0010	L0.0010	L0.0010
Vanadium, T.	0.0070	L0.0020	L0.0020	0.0050	L0.0020	L0.0020	0.0060	0.0025	L0.0020	0.0050	L0.0020	L0.0020
Iron, Ext.	1.890	0.380	0.170	0.340	0.330	0.290	1.080	0.315	0.140	0.420	0.095	L0.020
Chlorophyll'a' Epilithon $mg\cdot m^{-2}$							150.4	47.4	21.4			
Chlorophyll'a' $ug\cdot L^{-1}$							3.4	2.3	1.6			
Threshold Odor Number	1.0	1.0	1.0	1.0	1.0	1.0				2.0	1.0	1.0
Biochemical Oxygen Demand										3.5	L1.0	L1.0
Chemical Oxygen Demand				12.1	10.2	8.4				12.7	8.6	L5.0
Oil and Grease				0.90	0.55	L0.20				0.33	L0.25	L0.20
Chromium Hexavalent				L0.0010	L0.0010	L0.0010				L0.0010	L0.0010	L0.0010
Discharge $m^3\cdot s^{-1}$	1.87	0.72	0.29									

Notes: All values are reported in $mg\ L^{-1}$ unless otherwise stated. N - Nitrogen; P - Phosphorus; T. - Total; L - Less than; Diss. - Dissolved; Ext. - Extractable; * - N = 1

cont'd...

Table 6 Summary of water quality data for the Lovett River, Pembina River and effluent discharges April to October, 1984.

Parameter / Station	LR5 max.	LR5 med.	LR5 min.	PR1 max.	PR1 med.	PR1 min.	PR2 max.	PR2 med.	PR2 min.
Temperature °C	15.3	7.0	0.0						
pH	8.5	8.1	7.9	8.4	7.9	7.6	8.6	8.1	7.9
Specific Conductance $uS{\cdot}cm^{-1}$	396.0	226.0	153.0	243.0	165.0	109.0	324.0	191.0	134.0
Dissolved Oxygen	11.9	10.2	8.0						
Oxygen % Saturation	118	83	79						
Turbidity N.T.U.	45.0	6.0	3.0	7.8	3.5	L0.1	30.0	4.0	1.5
Non-Filterable Residue	70.6	13.2	7.0	14.6	7.2	2.2	55.2	9.5	5.8
Total Dissolved Solids	235.0	123.0	81	128.0	83.0	54.0	178.0	101.0	70.0
Alkalinity, T. as $CaCo_3$	174.3	98.6	72.5	115.1	68.5	42.4	155.5	87.0	62.0
Hardness, T. as $CaCO_3$	67.0	58.0	46.0	105.0	81.0	67.0	100.0	51.5	42.0
Bicarbonate	201.0	120.0	88.0	136.0	84.0	52.0	176.0	106.0	76.0
Carbonate	7	L6	L5	L5	L5	L5	7	7	6
Calcium	22.00	16.00	11.00	29.00	16.5	10.00	30.00	15.50	12.00
Magnesium	3.00	2.00	2.00	8.00	5.00	3.00	6.00	4.00	2.00
Sodium	66.00	27.00	15.00	7.00	5.00	2.00	39.00	14.00	7.00
Chloride	5.00	2.00	L1.00	L1.00	L1.00	L1.00	3.00	L1.00	L1.00
Sulphate	25.0	11.0	L5.0	17.0	12.0	9.0	17.0	9.0	7.0
Potassium	1.20	0.90	0.60	0.80	0.55	0.50	1.00	0.70	0.50
Fluoride	0.35	0.16	0.14	0.15	0.13	0.10	0.23	0.13	0.09
Nitrogen, T. as N	3.580	0.974	0.491	0.338	0.204	0.112	1.630	0.463	0.209
Nitrogen Ammonia, Diss. as N	0.123	0.022	0.004	0.022	0.005	L0.002	0.045	0.007	L0.002
Nitrogen $NO_3 + NO_2$ Diss. as N	1.370	0.581	0.262	0.198	0.014	0.002	1.260	0.206	0.049
Nitrogen NO_2, Diss. as N	0.140	0.015	0.003	L0.050	L0.001	L0.001	L0.050	L0.006	L0.001
Nitrogen T. Kjeldahl as N	0.480	0.280	0.120	0.260	0.190	0.100	0.380	0.250	0.160
Nitrogen T. Partic. as N	0.140	0.065	0.030	0.130	0.090	L0.010	0.840	0.090	L0.010
Phosphorus, T. as P	0.059	0.020	0.008	0.024	0.016	L0.006	0.052	0.010	L0.006
SRP	0.015	0.008	L0.002	0.009	0.008	L0.002	0.008	0.006	L0.002
Silica Reactive	7.70	6.50	4.90	7.50	6.60	5.90	7.60	6.40	4.40
Carbon Inorganic, Diss.	43.40	25.60	17.70	26.30	16.55	11.50	35.60	20.80	16.30
Carbon Organic, Diss.	6.20	3.50	2.00	7.60	5.70	2.70	7.10	5.35	2.90
Phenolics	0.010	0.004	L0.002	0.018	0.004	L0.002	0.016	0.004	L0.002
Mercury, T.	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	L0.0001	0.0002	L0.0001	L0.0001
Cadmium, T.	0.0030	L0.0010	L0.0010	L0.0010	L0.0010	L0.0010	0.0040	L0.0010	L0.0010
Arsenic, T.	0.0049	0.0019	0.0014	0.0009	0.0006	L0.0002	0.0046	0.0012	0.0006
Copper, T.	0.0030	0.0020	L0.0010	0.0080	0.0015	L0.0010	0.0070	0.0020	L0.0010
Lead, Ext.	L0.003	L0.003	L0.003	L0.003	L0.003	L0.003	L0.003	L0.003	L0.003
Manganese, T.	0.059	0.026	0.015	0.009	L0.008	L0.008	0.049	0.015	L0.008
Nickel, T.	0.007	L0.001	L0.001	0.007	L0.001	L0.001	0.006	0.003	L0.001
Zinc, T.	0.014	0.005	L0.001	0.011	0.005	L0.001	0.015	0.005	L0.001
Selenium, T.	0.0008	0.0003	L0.0002	L0.0002	L0.0002	L0.0002	0.0004	L0.0002	L0.0002
Molybdenum, T.	0.0340	0.0100	L0.0010	0.0040	L0.0010	L0.0010	0.0230	0.0065	L0.0010
Chromium, T.	0.0110	0.0030	L0.0010	0.0130	0.0020	L0.0010	0.0070	L0.0010	L0.0010
Cobalt, T.	0.0060	L0.0010	L0.0010	0.0050	L0.0010	L0.0010	0.0050	L0.0010	L0.0010
Aluminum, Ext.	0.6310	0.1550	0.0570	0.2040	0.0845	L0.0200	0.3200	0.1060	L0.0200
Beryllium, Ext.	L0.0010	L0.0010	L0.0010	L0.0010	L0.0010	L0.0010	0.0200	L0.0010	L0.0010
Vanadium, T.	0.0060	L0.0020	L0.0020	0.0070	L0.0020	L0.0020	0.0070	0.0025	L0.0020
Iron, Ext.	2.950	0.350	0.160	0.510	0.290	L0.020	2.210	0.280	0.150
Chlorophyll'a' Epilithon $mg{\cdot}m^{-2}$	108.920	63.270	3.010						
Chlorophyll'a' $ug{\cdot}L$	4.400	1.400	0.120						
Threshold Odor Number									
Biochemical Oxygen Demand									
Chemical Oxygen Demand									
Oil and Grease									
Chromium Hexavalent									
Discharge $m^3{\cdot}s^{-1}$									

Notes: All values are reported in $mg{\cdot}L^{-1}$ unless otherwise stated. N - Nitrogen; P - Phosphorus; T. - Total; L -
Ext. - Extractable. a - Alberta Surface Water Quality Objectives by Alberta Environment (1977); b - Environ

Median water temperatures in the Lovett River at station LR1 and LR5 were 5.9°C and 7.0°C, respectively (Table 6). The slightly higher temperature at LR5 (downstream) could be the result of longitudinal heating, however diurnal effects are known to be a major influence on the thermal characteristics of foothills streams (Miller and MacDonald 1949). Thus, the time of sampling may influence longitudinal patterns. At both stations maximum and minimum temperatures were recorded in July and October 1984, respectively. IEC Beak (1985) reported that temperatures of receiving streams above and below western Alberta coal mine stations remain relatively unchanged.

4.3 DISSOLVED OXYGEN

The median concentrations of dissolved oxygen at stations LR1 and LR5 (Table 6) were identical (10.2 $mg \bullet L^{-1}$) during the period of observation. No significant longitudinal trends were evident, and concentrations were generally greater than 85% of saturation at both locations. The highest concentrations (greater than 11.0 $mg \bullet L^{-1}$) occurred in spring and fall, during the period of lowest water temperatures. The lowest values (greater than 8.0 $mg \bullet L^{-1}$) occurred during late July and August when maximum temperatures were recorded. The dissolved oxygen levels were always above the ASWQO of 5.0 $mg \bullet L^{-1}$, a level generally considered adequate for the survival of sport fish.

4.4 TURBIDITY

Turbidity is a measure of optical interference by suspended sediment (organic and inorganic) to the transmission of light in water. High turbidity levels may reduce photosynthesis of aquatic macrophytes and benthic algae (e.g., Wetzel 1975), and bring about a reduction of fish productivity.

Turbidity levels in the Lovett River varied considerably. Median levels were lowest at station LR1 (2.0 Nephelometric Turbidity Units - N.T.U.), increased notably at LR2, reached a maximum at LR3 (12.0 N.T.U.) and subsequently decreased to 6.0 N.T.U. at station LR5 (Table 6 and Figure 5). Elevated turbidity levels in the Lovett River also contributed to a slight increase in the turbidity of the Pembina River (Figure 5).

The elevated levels downstream of the background station appear to be correlated with discharges from the impoundments, particularly from CC-IM, MA-IM and MB-IM. In both the Lovett River and impoundment effluents, highest values were recorded during the sampling trips of 11 and 25 September, following the major rain storms that occurred that month.

The high turbidity levels associated with MA-IM, MB-IM and CC-IM impoundments can be explained since mining in 1984 was concentrated in these areas, while the CC-IM impoundment also received drainage from the plant area.

The Alberta Surface Water Quality Objective for turbidity has been set at 25 Jackson Units [assumed to approximate 25 N.T.U.; Standard Methods (1985)] over "natural" turbidity. However, this objective is difficult to apply in any developed river basin since true natural data (i.e. pre-impact data) are usually unavailable. The only alternative is to make upstream-downstream comparisons on the assumption that the

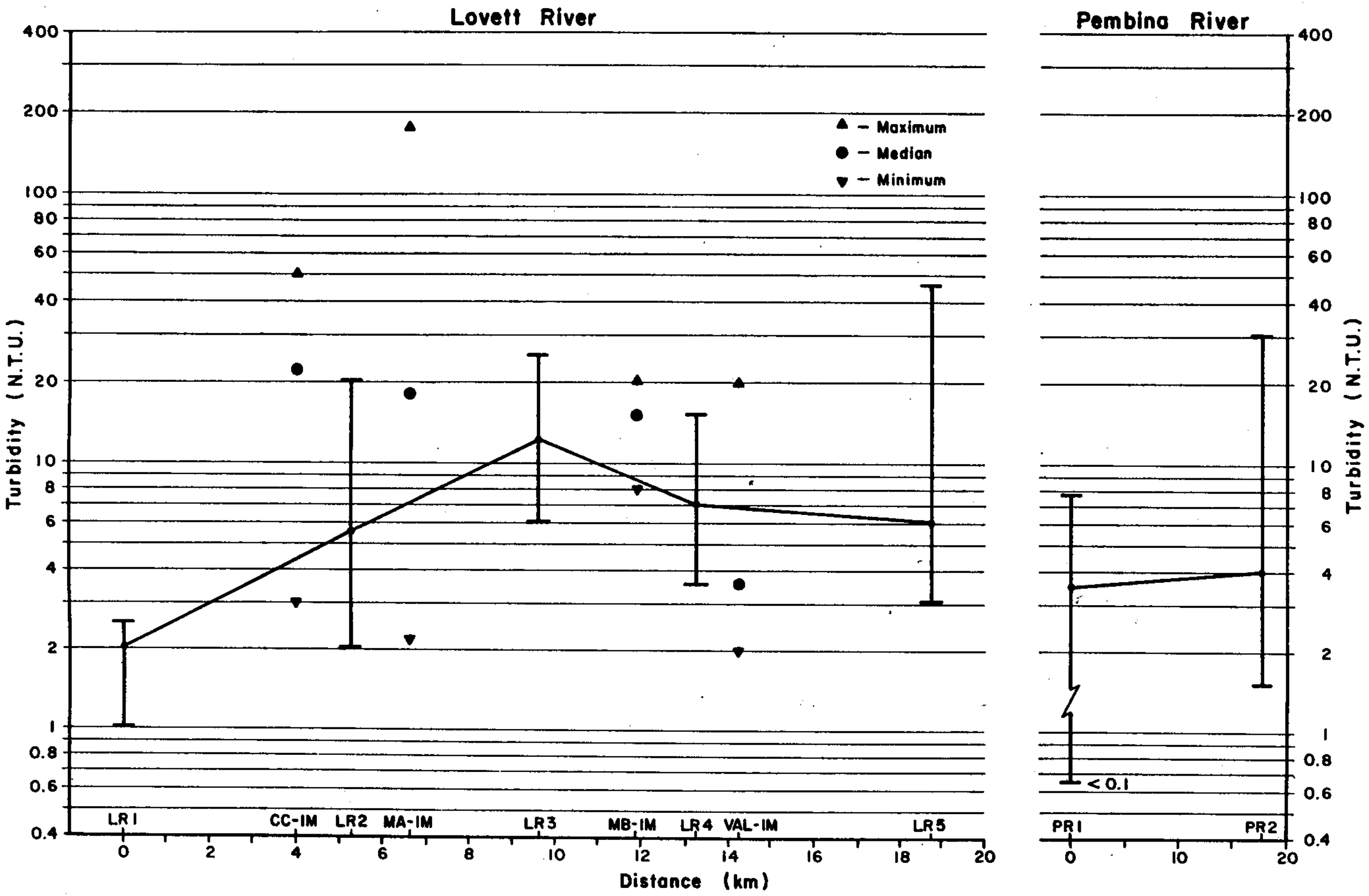


Figure 5 Ranges and longitudinal profile of median turbidity levels in the Lovett River and Pembina River, 1984.

upstream data would be representative of pre-impact conditions further downstream. Based upon this approach, comparisons were made between the turbidity data sets at LR1 and LR5. The longitudinal increases in median turbidity levels are within the ASWQO. However, it should be recognized that during the high discharge events of September 11 and 25, 1984, individual exceedances of the ASWQO occurred between LR1 and LR5.

4.5 SUSPENDED SEDIMENT

4.5.1 Suspended Sediment Yield

The following analysis and data were supplied by R. Drury, River Engineering Branch, Technical Services Division.

Fifteen sets of integrated suspended sediment samples were collected by the River Engineering Branch at station 07BA903 (upstream), and nineteen sets were collected at station 07BA003 (downstream). It is important to note that these data are distinct from the non-filterable residue (NFR) data discussed subsequently in Section 4.6. The latter data include discrete, non-integrated grab samples and the time-integrated composite samples.

The individual sample concentrations are listed by date in Table 7. Sample concentrations at the upstream site were frequently below 10 mg•L^{-1}, but downstream concentrations were higher and more variable.

Using the calculation described in Section 3.5.2 the undisturbed watershed upstream of station 07BA903 (area = 48.6 km^2) yielded a total suspended sediment load of 53 200 kg between May 1 and October 31, 1984 equivalent to an areal sediment export coefficient or sediment yield of

Table 7 Suspended sediment concentrations ($mg \cdot L^{-1}$) in the Lovett River, 1984.

DATE	STATION 07BA903	STATION 07BA003
May 10	5.0	-
May 18	20.0	-
May 23	5.5	-
May 30	5.0	-
June 5	6.5	8.5
June 11	5.5	16.0
June 18	4.5	12.0
June 26	3.5	8.0
July 4	3.0	8.5
July 9	4.0	6.0
July 17	-	8.7
July 24	-	11.0
July 31	-	32.0
August 7	-	22.0
August 14	-	11.0
August 22	-	35.0
August 29	-	17.5
September 7	13.5	470.3
September 10	-	59.3
September 17	2.5	10.0
September 25	3.0	46.5
October 2	6.0	24.5
October 9	-	8.0

1100 kg•km^{-2} (Table 8). If the remaining portion of the basin downstream of station 07BA903 had a similar export coefficient, the hypothetical estimate of annual total sediment production for the entire Lovett basin would be: 1100 kg•km^{-2} times 101 km^2 at station 07BA003 = 111 100 kg. This is probably a fairly accurate estimate considering the uniformity of the basin. In actual fact the sediment load at station 07BA003 was 408 900 kg which represents an increment (actual-hypothetical) of 297 800 kg. Assuming that all of the incremental sediment is derived from the 24.5 km^2 of disturbed mining area in the basin (both current and historical), the resulting sediment export coefficient for this disturbed area would be: 12 200 kg•km^{-2}.

These measured and hypothetical yields, from the natural basin and the mined area, can be compared to data for other creeks in the region. Similar data have been collected for the following basins:

Cache Percotte Creek
Whiskeyjack Creek
Wampus Creek (area = 28.2 km^2, stream gradient = 18.9 m/km; see Nip 1990)
Deerlick Creek (area = 14.8 km^2, stream gradient = 25.6 m/km; see Nip 1990)
Eunice Creek (area = 16.1 km^2, stream gradient = 34.9 m/km; see Nip 1990)

The first two basins, located near Hinton, are the subject of experimental studies by the Alberta Forest Technology School and are essentially undisturbed. The latter three basins are part of the Tri-Creeks experimental study (Alberta Forestry, Forest Land use

Table 8 Suspended sediment loads[1] (kg) in the Lovett River, 1984.

Monitoring Station	May-June	July-Aug.	Sept-Oct.	Total
Lovett River at station 07BA903	38,300	3,200	11,700	53,200
Lovett River at station 07BA003	165,400	29,500	214,100	408,900

1) Prepared by Alberta Environment, River Engineering Branch

Table 9 Summary of sediment yields[1] from watersheds in the Lovett River region.

Stream	Years of Sediment Data	Sediment Yield $kg \cdot km^{-2} \times 10^3$		
		Min.	Mean	Max.
Lovett River	0.5	1,100	4,000	12,200
<u>Undisturbed</u>				
Cache Percotte Creek	10	110	1,100	3,900
Whiskeyjack Creek	14	120	1,100	3,900
<u>Disturbed</u>				
Wampus Creek	16	2,700	27,300	136,400
Deerlick Creek	15	2,200	11,300	38,900
Eunice Creek	15	1,800	13,000	33,500

1) Prepared by Alberta Environment, River Engineering Branch

Branch). Wampus has been extensively logged; Deerlick has been logged to a lesser degree; Eunice has not been logged but has been subjected to major seismic exploration and stream crossings. Calculated maximum, mean and minimum yields for each basin are given in Table 9. The mean "undisturbed" and "disturbed" basin yields are similar in order of magnitude to the corresponding estimates developed for the Lovett River for 1984.

The Alberta Surface Water Quality Objective for suspended sediments, suspended solids, or NFR has been set at 10 $mg \bullet L^{-1}$ over background concentration. Based upon the approach described for turbidity (Section 4.4), comparisons were made between the suspended sediment data sets at station 07BA903 and 07BA003 (Table 7). In 4 out of 10 paired samples the ASWQO was exceeded.

4.5.2 Sediment Size Analysis

Only the samples collected on 7 September 1984 at station 07BA003 contained sufficient material for particle size analysis. The results indicate a high percentage of clay (Table 10) in the suspended sediment load.

Historical particle size data for other streams in the foothills region are summarized in Table 11. These streams include the three Tri-Creeks Study basins as well as the McLeod River just above its confluence with the Embarras River. The variability in sediment composition is large, but silt is the dominant size fraction despite the differences in drainage areas and the variations in watershed disturbances.

Table 10 Suspended sediment size analyses[1] [2], for the Lovett River, 1984.

Monitoring Station	Date	% Sand	% Silt	% Clay
Lovett River at station 07BA003	7 Sept. No. 29	4.4	18.0	77.6
	7 Sept. No. 30	1.6	14.1	84.3
	7 Sept. No. 31	2.4	11.7	85.9
	Average	2.8	14.6	82.6

1) Prepared by Alberta Environment, River Engineering Branch
2) Clay < 0.004 mm
Silt 0.004 - 0.062 mm
Sand 0.062 - 2.000 mm

Table 11 Suspended sediment composition[1] at WSC gauging stations.

Stream	Station	Sample Size	Size Range (%) Sand	Silt	Clay
Deerlick Creek	07AF004	5	7-18	53-73	19-40
Eunice Creek	07AF005	4	9-44	43-57	8-34
Wampus Creek	07AF003	9	8-38	45-66	17-38
McLeod River above Embarras River	07AF002	1	18	71	11

1) Prepared by Alberta Environment, River Engineering Branch

Suspended sediments collected at the mouth of the Lovett River contain considerably more clay than any of the other rivers. The Lovett River samples were collected after heavy rains and may not reflect the average suspended sediment particle size in the river. At that time the contribution of non-point sources (e.g. river bank erosion, road crossings) to the river's sediment load was probably considerable. Another contributing factor to the unusual sediment composition could be the selective retention of larger size fractions in the mine impoundments.

4.6 NON-FILTERABLE RESIDUE

4.6.1 Discrete Samples

As noted in Section 3.11, both discrete samples (fortnightly intervals) and time-integrated composite samples (3 hr. intervals) were taken for NFR analyses by Water Quality Control Branch staff.

The median concentration for the discrete samples from the Lovett River and the four impoundments are plotted on Figure 6. The median levels were lowest at LR1 (6.0 mg•L^{-1}) and increased significantly through LR2 to LR3. The maximum median concentration was measured at LR3 (20 mg•L^{-1}) and declined thereafter to 13.2 mg•L^{-1} at both LR4 and LR5.

By employing the ASWQO for suspended solids (NFR) in the manner discussed in Section 4.5.1, and comparing paired data for upstream (LR1) and downstream sites (LR5), it was observed that 4 out of 12 samples exceeded the objective. Within the minesite the frequency of exceedance was variable: 4 out of 11 times between LR1 and LR2; 5 out of 12 times between LR2 and LR3; once out of 12 times between LR3 and LR4; 2 out of

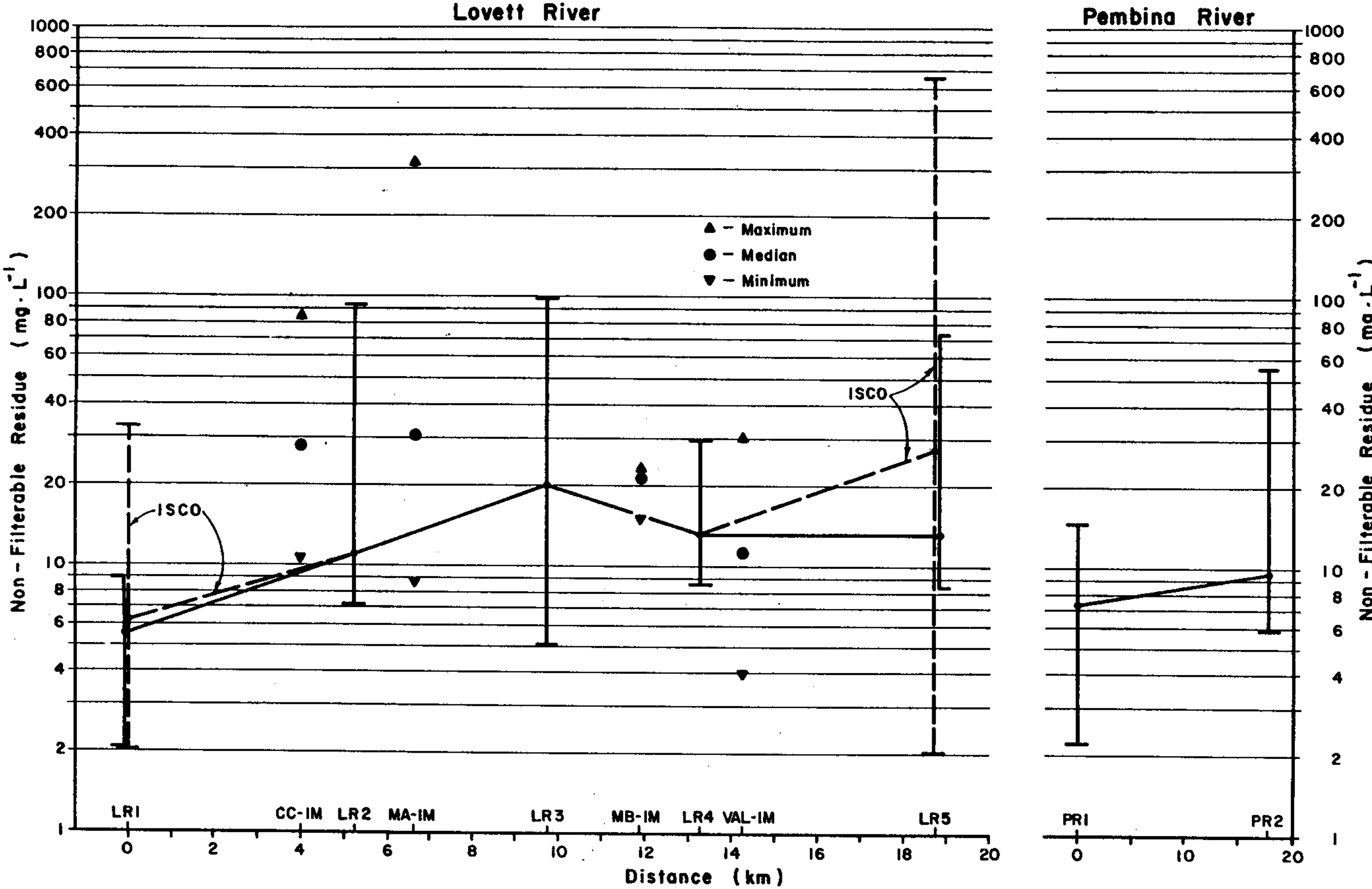


Figure 6 Ranges and longitudinal profiles of median concentrations of non-filterable residue levels in the Lovett River and Pembina River, 1984.

12 times between LR4 and LR5. The sampling dates with most exceedances were July 31, August 29, September 11, and September 25, and in all cases followed rain events.

Note that as part of its Licence to Operate under the Clean Water Act, the Luscar Sterco (1977) Ltd. coal mine was required to monitor and control the discharge of suspended solids from its various impoundments. The mine was required to submit compliance reports based on composite samples in which NFR was not to exceed 50 $mg \cdot L^{-1}$ or exceed background by more than 10 $mg \cdot L^{-1}$. The terms of the licence could be waived for 48 hours during rainstorms greater than the 1 in 10 year 24-hour precipitation event. Based on these terms, the mine was in compliance with its licence 95% of the time during the 1984 study period. However, the grab sample data presented in this report cannot be used for compliance purposes.

Based on statistical difference testing using the Wilcoxon Signed-Rank Matched-Pairs test, the median NFR value at LR2 is significantly higher than that at LR1 (Table 12). The median value at LR3 is significantly higher than that of LR2, while LR4 is significantly lower than LR3.

The high median NFR concentrations in CC-IM and MA-IM impoundments (Figure 6) are correlated with the zone of increasing river concentrations, and the lower NFR concentrations of MB-IM and VAL-IM correlate with the zone of decreasing river concentrations. In order to quantify the influence of point and non-point sources on river NFR concentrations, a mass balance analysis was undertaken. The objective was to compare predicted versus observed NFR concentrations at LR2, using LR1 and CC-IM loading data. This analysis could not be undertaken with other impoundments since discharge data were unavailable for them.

Table 12 Levels of significance (P) of differences between median values of selected variables based on the Wilcoxon Signed-Rank Matched Pairs Test.

	Variable								
Station	Non-Filterable Residue	Total Dissolved Solids	Calcium	Magnesium	Sodium	Chloride	Sulphate	Potassium	Bicarbonate
LR1-LR2	0.005	0.003	0.003	0.043	0.003	0.043	0.005	0.003	0.003
LR2-LR3	0.033	0.965	0.273	0.317	0.721	0.500	0.285	0.686	0.779
LR3-LR4	0.033	0.197	0.263	0.201	0.263	0.273	0.114	0.018	0.689
LR4-LR5	0.594	0.003	0.933	0.423	0.018	0.068	0.018	0.022	0.003
PR1-PR2	0.182	0.003	0.139	0.028	0.003	0.043	0.168	0.012	0.003

NOTE: Two-tailed "P" values ≤ 0.05 are significant

The results are summarized in Table 13. The instantaneous load at LR2 is always greater than the sum of the loads from CC-IM and LR1, suggesting input from the two small, ungauged, tributaries and a muskeg area downstream from LR1. Regardless of these data gaps, the NFR contributions from CC-IM were always on the same order of magnitude as the ambient NFR load at LR1.

On five out of eight sampling dates the predicted NFR concentrations at LR2 were similar to the observed. On these dates, the increasing NFR concentrations between LR1 and LR2 are primarily due to effluent discharged from CC-IM.

On the three remaining dates the predicted NFR concentrations at LR2 were much greater than the observed, indicating the presence of important, unaccounted inputs to the stream. Speculatively, these inputs could be the result of erosion from road crossings or disturbance of overburden, etc., near the water course. Thus, both point and non-point sources appear to be involved in the increasing NFR concentration between LR1 and LR2. This is probably the pattern downstream to LR3, since the same potential sources are present downstream from LR2.

The net impact of the Lovett River on the Pembina River, as indicated by these fortnightly data was to increase the median concentration of NFR in the latter from 7.2 to 9.5 mg•L^{-1}

4.6.2 Time Integrated Composite Samples

The daily NFR concentration estimates provided by the composite samples from LR1 and LR5 enhance the overall picture of suspended sediment flux through the Lovett River.

Table 13 Instantaneous Concentration [c] of NFR (mg•L^{-1}), Discharge [Q] (m^3•s^{-1}), and Loading (L) (g•s^{-1}) at LR1, CC-IM, and LR2.

DATE	LR1			CC-IM			LR2			Predicted [c] at LR2
	[C]	(Q)	(L)	[C]	(Q)	(L)	[C]	(Q)	(L)	
May 23	6.0	1.010	6.06	28.2	0.120	3.38	9.6	1.22	11.71	8.4
June 5	5.8	0.651	3.78	23.4	0.113	2.64	91.2	-	-	8.4
July 4	3.0	0.357	1.07	20.0	0.173	3.46	9.0	0.723	6.51	8.6
July 31	4.8	0.137	0.66	80.4	0.077	6.19	33.4	0.287	9.59	32.0
August 14	6.4	0.129	0.83	27.0	0.064	1.73	11.0	0.308	3.39	13.3
August 28	2.0	0.092	0.18	10.6	0.116	1.23	9.6	0.204	1.96	6.8
September 11	5.0	0.492	2.46	42.4	0.101	4.28	18.6	0.801	14.90	11.4
September 25	9.0	0.295	2.66	79.8	0.016	1.28	29.4	0.521	15.32	12.7

The median values and ranges for the composite samples have been superimposed on the longitudinal profile of discrete NFR data (Figure 6). It is apparent that the maximum values (and medians) are higher then those indicated by the discrete samples, but the general upstream-downstream pattern of increase is similar.

A detailed daily plot of composite sample NFR estimates is presented in Figure 7. The concentrations at LR5 are consistently higher than those at LR1, with the exception of one date. In general, the highest NFR concentrations at both stations are associated with high precipitation and discharge events, and during these events the concentrations at LR5 are approximately one order of magnitude higher than those at LR1.

The data base at LR5 is incomplete during late summer due to equipment malfunctions, however at least five major sediment transport events (NFR > 100 $mg \cdot L^{-1}$) are indicated during the May to October interval. These occurred during May 17-19, June 6-19, August 5-6, September 7-9, and September 21-23. Only the event of August 5-6 was not associated with intense or prolonged precipitation, and may be indicative of anthropogenic streambed or bank disturbances. None of these five events were sampled during the regularly scheduled fortnightly trips.

The daily NFR data underscore the problems inherent in defining water quality in the dynamic foothills stream environment on a fixed time schedule. Whether variability is introduced by "flashy" hydrologic characteristics, by anthropogenic influences, or by a combination of both, it is important to be aware of short-term changes and their potential influence on data interpretation.

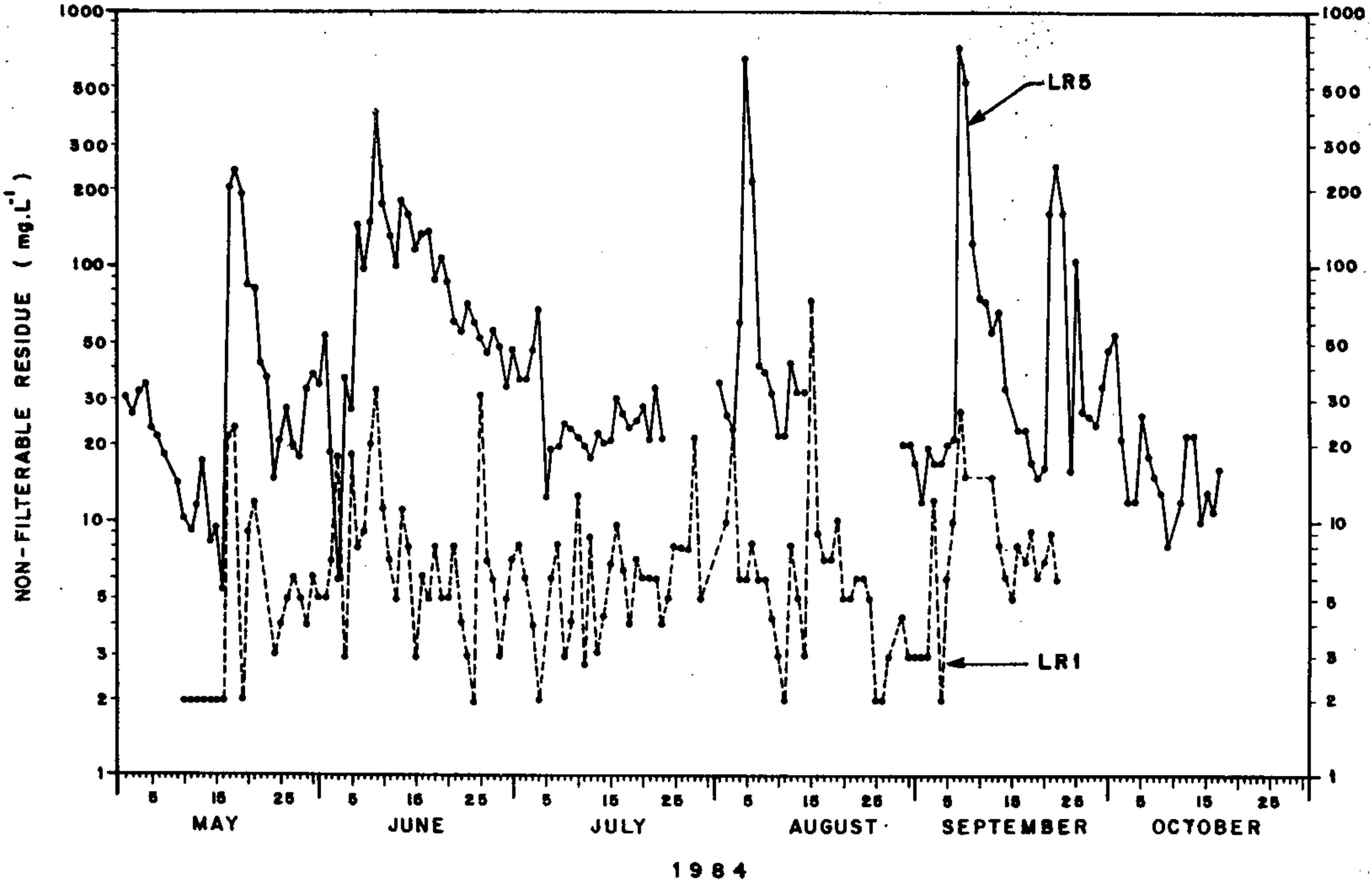


FIGURE 7. DAILY NFR ESTIMATES FROM THE TIME-INTEGRATED COMPOSITE SAMPLES AT LR1 AND LR5.

No significant difference was detected when composite and discrete sample data from LR1 were paired for four dates and tested statistically (Wilcoxon signed - Rank Matched - pairs test; $p < 0.05$). However, the same test performed on data for eight pairs of composite and discrete samples from LR5 indicated that levels of NFR were significantly higher in composites. Composite samples from LR5 had NFR levels which were consistently higher than grab samples by a factor of two to ten. Considering that NFR and discharge are generally positively correlated, detailed hydrographs from the Lovett River at LR5 were examined to determine whether grabs were collected at a lower discharge than the average discharge for the corresponding composite. This was the case for three out of eight pairs only. Fluctuations in river discharge did not explain why NFR levels in composites were greater than in grabs for the remaining five pairs of samples. Although variability in NFR levels may have occurred as a result of rainfall for some samples, at least two sets of samples were collected after a dry period of at least three days and at a time of stable discharge. The underlying causes of fluctuations in NFR in disturbed watersheds is a topic worthy of further investigation.

The ASWQO for suspended solids, applied in the manner described in Section 4.6.1, indicates that on 89 out of 97 dates the objective was exceeded between LR1 and LR5.

4.7 TOTAL DISSOLVED SOLIDS

Total dissolved solids concentration [TDS] is a calculated index depicting the amount of dissolved substances in water.

The background TDS concentrations at LR1 were lowest in the spring and fall, and highest in summer, reflecting an inverse relationship with stream discharge rates. The seasonal fluctuations of [TDS] in the four impoundment discharges were somewhat variable, peaking either in mid-summer (CC-IM, MB-IM) or late fall (VAL-IM, MA-IM). Median TDS concentrations in the impoundments were similar and at least five times higher than the median value at LR1(59 $mg \bullet L^{-1}$).

The median TDS concentrations in the Lovett River were lowest at LR1 (Figure 8). They increased significantly ($p < 0.003$) at LR2 (100 $mg \bullet L^{-1}$), remained relatively constant through LR3 and LR4, and increased to their highest value (123.0 $mg \bullet L^{-1}$) at LR5. The discharge of the Lovett River into the Pembina River resulted in a significant increase ($p < 0.003$) in [TDS] between PR1 (83 $mg \bullet L^{-1}$) and PR2 (101 $mg \bullet L^{-1}$).

A mass balance analysis between stations CC-IM and LR1 indicated that on most occasions the predicted and observed concentrations at station LR2 were relatively similar (Table 14). These results suggest that the major source of increased [TDS] between LR1 and LR2 was the Lower Coal Creek Impoundment discharge. The absence of flow data for the remaining impoundments and for the miscellaneous tributaries between LR2 and LR5 makes it impossible to quantify the influence of the other anthropogenic [TDS] discharges on the Lovett River. However, the longitudinal pattern of river [TDS] corresponds with effluent qualities, suggesting a relationship.

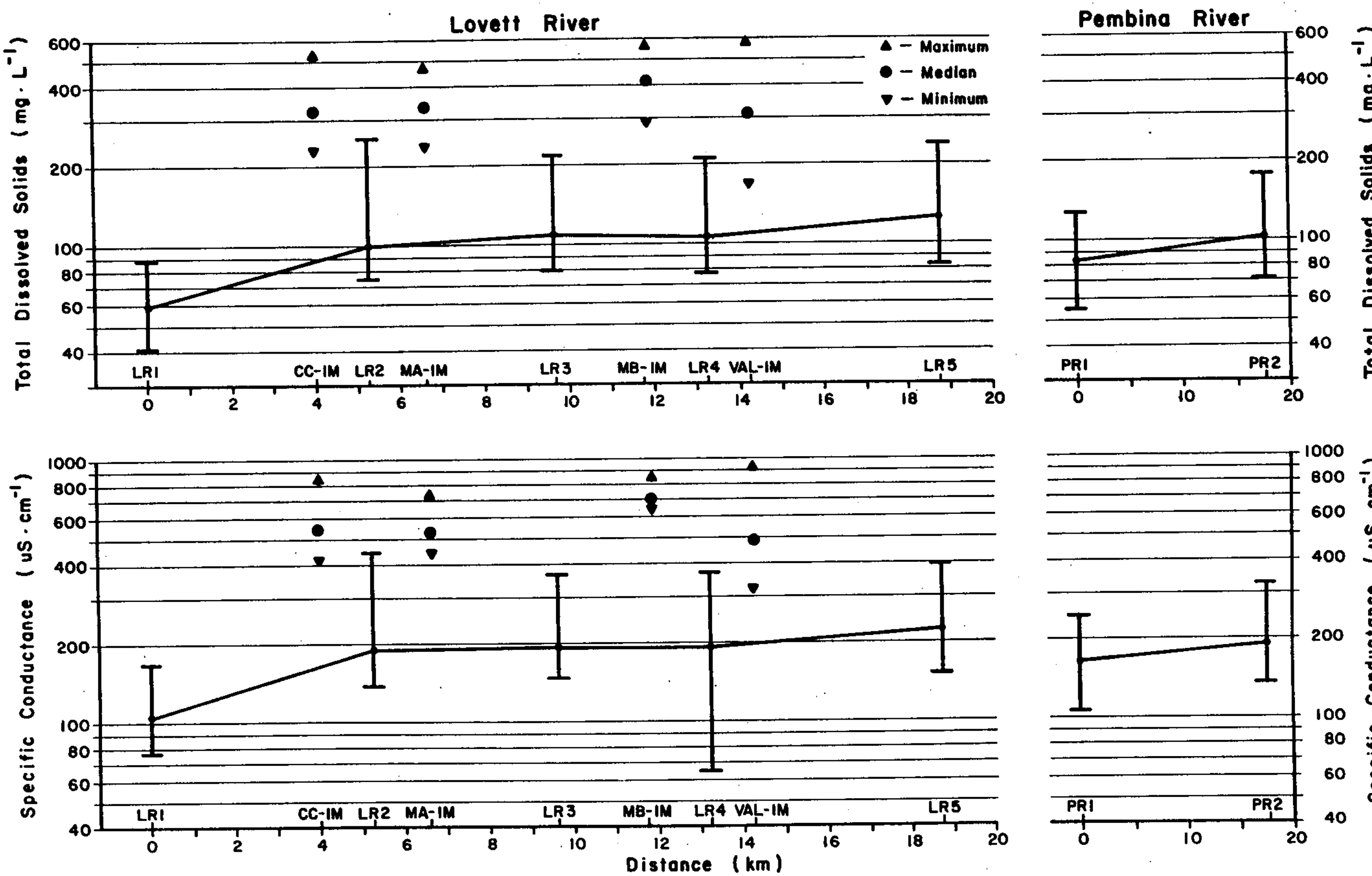


Figure 8 Ranges and longitudinal profiles of median concentrations of total dissolved solids and levels of specific conductance in the Lovett River and Pembina River, 1984.

Table 14 Instantaneous Concentration [c] of TDS ($mg \cdot L^{-1}$), Discharge [Q] ($m^3 \cdot s^{-1}$), and Loading (L) ($g \cdot s^{-1}$) at LR1, CC-IM, and LR2.

DATE		LR1			CC-IM			LR2			Predicted [c] at LR2
		[C]	(Q)	(L)	[C]	(Q)	(L)	[C]	(Q)	(L)	
May	23	41	1.010	41.41	287	0.120	34.44	78	1.220	95.16	67
June	5	57	0.651	37.11	305	0.113	34.47	104	-	-	94
July	4	70	0.357	24.99	306	0.173	52.94	131	0.723	94.71	147
July	31	80	0.137	10.96	473	0.077	36.42	185	0.287	53.10	221
August	14	86	0.129	11.09	494	0.064	31.62	219	0.308	67.45	221
August	28	89	0.092	8.19	525	0.116	60.90	250	0.204	51.00	332
September	11	49	0.492	24.11	317	0.101	32.02	88	0.801	70.49	95
September	25	60	0.295	17.70	395	0.016	6.32	157	0.521	81.80	77

Despite the elevated concentration of TDS, the resulting levels in the Lovett River are considered low. Assessed independently, these levels likely have no adverse affects on aquatic life. McNeely et al. (1979) reported that waters with [TDS] concentrations of less than 1000 mg•L^{-1} are considered fresh (non-saline).

4.8 SPECIFIC CONDUCTANCE

Specific conductance is a measure of the mobility of ions in solution, and is dependent upon ionic concentration and temperature. It may or may not be closely correlated to [TDS], depending on the nature of the dissolved constituents.

Median specific conductance values in the Lovett River ranged from 106 uS•cm^{-1} (LR1) to 226 uS•cm^{-1} (LR5) Figure 8 and reveal a longitudinal pattern similar to that described for [TDS]. The discharge of the Lovett River into the Pembina River resulted in an increase in median specific conductance values in the latter from 165 uS•cm^{-1} (PR1) to 191 uS•cm^{-1} (PR2).

As with [TDS], the specific conductance of impoundment discharges was much higher than background river values at LR1. The impoundment discharges ranged from 492 uS•cm^{-1} to 700 uS•cm^{-1}, and based on the analysis in Section 4.7 were probably implicated in river specific conductance changes.

4.9 MAJOR IONS

The concentrations of all major ions increased immediately downstream of station LR1, and showed significant differences between LR1 and LR2, and, in many cases, between LR4 and LR5 (Tables 6 and 12). The water at station LR1 was of the calcium bicarbonate type with an ionic dominance of $HCO_3^- > Ca^{++} > Na^+ > Mg^{++} > SO_4^= > Cl^- > K^+$ (illustrated as millequivalents in Figure 9). Downstream, at station LR2, the median concentrations of sodium and sulphate increased significantly and became the second and fourth most dominant ions, respectively. These increases resulted in the water becoming a sodium bicarbonate type; this condition prevailed downstream to station LR5. In 1975, the ionic dominance was similar to that recorded at LR1 during the current study period, but was consistent throughout the reach (EPEC consulting Western Ltd. 1976). As described for [TDS] and specific conductance, the major ions showed some seasonal variations with the highest concentrations generally occurring during summer, a period of relatively low flow in the stream.

Below LR2, and through to LR4, there was often a slight decline in concentrations. Most major ions increased again between LR4 and LR5.

The increased concentrations of sodium and sulphate were correlated longitudinally with discharges from the impoundments (not shown on Figure 9; see Table 6). Effluents from each of the impoundments exhibited particularly high median concentrations, ranging from 94.5 $mg \bullet L^{-1}$ to 142 $mg \bullet L^{-1}$ (sodium) and from 30.0 $mg \bullet L^{-1}$ to 44.5 $mg \bullet L^{-1}$ (sulphate). The major river concentration changes occurred below CC-IM and VAL-IM. Most major ions in the Pembina River were significantly increased between PR1 and PR2, as a consequence of the Lovett River input. However, two ions (magnesium and sulphate), actually

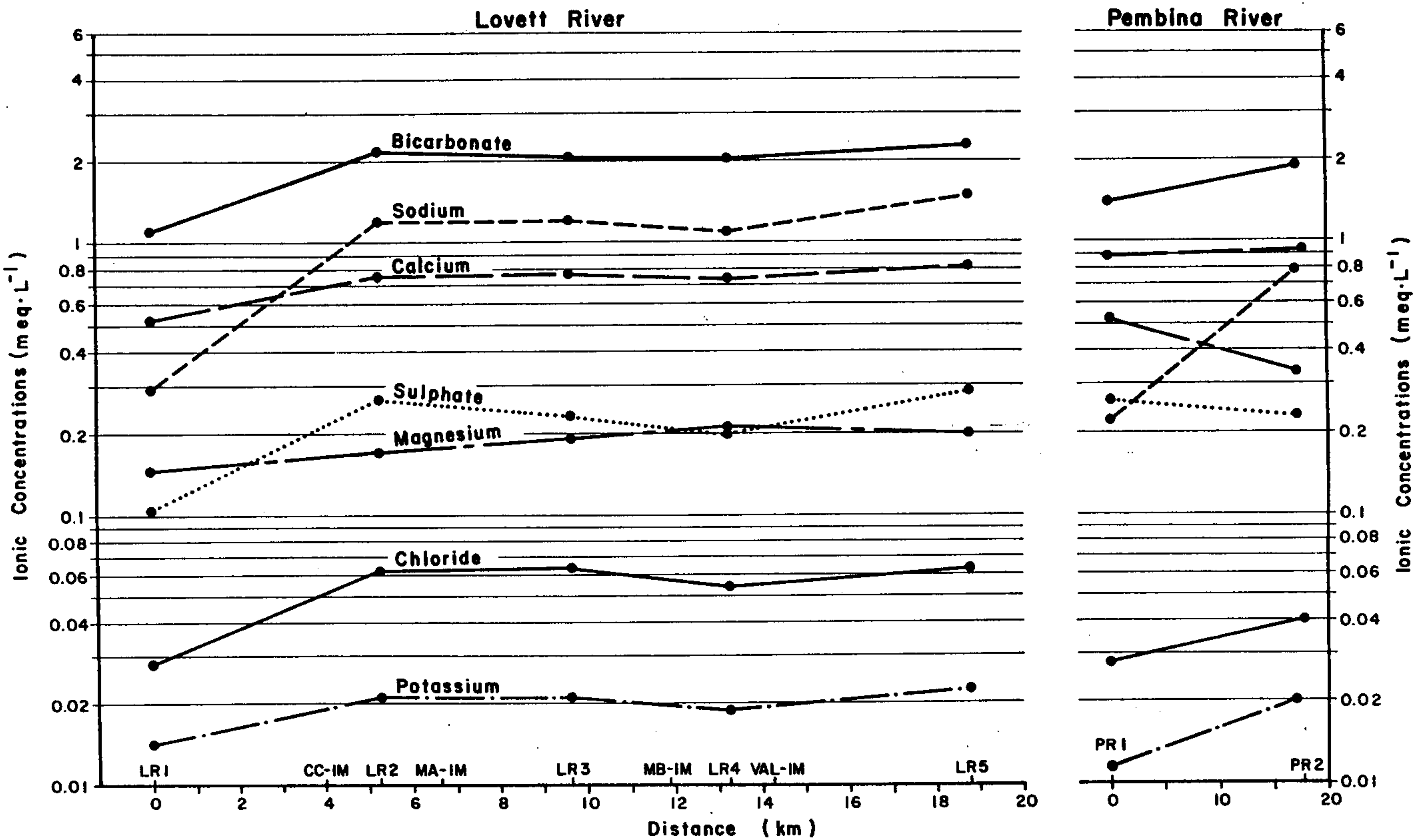


Figure 9 Longitudinal profiles and ionic dominance of major ions in the Lovett River and Pembina River, 1984.

decreased between PR1 and PR2, reflecting the different major ion chemistry of the Pembina River system.

Provincial surface water quality objectives have not been specified for the major ions discussed above. This is because they are often too variable in the natural state to permit the definition of absolute limits and because most are considered harmless even when present in moderately high concentrations (McNeely et al. 1979).

The changes in major ion concentrations in the Lovett River downstream of LR1, when viewed individually, are not likely to affect aquatic life. Changes of this magnitude can occur naturally. They are common in the winter period when streams return to base flow conditions and the relative influence of groundwater increases.

4.10 TOTAL HARDNESS

Total Hardness is principally determined by the sum of calcium and magnesium ions and is expressed as an equivalent of calcium carbonate. Median total hardness concentrations in the Lovett River ranged from 46.5 $mg \bullet L^{-1}$ (LR1) to 60.0 $mg \bullet L^{-1}$ (LR4) and fluctuate among stations in a pattern similar to that of TDS and specific conductance (Table 6). In the Pembina River, a notable decrease (81.0 to 51.5 $mg \bullet L^{-1}$) is apparent downstream of the Lovett River confluence. The decrease in total hardness is mainly due to an important decrease in the concentration of magnesium, which results from a dilution effect by the Lovett River.

The elevated total hardness concentrations in the Lovett River are not considered important and most likely have no adverse effects on the aquatic life. Waters with total hardness ranging from 30 to 60 mg•L^{-1} are considered soft (McNeely et al. 1979).

4.11 TOTAL ALKALINITY

Alkalinity is a measure of a water's capacity to neutralize acids. This variable indicates the presence of carbonates, bicarbonates and hydroxides, and other less significant buffering factors.

In the Lovett River, median total alkalinity levels ranged from 50.7 to 98.6 mg•L^{-1} (Table 6). The levels were lowest at station LR1, increased at station LR2 then remained relatively constant before reaching the highest level at station LR5. The fluctuations of total alkalinity levels among stations were similar to that shown for TDS.

The increase in total alkalinity downstream of station LR1 was mainly due to increases in the concentrations of bicarbonate described previously. Such an increase was not considered important and should have no effect on aquatic life because the elevated levels are similar to the maximum values observed at station LR1. Although there are no objectives or guidelines to protect aquatic environments, total alkalinity should be maintained at natural background levels with no sudden variations (McNeely et al. 1979).

4.12 pH

The median pH values in the Lovett River were consistently alkaline, ranging from 7.7 (station LR1) to 8.2 at stations LR2 and LR3 (Table 12). Following an increase at station LR2, the median pH values remain above the background level throughout the study area reaching a level of 8.1 at station LR5. The highest pH values in the river occurred in August while the lowest values were generally recorded in April and May. The increase in pH downstream of station LR1 is likely the result of discharges from the four impoundments (stations CC-IM, MA-IM, MB-IM, and VAL-IM). The median pH of the discharges were notably higher than the background level of the river.The elevated pH of the Lovett River appeared to influence the pH of the Pembina River; the median pH value at the background Station PR1 was 7.9 but increased at station PR2 to 8.1.

In 1975, the pH of the Lovett River remained essentially unchanged throughout the study area. The mean pH at locations near stations LR2, LR5 were 7.8 and 7.9, respectively, while the pH in the Pembina River was 7.8 downstream of the Lovett River confluence (EPEC Consulting Western Ltd. 1976).

Although there is a definite increase in the Lovett River, the median values are within the Alberta Surface Water Quality Objectives of 6.5-8.5.

4.13 NITROGEN

Concentrations of all nitrogen fractions in the Lovett River increased downstream of the mine, and, for some nitrogen fractions, the changes were important. Elevated concentrations were also recorded in the Pembina River downstream of its confluence with the Lovett River.

4.13.1 Total Nitrogen

Median total nitrogen concentrations [TN], defined as the sum of total kjeldahl nitrogen [TKN] plus the sum of nitrate and nitrite nitrogen [NO_3+NO_2], ranged from 0.203 mg•L^{-1} at station LR1 to 0.974 mg•L^{-1} at station LR5 (Table 6 and Figure 10). At LR1, the [TN] consisted primarily of [TKN] which had a median concentration of 0.180 mg•L^{-1}. However, between stations LR1 and LR5 a change in TN composition occurred, and the dominant fraction became [NO_3+NO_2].The highest concentration of total nitrogen at LR1 occurred during high discharge events, whereas the remaining stations frequently revealed highest [TN] during summer low flow.

Total nitrogen concentration increased significantly ($P = 0.012$) (Table 15) between LR1 and LR2, and between LR4 and LR5. The elevated concentrations of [TN] downstream from LR1 were correlated with discharges from the impoundments. Median concentrations of total nitrogen in the effluents reached levels as high as 45.040 mg•L^{-1} (MB-IM); median values for all effluents ranged between 15 to 225 times higher than the (background) median level at LR1. A significant increase in [TN] ($P = 0.003$) was also observed in the Pembina River as a consequence of the Lovett River input.

In spite of the [TN] increases observed in the Lovett River, median values at all stations remained below the ASWQO of 1.0 mg•L^{-1}. However, the maximum values at LR2, LR4, LR5, and PR2 exceeded this objective.

4.13.2 (Nitrate + Nitrite) Nitrogen

Compared to the other nitrogen fractions, [NO_3+NO_2] underwent the largest degree of change between upstream and downstream stations. Median concentrations ranged from 0.006 at LR1 to 0.581 mg•L^{-1}

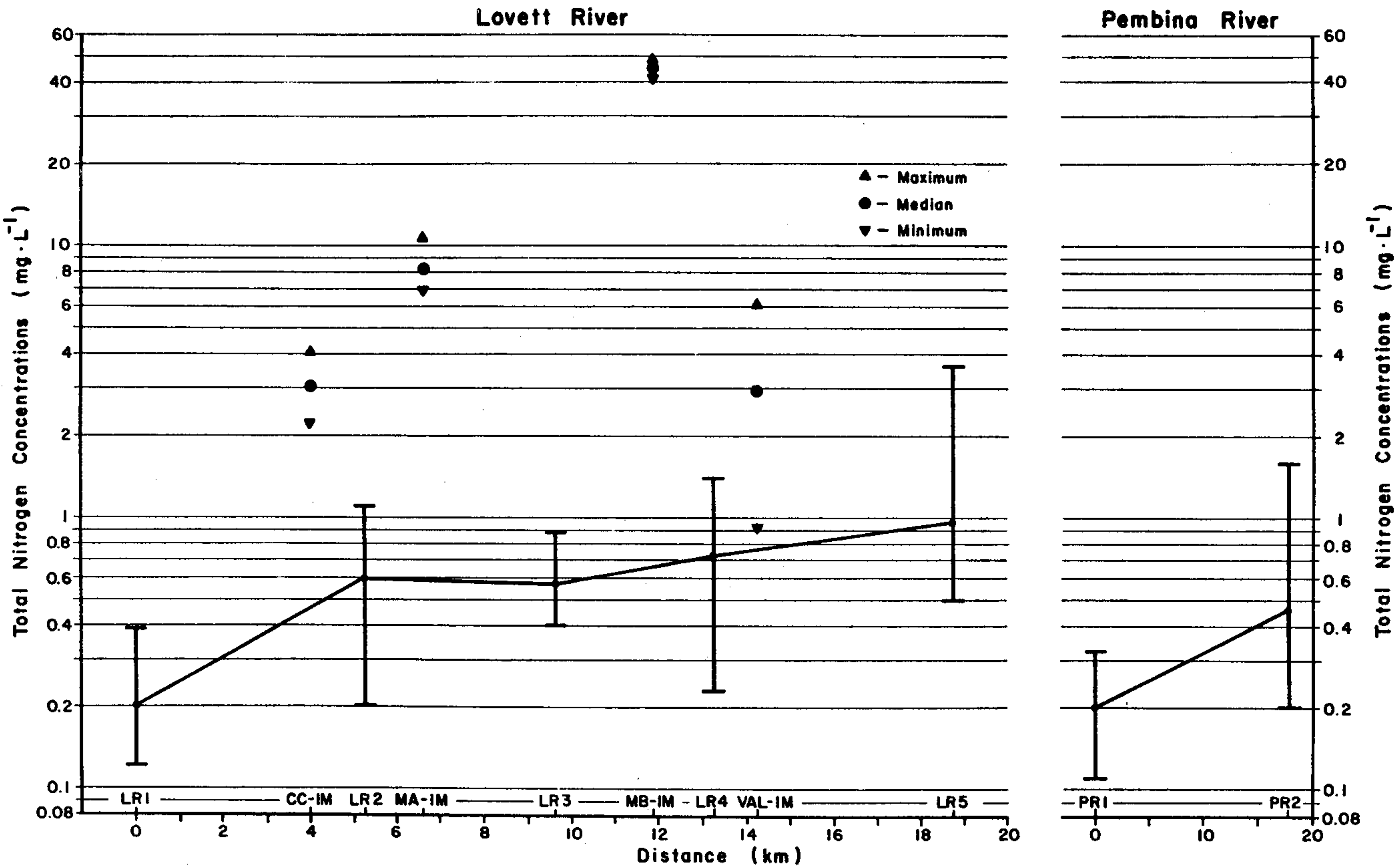


Figure 10 Ranges and longitudinal profile of median total nitrogen concentrations in the Lovett River and Pembina River, 1984.

Table 15 Levels of Significance (P) of differences between median values of selected variables based on the Wilcoxon Signed-Rank Matched Pairs-Test.

	Variable							
Station	TN	TKN	TAN	NO_3+NO_2	TP	SRP	DOC	TOC
LR1-LR2	0.012	0.052	0.005	0.012	0.050	0.401	0.110	0.023
LR2-LR3	0.575	0.788	0.003	0.208	0.834	0.068	0.919	0.695
LR3-LR4	1.000	0.933	0.965	0.889	0.398	0.893	0.760	0.575
LR4-LR5	0.012	0.168	0.131	0.033	0.721	0.361	0.097	0.005
PR1-PR2	0.003	0.007	0.021	0.003	0.894	0.024	0.929	0.002

NOTE: Two-Tailed "P" values $\leq$ 0.05 are significant at LR5 (Table 6 and Figure 11). At station LR1 the [NO_3+NO_2] showed a slight seasonal variation with the highest values occurring in spring, while at the downstream station the highest concentrations generally occurred during summer low flow.

The longitudinal pattern of [NO_2+NO_3] increase was correlated with discharges of impoundment effluents high in inorganic nitrogen. Individual concentrations in the effluents ranged from 0.483 to 35.30 mg•L^{-1} which were approximately 81 to 5883 times higher than the (background) median value at LR1.

Median concentrations of NO_3+NO_2 increased significantly (P = 0.012) between LR1 (0.006 mg•L^{-1}) and LR2 (0.319 mg•L^{-1}), and between PR1 (0.004 mg•L^{-1}) and PR2 (0.205 mg•L^{-1}) (P = 0.003). The median concentrations increased downstream progressively, reaching their maximum at LR5.

A mass balance analysis between station CC-IM and LR1 indicated that on most occasions the predicted and observed concentrations at LR2 were relatively similar (Table 16). These results suggest that the major source of increased [NO_3+NO_2] between LR1 and LR2 was the lower Coal Creek Impoundment discharge.

No Alberta Surface Water Quality Objective has been set for [NO_3+NO_2]. However, this form of nitrogen can contribute to the fertility of surface water, especially in the presence of adequate concentrations of available phosphorus.

Nitrite is a readily oxidized, unstable form of inorganic nitrogen, occurring as an intermediate form between ammonia and nitrate. No Alberta Surface Water Quality Objective has been established for

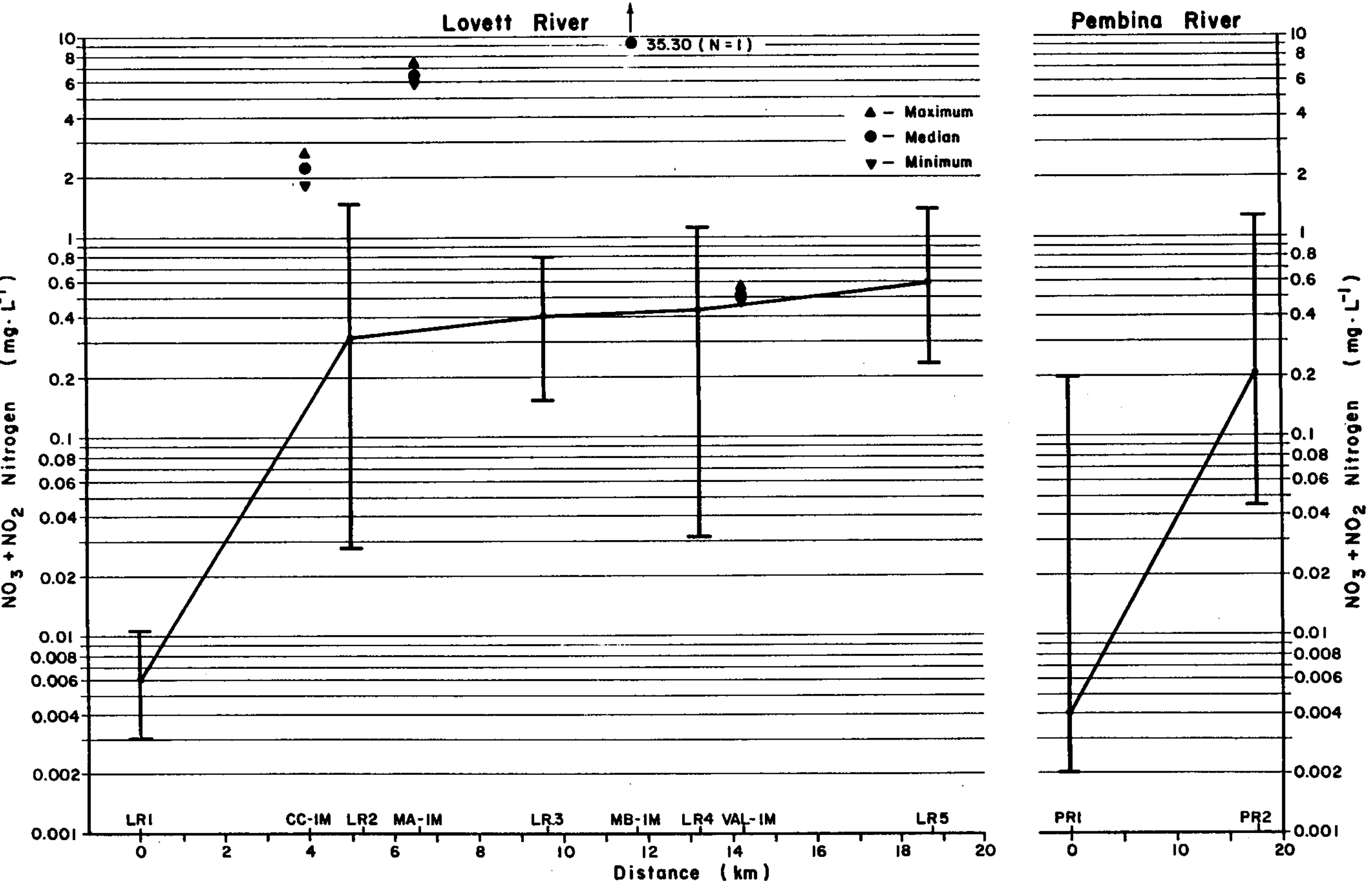


Figure 11 Ranges and longitudinal profile of median nitrate + nitrite nitrogen concentrations in the Lovett River and Pembina River, 1984.

Table 16 Instantaneous Concentration [c] of [NO_3+NO_2] (mg•L^{-1}), Discharge [Q] (m^3•s^{-1}), and Loading (L) (g•s^{-1}) at LR1, CC-IM, and LR2.

DATE	LR1			CC-IM			LR2			Predicted [c] at LR2
	[C]	Q	L	[C]	Q	L	[C]	Q	L	
April 25										
May 8	0.004	0.229	0.0009	2.536	0.081	0.2054	0.401	–		0.666
May 23	0.004	1.010	0.004	2.200	0.120	0.2640	0.293	1.22	0.3575	0.237
June 5	0.013	0.651	0.0085	2.180	0.113	0.2463	0.322	–		0.334
July 4	0.007	0.357	0.0025	1.920	0.173	0.3322	0.027	0.723	0.0195	0.632
August 28	0.003	0.092	0.0003	4.200	0.116	0.4872	1.455	0.204	0.2968	2.344
September 11	0.005	0.492	0.0025	2.860	0.101	0.2889	0.315	0.801	0.2523	0.491

nitrite, although a guideline of 0.06 mg•L^{-1} has been recommended by the Canadian Water Quality Guidelines (CCREM 1987) for the protection of aquatic life. Nitrite concentrations in the Lovett River exceeded this guideline on two dates at one station (LR5).

4.13.3 Total Ammonia Nitrogen

Inorganic nitrogen measured in the form of total ammonia nitrogen concentration [TAN] is significant to aquatic systems because it contributes to the fertility of water, and, because under certain conditions, it can be toxic to fish.

TAN concentrations in the Lovett River underwent substantial changes between stations upstream and downstream of the mine (Table 6 and Figure 12). There was a significant increase in [TAN] ($P = 0.005$) between LR1 (0.006 mg•L^{-1}) and LR2 (0.025 mg•L^{-1}). Median concentrations declined slightly between LR2 and LR4 and finally increased again to 0.022 mg•L^{-1} at LR5. The median [TAN] in the Pembina River increased slightly between PR1 (0.005 mg•L^{-1}) and PR2 (0.007 mg•L^{-1}).

No distinct seasonal characteristics were evident for [TAN], although the highest concentrations were measured in summer and autumn at the various stations. Effluent concentrations are generally one order of magnitude higher than background concentrations at LR1, except for MB-IM which is three orders of magnitude higher (Figure 12). The largest single increment in [TAN] occurred between LR1 and LR2, and probably reflects the presence of a larger volume of outflow from CC-IM, since the high [TAN] at MB-IM had little effect on the river.

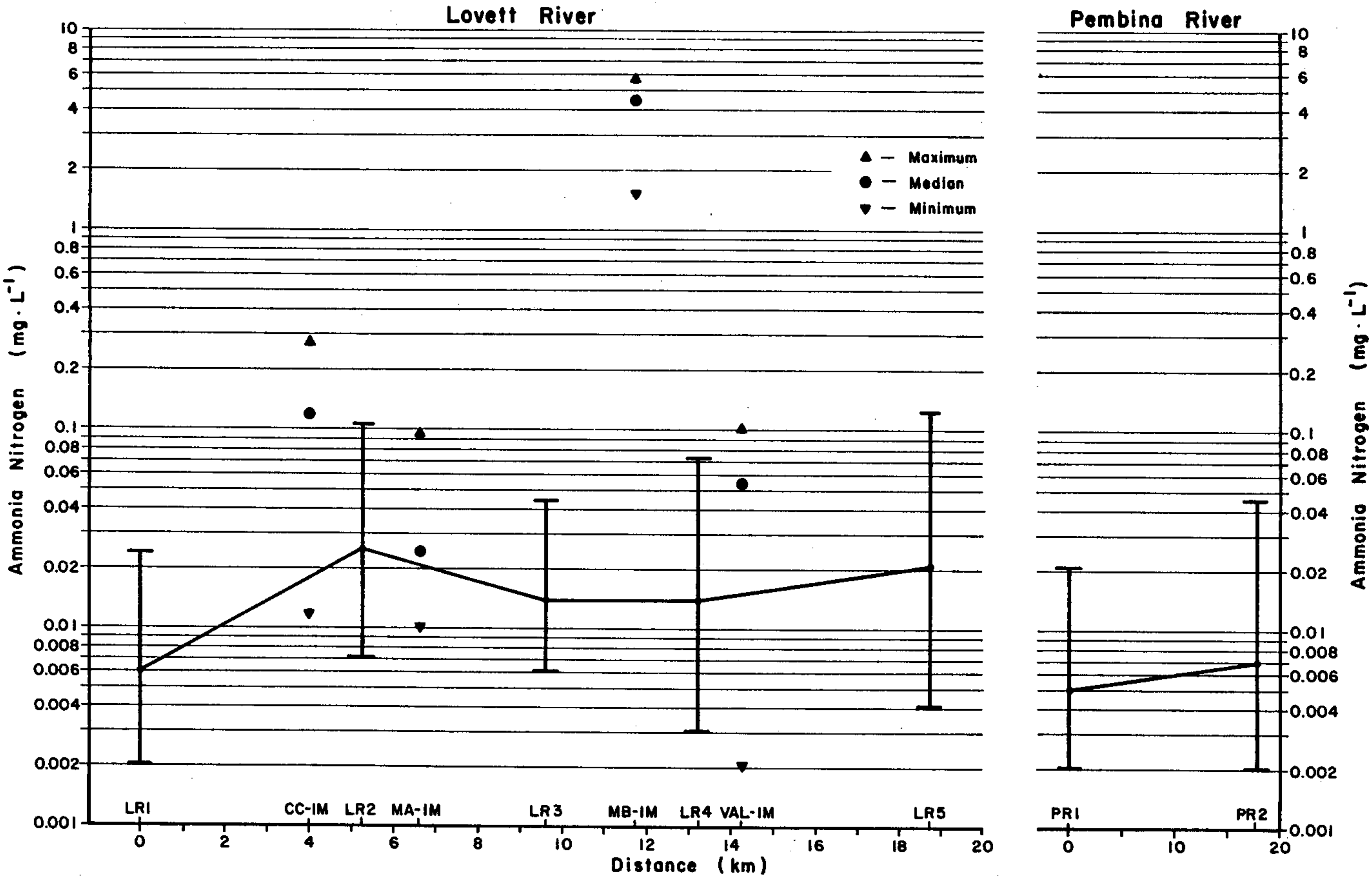


Figure 12 Ranges and longitudinal profiles of median ammonia nitrogen concentrations in the Lovett River and Pembina River, 1984.

The proportion of un-ionized ammonia (NH_3) in [TAN] in surface water, and its relative toxicity, is controlled by <u>in situ</u> temperature and pH. The maximum value of [TAN] (0.123 $mg \bullet L^{-1}$) recorded in the Lovett River, as well as all other values, were below the recommended guidelines for [TAN] published by C.C.R.E.M.

4.13.4 Total Kjeldahl Nitrogen

Total kjeldahl nitrogen is the sum of organic nitrogen and TAN. In the Lovett River, [TKN] was a close representation of organic nitrogen because [TAN] usually constituted less than 10% of [TKN].

Compared to the other nitrogen fraction, [TKN] revealed statistically insignificant changes in the Lovett River (Tables 6 and 15). Median concentrations ranged from a low of 0.180 $mg \bullet L^{-1}$ at LR1 to a high of 0.300 $mg \bullet L^{-1}$ at LR2. The change between LR1 and LR2 was probably due to discharge from the Lower Coal Creek Impoundment.

A comparatively high concentration of TKN in the effluent of MB-IM (median = 8.390 $mg \bullet L^{-1}$) had little effect on the river, presumably due to a low effluent flow rate. A significant increase in [TKN] did occur between PR1 (0.190 $mg \bullet L^{-1}$) and PR2 (0.250 $mg \bullet L^{-1}$), once again reflecting the influence of the Lovett River on the Pembina.

4.14 PHOSPHORUS

Median total phosphorus concentrations [TP] in the Lovett River ranged from 0.012 $mg \bullet L^{-1}$ (LR1) to 0.029 $mg \bullet L^{-1}$ (LR3) (Table 6 and

Figure 13). The only significant change in [TP] was the increase which occurred between LR1 and LR2, (Table 15) reflecting the input of effluent from CC-IM. In general, the effluent [TP]'s were low, and the median [TP] at MA-IM and VAL-IM were below the river median concentrations.

River [TP] declined below LR3, and dropped between PR1 and PR2. This may have been due to increased plant uptake of phosphorus in that reach, stimulated by excessive levels of inorganic nitrogen. Although the river median [TP] values were well below the ASWQO of 0.05 $mg \cdot L^{-1}$, the objective was exceeded by the maximum values at LR2, LR3, LR5, and PR2.

Median soluble reactive phosphorus concentrations [SRP] displayed little longitudinal variation in the Lovett River, ranging only from 0.007 $mg \cdot L^{-1}$ (LR3) to 0.009 $mg \cdot L^{-1}$ (LR1) (Table 6 and Figure 14). No significant changes were evident in the Lovett River, however the decrease in [SRP] between PR1 and PR2 proved to be significant (Table 15). Median [SRP] in the impoundment discharges were below the median [SRP] measured in the river.

4.15 REACTIVE SILICA

In the Lovett River, median concentrations of reactive silica ranged from 6.5 $mg \cdot L^{-1}$ (LR5) to 7.4 $mg \cdot L^{-1}$ at station LR1 (Table 6). The concentrations were essentially uniform throughout the reach, and exhibited no seasonal relationship. Similar values occurred in the Pembina River.

Most natural waters contain concentrations of silica from 1 to 30 $mg \cdot L^{-1}$ (McNeely et al. 1979). The concentrations of reactive

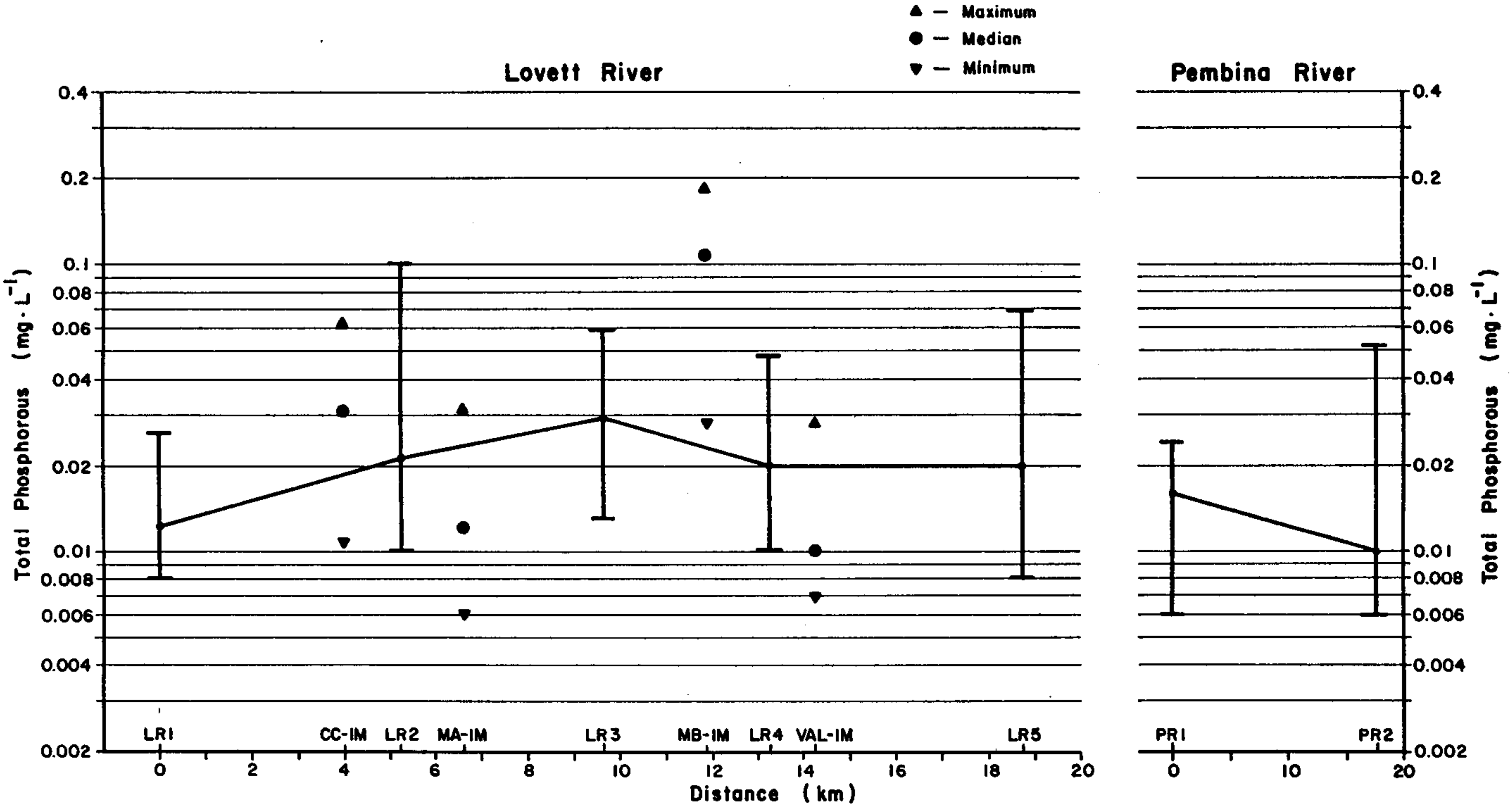


Figure 13 Ranges and longitudinal profile of median total phosphorous concentrations in the Lovett River and Pembina River, 1984.

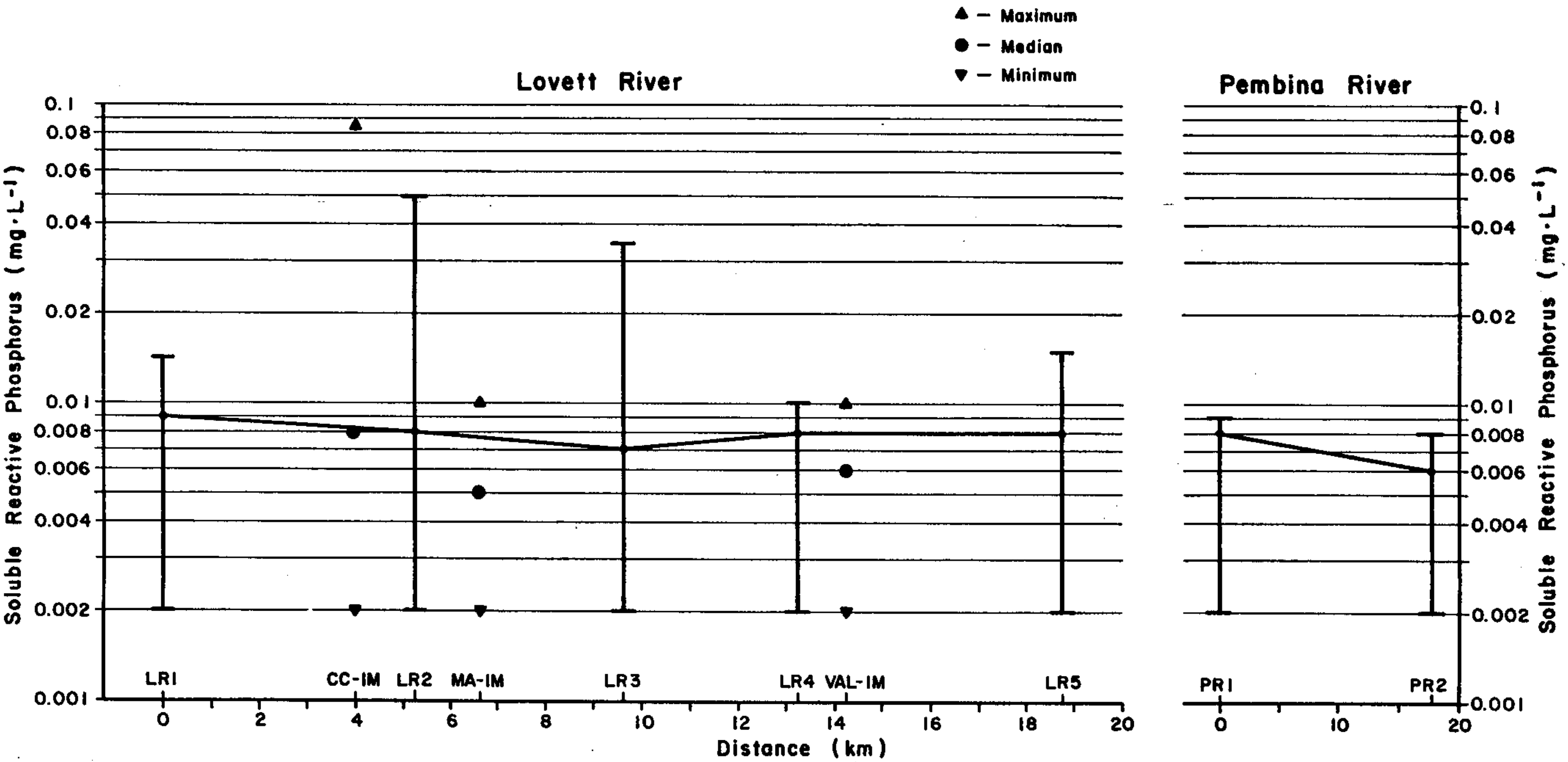


Figure 14 Ranges and longitudinal profile of median soluble reactive phosphorus concentrations in the Lovett River and Pembina River, 1984.

silica in the impoundment effluents were also low; they ranged from 3.30 to 5.95 mg•L^{-1}.

4.16 CARBON

Dissolved organic carbon concentrations [DOC] displayed little longitudinal variation in the Lovett River (Table 6). Median [DOC] ranged from 3.50 mg•L^{-1} (LR5) to 4.7 mg•L^{-1} (LR1); no significant changes were measured (Table 15). Median [DOC] in the impoundment effluents were less than river median concentrations. In the Pembina River median [DOC] decreased slightly between PR1 and PR2 as a consequence of the Lovett River inflow.

Unlike [DOC], dissolved inorganic carbon concentrations [DIC] did vary substantially in the Lovett River (Table 6). Concentrations of [DIC] increased significantly (Table 17) between LR1 (12.2 mg•L^{-1}) and LR2 (20.9 mg•L^{-1}) and increased slowly thereafter. The impoundment effluents were much higher in [DIC] than the river, and changes in river [DIC] appeared to be correlated with their inputs. The input of the Lovett River to the Pembina caused a slight increase in [DIC] between PR1 (16.6 mg•L^{-1}) and PR2 (20.8 mg•L^{-1}).

No numerical values have been specified in the ASWQO for [DOC] or [DIC]. The values for both variables observed in the Lovett and Pembina rivers are within the normal range observed in the foothills aquatic environment in Alberta (WQCB, unpublished data).

4.17 PHENOLIC MATERIALS

Median concentrations of phenolic materials were generally low in the Lovett River, and decreased in a downstream direction from

Table 17 Levels of significance (P) of differences between median values of selected variables based on the Wilcoxon Signed-Rank Matched Pairs Test.

	Variable										
Station	Al	Mo	Ni	Mn	As	Fe	Se	Cr	Zn	Cu	V
LR1-LR2	0.010	0.005	0.285	0.002	0.002	0.170	0.106	0.138	0.029	0.225	0.361
LR2-LR3	0.657	0.594	0.080	0.136	0.033	0.147	0.285	0.028	0.285	0.789	0.500
LR3-LR4	0.477	0.859	0.345	0.100	0.022	0.071	0.109	0.866	0.286	0.735	0.419
LR4-LR5	0.689	0.583	1.000	0.689	0.241	0.695	0.012	0.345	0.575	0.715	0.273
PR1-PR2	0.182	0.012	0.208	0.005	0.003	0.477	0.109	0.893	0.139	0.686	0.094

NOTE: Two-tailed "P" values ≤ 0.05 are significant

0.007 mg•L^{-1} (LR1) to 0.004 mg•L^{-1} (LR5). The median concentrations of all impoundment effluents (0.002 mg•L^{-1}) were less than the river medians. The median values in the Pembina River remained unchanged between PR1 and PR2 (0.004 mg•L^{-1}).

Strong seasonal patterns were evident at the river stations. The highest concentrations occurred during high flow events, and vice-versa. Conversely, concentrations in the impoundment effluents displayed no seasonality, and were usually near the detection limit.

Although all median values except LR1 were below the ASWQO of 0.005 mg•L^{-1}, individual samples frequently exceeded the objective. At the background station on the Lovett (LR1), 7 out of 13 samples exceeded the objective, as did 4 out of 12 samples on the Pembina at PR1. This was obviously a natural occurrence originating mainly from natural hydrocarbons and decaying vegetation.

4.18 METALS AND TRACE ELEMENTS

Analyses were conducted on samples from all sampling locations for 16 metals and trace elements. Metals are reported as "total" or "extractable" concentrations as indicated in Table 6.

Five constituents were seldom detected (Table 6). These include mercury (2 detections out of 86 samples), cadmium (7 out of 87), lead (2 out of 86), cobalt (13 out of 86) and beryllium (3 out of 86). Most concentrations were close to the analytical limit and the detections were variable in time and location.

Four other constituents were detected regularly (copper, vanadium, nickel, and iron) but inter-site differences were not statistically significant (Table 17).

Median concentrations of iron ranged from 0.220 mg•L^{-1} (LR1) to 0.350 mg•L^{-1} (LR5) and from 0.290 mg•L^{-} (PR1) to 0.280 mg•L^{-1} (PR2). The observed concentrations often exceeded the ASWQO and CCREM guidelines (0.3 mg•L^{-1}), especially at LR3, LR4 and LR5. Major increases in iron concentrations were recorded downstream of impoundments on June 5, and September 11 and 25.

Nickel was detected 36 times in 86 samples and concentrations were well below the CCREM guidelines of 0.065 mg•L^{-1} and usually near the detection limit of 0.001 mg•L^{-1}. Median concentrations ranged from L.001 mg•L^{-1} at LR1 and LR2 to 0.003 mg•L^{-1} at LR3.

Median concentrations of vanadium were below detection at all stations, except LR4 (0.0035 mg•L^{-1}) and PR2 (0.0025 mg•L^{-1}). This substance was detected 28 times in 86 samples, and concentrations were always less than 0.008 mg•L^{-1}. Insufficient information is available to set water quality guidelines or objectives for this metal.

The longitudinal pattern of median copper concentrations was uniform and below detection (0.001 mg•L^{-1}), except at LR5 (0.002 mg•L^{-1}). Insignificant differences were noted between PR1 and PR2, and all median values were below the ASWQO (0.020 mg•L^{-1}) and at or below CCREM guidelines (0.0002 mg•L^{-1}). Sixteen measurements were above the CCREM guidelines, but below the ASWQO; all values were below 0.008 mg•L^{-1}.

Seven constituents (Al, Mo, Mn, As, Se, Cr, Zn) were detected regularly and showed statistically significant differences among sites

(Table 17). Median aluminum concentrations increased significantly from LR1 (0.0540 $mg \bullet L^{-1}$) to LR2 (0.1380 $mg \bullet L^{-1}$). The maximum median concentration was recorded at LR3 (0.1590 $mg \bullet L^{-1}$). In the Pembina River median concentrations ranged from 0.0745 $mg \bullet L^{-1}$ at PR1 to 0.1060 $mg \bullet L^{-1}$ at PR2. Concentration increases in aluminum between LR1 and LR2 were most likely related to the discharges from CC-IM which had a median concentration of 0.4010 $mg \bullet L^{-1}$ and where concentrations as high as 1.1400 $mg \bullet L^{-1}$ were measured. Loading estimates (Table 18) illustrate the importance of the combined effect of high aluminum concentrations in the effluent and high discharges from the CC-IM impoundment on aluminum concentrations measured at LR2. Alumino silicate minerals are abundant in all rock types and most geologic materials, especially clays (CCREM 1987). It is not unexpected to find that high aluminum levels occur at times when suspended sediment loads in the impoundments is highest. Although maximum concentrations measured in MA-IM (2.240 $mg \bullet L^{-1}$) were even higher than in CC-IM, the median concentration in the MA-IM was lower (0.2110 $mg \bullet L^{-1}$). CCREM guidelines for the protection of aquatic life (0.1 $mg \bullet L^{-1}$) were exceeded in 6 out of 25 samples from background sites (LR1 and PR1) whereas guidelines were exceeded in 37 out of 61 samples at remaining sites on the Lovett and Pembina rivers.

Median molybdenum concentrations at LR2 (0.0030 $mg \bullet L^{-1}$) were significantly higher than at LR1 (L.0010 $mg \bullet L^{-1}$) as a consequence of discharges from CC-IM. Median molybdenum concentrations in the Pembina River were below detection at PR1, but increased significantly to 0.0065 $mg \bullet L^{-1}$ at PR2 (Table 17). MB-IM had the highest median molybdenum

Table 18 Instantaneous Concentration [c] of Al ($mg \bullet L^{-1}$), Discharge [Q] ($m^3 \bullet s^{-1}$), and Loading (L) ($g \bullet s^{-1}$) at LR1, CC-IM, and LR2.

DATE	LR1			CC-IM			LR2			Predicted [c] at LR2
	[C]	(Q)	(L)	[C]	(Q)	(L)	[C]	(Q)	(L)	
May 23	0.0610	1.010	0.0616	1.0000	0.120	0.120	0.0550	1.22	0.0671	-0.1607
June 5	0.0540	0.651	0.0035	0.4010	0.113	0.0453	3.1800	-	-	-
July 4	0.0230	0.357	0.0082	NA	0.173	-	0.1060	0.723	0.0766	-
July 31	0.0430	0.137	0.0059	NA	0.077	-	0.3640	0.287	0.1045	-
August 14	0.0430	0.129	0.0055	0.2650	0.064	0.0170	0.1170	0.308	0.0360	-0.1166
August 28	L.0200	0.092	0.0018	0.0430	0.116	0.0050	0.0430	0.204	0.0088	-0.0327
September 11	.1130	0.492	0.0556	NA	0.101	-	0.1590	0.801	0.1273	-
September 25	0.0380	0.295	0.0112	.9100	0.016	0.0146	0.2420	0.521	0.1261	-0.0830

concentration (0.1050 mg•L^{-1}), but maximum concentrations for the study period were recorded at MA-IM (0.1700 mg•L^{-1}). No guidelines have been established for molybdenum in the aquatic environment. Concentrations in the Lovett and Pembina rivers, as well as in impoundments were within the environmental range (<1 mg•L^{-1}) specified by McNeely et al. (1978). CCREM guidelines for irrigation (0.1 mg•L^{-1}) or livestock watering (0.5 mg•L^{-1}) were not exceeded in any of the Lovett or Pembina river samples.

Median manganese concentrations at LR2 (0.027 mg•L^{-1}) were significantly higher than at LR1 (0.016 mg•L^{-1}), and a significant concentration increase was also recorded in the Pembina River between PR1 (<.008 mg•L^{-1}) and PR2 (0.015 mg•L^{-1}) (Table 17). Discharges from CC-IM are the likely reason for increases in Mn concentrations observed between LR1 and LR2. The median concentration of CC-IM (0.054 mg•L^{-1}) was considerably lower than that of samples from MA-IM (0.140 mg•L^{-1}), where concentrations as high as 0.245 mg•L^{-1} were measured. Discharges from MA-IM explain the higher manganese concentrations recorded at LR3. ASWQO specify that manganese concentrations should not exceed 0.05 mg•L^{-1}. Guidelines were not exceeded at LR1, but they were exceeded in two samples from LR2 and LR5 and once at all remaining Lovett River sites. ASWQO were not exceeded at PR1 or PR2.

Median arsenic concentrations increased significantly from LR1 (0.0006 mg•L^{-1}) to LR2 (0.0029 mg•L^{-1}), then declined significantly between LR2 and LR3 (0.0021 mg•L^{-1}) and between LR3 and LR4 (0.0019 mg•L^{-1}). A significant increase in median arsenic concentration was also recorded in the Pembina River between PR1 (0.0006 mg•L^{-1}) and PR2 (0.0012 mg•L^{-1}) downstream of the Lovett River confluence. CC-IM had a median arsenic concentration of 0.0137 mg•L^{-1} and a maximum of 0.0470 mg•L^{-1}. Discharges from this impoundment explain the concentration increase between LR1 and LR2. ASWQO for arsenic (0.01 mg•L^{-1}) were exceeded on September 28 at LR2 (0.0532 mg•L^{-1}) and at LR3 (0.0485 mg•L^{-1}). The value recorded at LR2 was also in excess of the CCREM guidelines (0.05 mg•L^{-1}) for the protection of aquatic life.

Median selenium concentrations were below detection (L.0002 mg•L^{-1}) at all river sites except LR5 which had a concentration of 0.0003 mg•L^{-1}. Selenium levels were remarkably similar in the four impoundments: CC-IM, MA-IM and VAL-IM had a medium concentration of 0.0014 mg•L^{-1}, whereas MB-IM had a concentration of 0.0019 mg•L^{-1}. One exceptionally high concentration of 0.0220 mg•L^{-1} was recorded on August 14 in CC-IM. ASWQO (0.01 mg•L^{-1}) were met in all river samples, but CCREM guidelines for the protection of aquatic life (0.001 mg•L^{-1}) were exceeded on one occasion at LR3.

Median chromium concentrations were below detection (L.0010 mg•L^{-1}) at all sites except LR3 (0.003 mg•L^{-1}), LR5 (0.003 mg•L^{-1}) and PR1 (0.0002 mg•L^{-1}). Inter-site differences were only statistically significant between LR2 and LR3 (Table 17). The measurable chromium concentrations at LR3 and LR5 were related to the discharges from MA-IM and VAL-IM with a median concentration of 0.003 and 0.002 mg•L^{-1}, respectively. ASWQO (0.05 mg•L^{-1}) and CCREM guidelines for the protection of fish (0.02 mg•L^{-1}) were not exceeded in any one river sample. However, CCREM guidelines for the protection of other aquatic life (0.002 mg•L^{-1}) were exceeded frequently at all sites.

Median zinc concentrations in the Lovett and Pembina rivers ranged from 0.004 mg•L^{-1} at LR1, to 0.007 mg•L^{-1} at LR3. All other sites, including PR1 and PR2 had median zinc concentrations of 0.005 mg•L^{-1}. Inter-site differences were statistically significant between LR1 and LR2 only (Table 17). Median zinc concentration in impoundments was comparable to river concentrations except in MA-IM which had a median concentration of 0.057 mg•L^{-1} and where a maximum of 0.167 mg•L^{-1} was recorded. ASWQO (0.05 mg•L^{-1}) and CCREM guidelines (0.030 mg•L^{-1}) for the protection of aquatic life were not exceeded on any sampling occasion in the Lovett River or in the Pembina River.

4.19 CHLOROPHYLL a

The median levels of planktonic chlorophyll 'a' and epilithic chlorophyll 'a' range from 0.5 to 2.3 µg•L^{-1} and from 7.8 to 47.4 mg•m^{-2}, respectively. Concentrations of both variables were higher at LR4 than LR1 (Wilcoxon test P = 0.028 and 0.046 for planktonic and epilithic chlorophyll a, respectively). This suggests an increase in primary productivity probably resulting from the nutrient enrichment of the Lovett River. Biological components of the stream will be addressed in more detail in section 5.0.

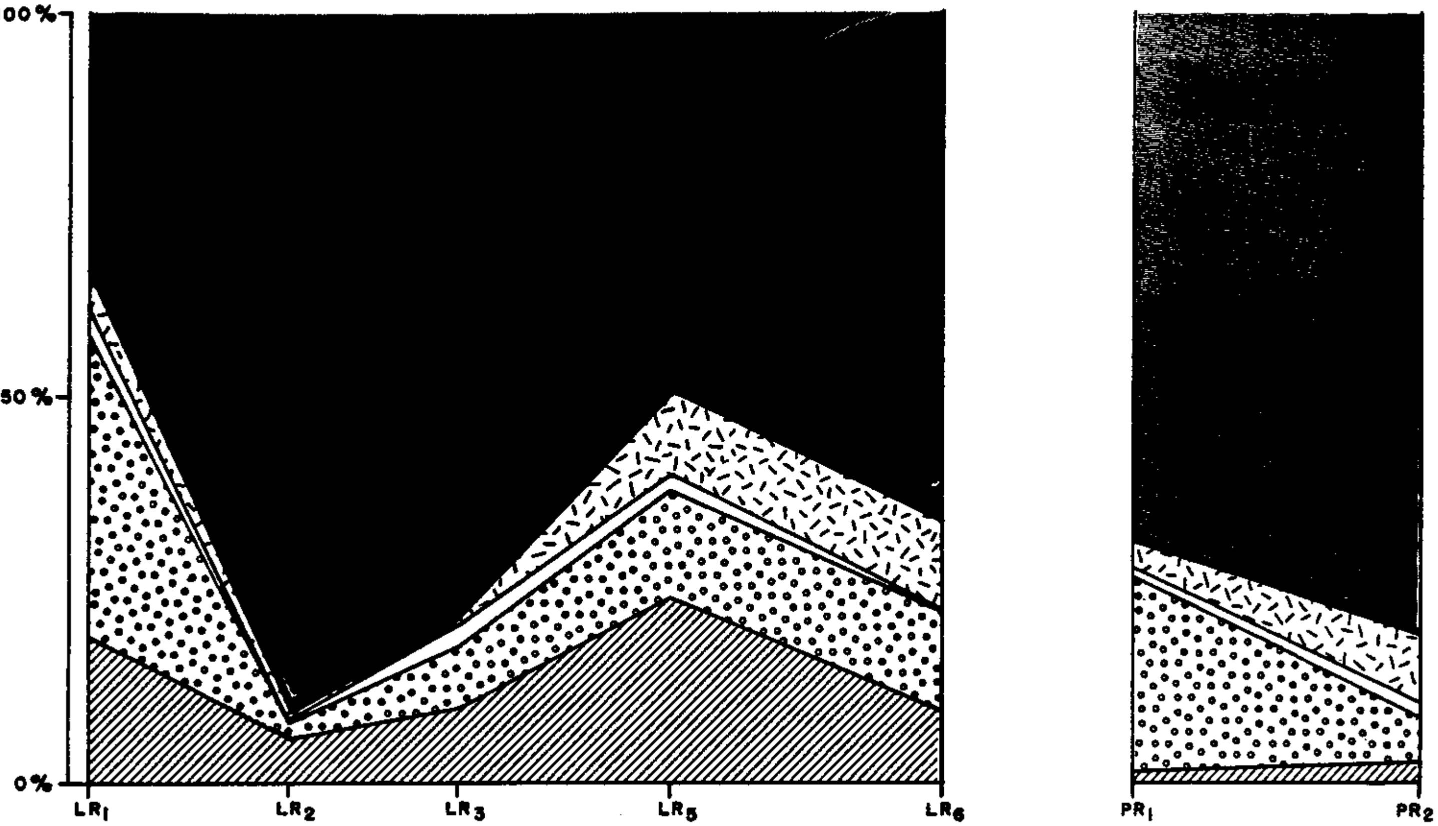
5.0 RESULTS - ZOOBENTHIC VARIABLES

A total of 110 different taxa was identified from the nine sampling locations on the Lovett and Pembina rivers. In the survey of erosional habitats, 74 and 80 taxa were encountered in the spring and fall, respectively. Sixty-four taxa were identified in the Ekman samples taken from depositional areas. Benthic invertebrate data are stored on a SPIRES storage and retrieval system maintained at the University of Alberta, Edmonton.

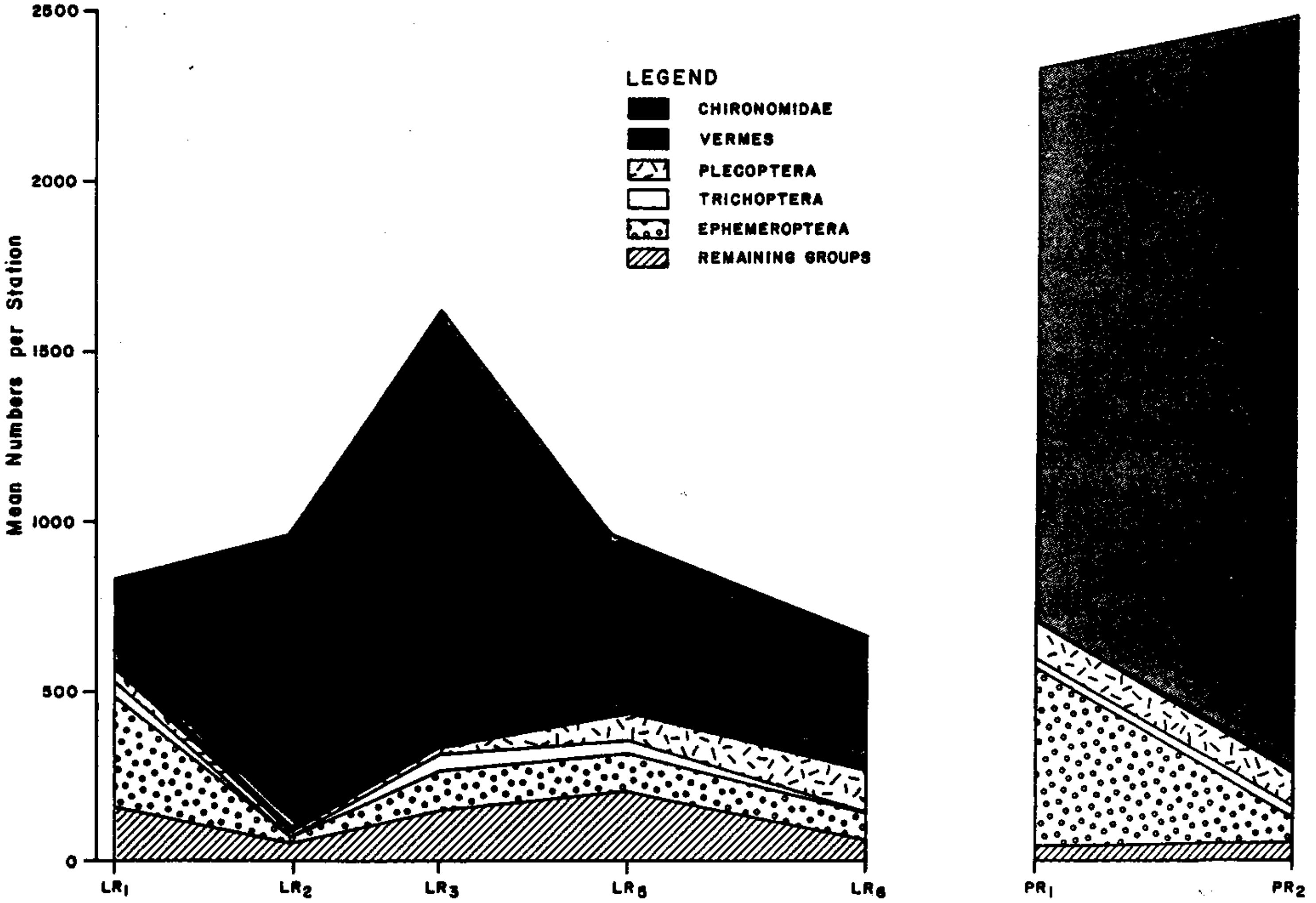
5.1 SPRING SURVEY

5.1.1 Major Zoobenthic Variables

Figures 15 a and b and Table 19 summarize data for major zoobenthic variables. The results of ANOVA and SNK tests are presented in Table 20. Approximately 40% of the benthic invertebrates collected at LR1 are Ephemeroptera (mayflies); Chironomidae (midges) are the second most important group and represent 30% of the total numbers (Figure 15 a). A major change occurs in the invertebrate assemblies at the first mine station (LR2). The number of taxonomic groups is significantly lower at this station than at the other stations (Table 19) and the density of most major taxonomic groups is depressed. Ephemeroptera appear to be particularly affected: they reach the lowest density at LR2 (Table 19) and their contribution to the total invertebrate density is reduced to 2%. Plecoptera (stoneflies) numbers are also significantly lower at LR2. Nematoda (round worms), Oligochaeta (bristle worms), and Chironomidae are the only major groups which show a tendency towards an increase in density at the first mine station (LR2). Chironomidae are



A. Percentage Contribution of Major Taxonomic Groups to Total Numbers



B. Distribution of Numbers between Major Taxonomic Groups

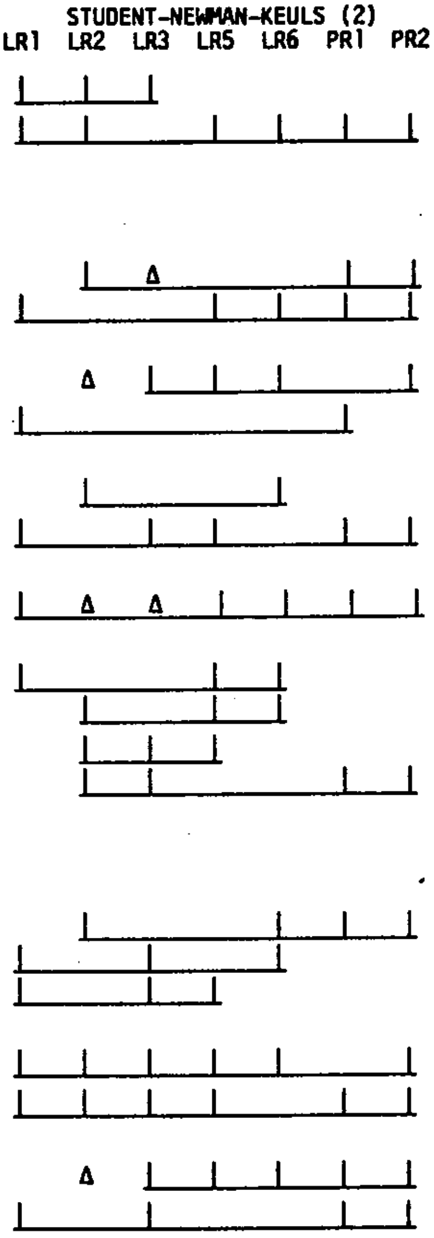
Figure 15 Spring survey

Table 19 Spring survey mean and standard error of major zoobenthic variables, 1984.

	LR1 x ± SE	LR2 x ± SE	LR3 x ± SE	LR5 x ± SE	LR6 x ± SE	PR1 x ± SE	PR2 x ± SE
Nematoda	10.8 ± 2.7	19.6 ± 7.8	36.2 ± 8.0	2.2 ± 0.8	2.8 ± 0.4	2.0 ± 0.7	6.0 ± 1.7
Oligochaeta	3.2 ± 1.1	8.0 ± 4.3	10.6 ± 3.3	8.8 ± 2.9	35.6 ± 33.4	0.4 ± 0.4	2.6 ± 1.9
Crustacea	6.2 ± 1.2	2.2 ± 1.0	26.6 ± 6.1	8.8 ± 1.9	10.4 ± 1.5	4.2 ± 1.5	4.4 ± 1.2
Ephemeroptera	329.6 ± 82.0	14.0 ± 1.5	119.2 ± 28.7	115.2 ± 37.7	81.8 ± 15.4	541.4 ± 86.4	86.2 ± 21.7
Trichoptera	28.8 ± 14.2	0.4 ± 0.4	44.8 ± 11.0	22.8 ± 12.2	2.8 ± 1.6	24.0 ± 10.7	25.2 ± 6.2
Plecoptera	43.8 ± 12.4	4.0 ± 0.7	17.6 ± 5.1	90.0 ± 21.0	122.4 ± 47.9	102.8 ± 15.4	113.2 ± 19.3
Chironomidae	246.4 ± 41.6	858.8 ± 167.1	1235.2 ± 280.1	503.4 ± 170.7	349.8 ± 75.1	1583.6 ± 231.5	2197.8 ± 1301.9
Misc. Diptera	27.6 ± 3.4	24.8 ± 5.2	21.8 ± 3.1	11.8 ± 2.8	11.2 ± 4.1	20.4 ± 4.2	21.6 ± 6.9
Remaining Group	132.4 ± 50.2	26.2 ± 5.9	102.6 ± 19.0	193.0 ± 51.8	41.8 ± 15.0	9.6 ± 1.7	26.0 ± 12.8
Total Numbers	827.8 ± 186.8	958.0 ± 176.7	1614.0 ± 332.4	956.0 ± 196.8	658.6 ± 145.0	2288.4 ± 227.7	2483.0 ± 1334.1
Total No. Taxa	39.4 ± 1.4	23.8 ± 1.2	36.4 ± 2.9	30.0 ± 1.0	29.6 ± 2.7	32.0 ± 1.0	32.4 ± 2.0

TABLE 20 Spring survey: summary of variance (ANOVA) and Student-Newman-Keuls test (SNK) on major zoobenthic variables (1), 1984.

	ANOVA	
	F	SIG(3)
Nematoda	5.59	***
Oligochaeta	2.10	n.s.
Crustacea	8.95	***
Ephemeroptera	18.44	***
Trichoptera	9.27	***
Plecoptera	16.72	***
Chironomidae	6.51	***
Misc. Diptera	2.05	n.s.
Remaining Groups	8.22	***
Total Numbers	3.39	*
Total No. Taxa	6.40	***



(1) all tests were performed on log(x+1) transformed data.

(2) horizontal lines station groups which do not differ significantly in their means (P>0.05)

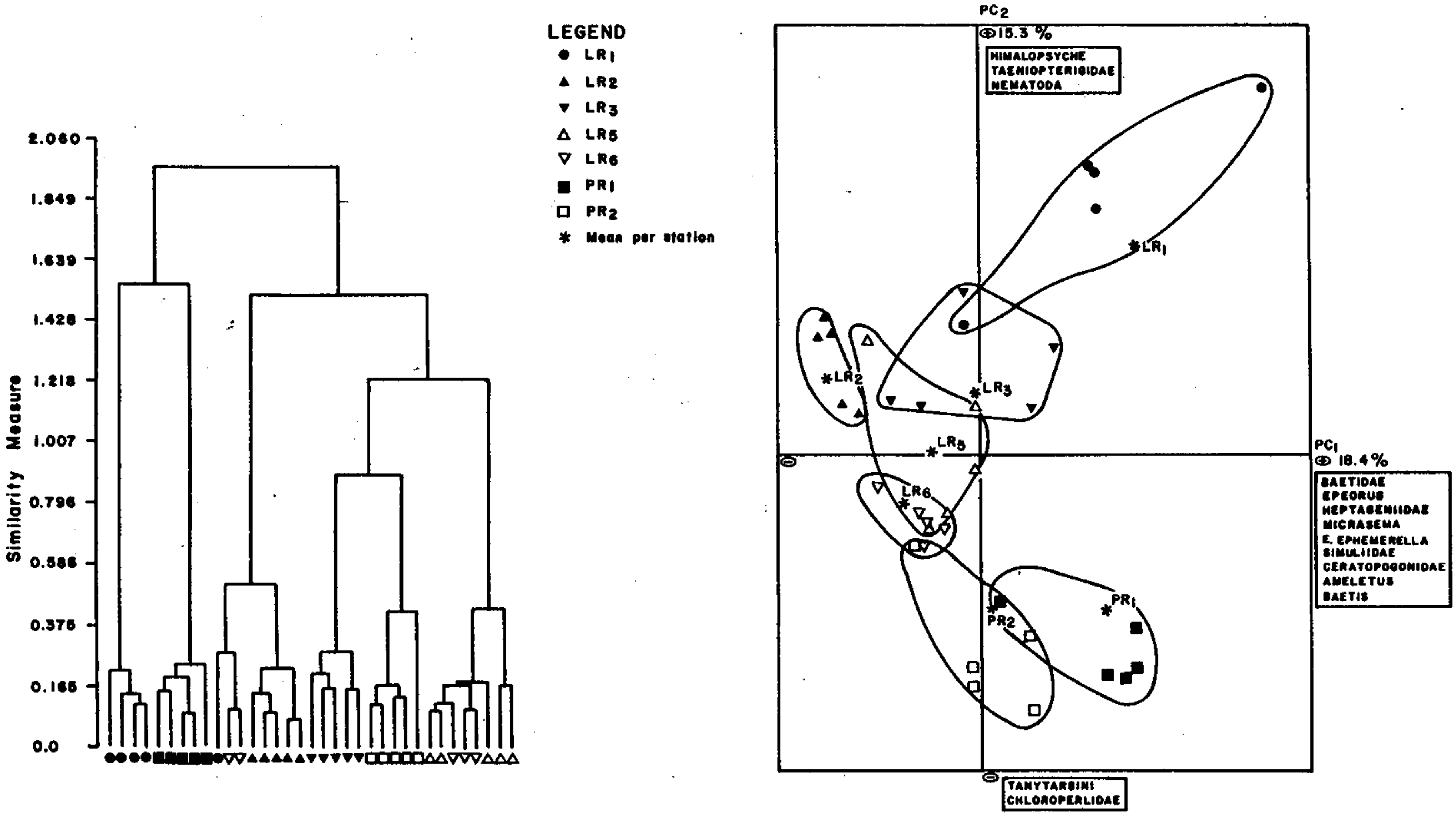
(3) n.s. - no significant difference ** - significant difference P<0.01
* - significant difference P<0.05 *** - significant difference P<0.001

the dominant fauna element at this station: they represent 88% of the total numbers. This taxon remains significantly more abundant at the second mine station (LR3) than at any other Lovett River station. Some recovery can be detected in the Ephemeroptera populations at LR3. In contrast, Plecoptera numbers remain depressed at LR3 but recover at the next station. Despite this apparent recovery of the two most sensitive orders, Chironomidae remain the numerical dominant group and Ephemeroptera never reach densities comparable to those of the control station again. A similar trend can be detected in the Pembina River: PR1, the control station, has more Ephemeroptera, but fewer Chironomidae than PR2, the station below the confluence with the Lovett River (Figure 15).

5.1.2 Cluster Analysis (CA)

Results of CA on spring data are presented in Figure 16 a. Clustering of individual samples occurs at two levels:

1. Intra-station clustering. In general, replicate samples from one station tend to cluster together. This indicates a high degree of similarity between the invertebrate associations in these samples, and suggests a good sample replication. The only exceptions to this pattern are one sample from LR1 and two samples from LR6 which do not cluster with the remaining samples from LR1 and LR6, respectively.
2. Inter-station clustering. Stations tend to form separate clusters. This is an indication of inter-station differences in the invertebrate associations. The clustering pattern between stations suggests that LR1 and PR1 (the control stations on the Lovett and



A. Cluster Analysis

B. Principal Component Analysis

Figure 16 Spring survey : Multivariate analysis

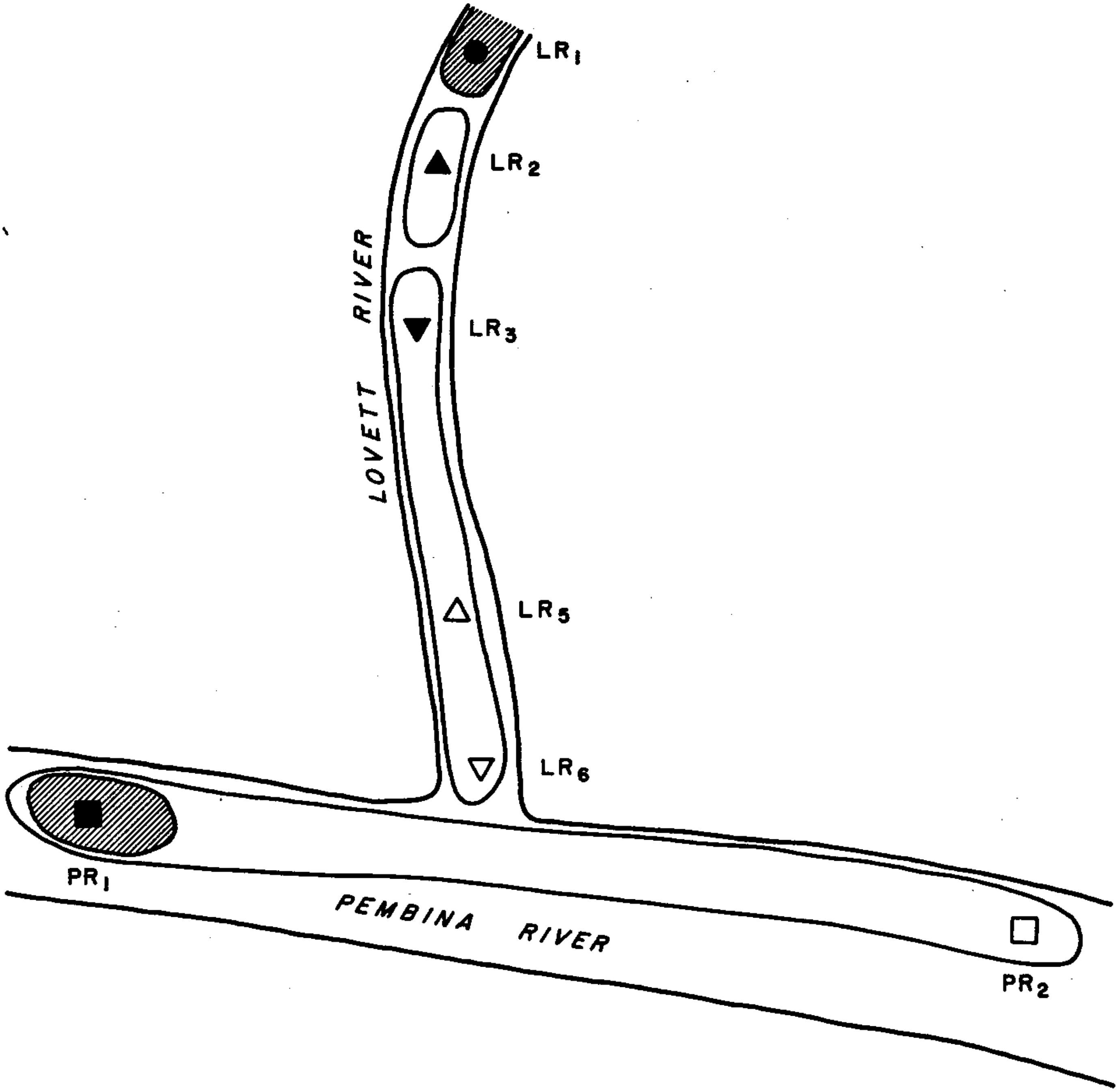


Figure 16C. Spring Survey (Neill Cylinder) .
Schematic presentation of site classification derived from the results of multivariate analyses on benthic invertebrate data .

Pembina Rivers, respectively) are different from the remaining stations. Although this gives the impression of similarity between LR1 and PR1, the fusion level of these two stations verifies the distinction in the invertebrate associations. The remaining stations split into smaller clusters. Station LR2, together with an atypical sample from LR1 and LR6, forms a separate cluster, while station LR3 and PR2 are split from stations LR5 and LR6. Samples from LR5 and LR6 are relatively homogeneous.

5.1.3 Principal Component Analysis (PCA)

The results of PCA performed on zoobenthic data from the spring survey are summarized in Table 21. A two-dimensional projection of the samples ordination on PC1 and PC2 is also presented in Figure 16 b. The results of ANOVA and SNK tests performed on the scores of the eight first principal components are also summarized in Table 21.

Significant inter-station differences exist between the mean scores for the first principal component (PC1) (ANOVA Table 21). The SNK test specifies that these differences exist between three station groups: stations LR1 and PR1 (control stations); station LR2 (the first mine station); and stations LR3, LR5, LR6, and PR2 (stations below the mine stations). These differences are primarily the result of density differences in taxa which have the highest loading on PC1 (Table 21). Station LR1 and PR1 have higher numbers of Baetidae, *Epeorus*, Heptageniidae, *Micrasema*, *Ephemerella (Ephemerella)*, Simuliidae, Ceratopogonidae, *Ameletus*, and *Baetis* while lowest densities for these taxa are recorded at station LR2.

Table 21 Spring survey: summary of principal component analysis (PCA) on zoobenthic data and of analysis of variance (ANOVA) and Student-Newman-Keuls test (SNK) on principal component scores, 1985.

PRINCIPAL COMPONENT	1	2	3	4	5	6	7	8
EIGENVALUES % VARIANCE	10.10 18.36	8.42 15.30	5.50 9.99	4.94 8.99	3.47 6.32	2.56 4.56	2.28 4.15	1.92 3.49
EIGENVECTORS ≥ 0.200	Baetidae 0.268 Epeorus 0.247 Heptageniidae 0.241 Micrasema 0.340 E. Ephemerella 0.219 Simuliidae 0.208 Ceratopogonidae 0.207 Ameletus 0.205 Baetis 0.204	Himalopsyche 0.238 Taeniopterigidae 0.232 Nematoda 0.215 Tanytarsini -0.242 Chloroperlidae -0.265	Tubificidae -0.281 Brachycentrus -0.271 Orthocladiinae 0.258 Diamesinae -0.250 Chelifera -0.245 Tanypodinae -0.235 Enchytraeidae -0.229 Acari -0.222 Rhyacophilidae 0.218	Collembola 0.370 Perlodidae 0.280 Dicranota 0.222 Rhithrogena 0.201 Mermithoidea 0.206 Chironomini -0.222 Hexatoma -0.229	Rhyacophila 0.316 Glossosoma 0.275 Capniidae 0.212 Dicranota -0.210 Elmidae -0.237 Hexatoma -0.242 E. Drunella -0.290 Cinygmula -0.327	Hemerodromia 0.316 Atherix 0.311 Ormosia 0.259 Plecoptera 0.235 Chironomini 0.230 Ceratopogonidae -0.231 Antocha -0.338	Naididae 0.401 Enchytraeidae 0.242 Elmidae 0.225 Clinocera 0.212 Acari 0.203 Hexatoma -0.207 Hesperoconopa 0.217 Leptophlebiidae -0.229 Arctopsyche -0.236 Pteronarcidae 0.289	Dicranota 0.376 Plecoptera 0.310 Clinocera 0.279 Glossosoma 0.227 Atherix -0.290
MEAN FACTOR SCORES AND SUMMARY OF SNK (1)								
STATION LR1	3.715	4.669 ◄	1.361	-0.682	1.185	0.146	0.136	0.450
STATION LR2	-4.336 ◄	1.677	1.112	-2.606	-0.766	-0.631	0.295	0.031
STATION LR3	-0.180	1.498	-3.606 ◄	-0.179	-1.662	0.477	-0.664	1.114
STATION LR5	-1.201	0.078	-0.747	3.699 ◄	0.431	-0.724	0.440	-0.043
STATION LR6	-1.860	-1.100	1.772	2.198 ◄	0.194	1.446	0.218	0.684
STATION PR1	3.653	-3.427	1.716	-0.730	-1.860	-1.071	-0.113	-0.294
STATION PR2	0.208	-3.393	-1.609	-1.700	2.653	0.358	-0.313	0.287
SUMMARY OF ANOVA								
F-ratio (df = 34)	13.39	40.54	9.82	31.12	8.806	1.648	0.287	0.886
F-probability	***	***	***	***	***	n.s.	n.s.	n.s.

(1) horizontal lines join score means which are not significantly different (P>0.05)
*** significant difference between stations (P<0.001)
n.s. no significant difference between stations (P>0.05)

PC2 accounts also for significant differences in the mean scores of stations. Station LR1; station LR2, LR3 and LR5; station LR5 and LR6; and station PR1 and PR2 form four significantly different station groups (SNK). Station LR1, which has the highest mean score, has the highest numbers of Himalopsyche, Taeniopterigidae and Nematoda (taxa with high positive eigenvector values), while stations PR1 and PR2 with the lowest negative scores are typified by higher numbers of Tanytarsini, and Chloroperlidae, which have high negative eigenvector values.

ANOVA shows that the mean scores for PC3 are significantly different among stations, and the SNK test points to differences between station LR3; station LR5, LR6; and stations LR1, LR2, LR5, LR6, PR1. Station LR3 is primarily typified by higher numbers of Tubificidae, but this station also has high densities of Brachycentrus, Orthocladiinae, Diamesinae, Chelifera, Tanypodinae, Enchytraeidae, Acari, and Rhyacophila. High densities of these taxa are less characteristic of other stations.

The first three principal components explain jointly 44% of the sample variance. It is of interest to compare the station grouping obtained by CA with that derived from SNK tests on PC scores. The first PC yields the same station classification as CA for a similarity measure of 1.4 (Figure 16 a) and distinguishes between control stations on the Lovett and Pembina Rivers, the first mine station, and the remaining stations. The second PC separates the two control stations by singling out LR1 and by emphasizing similarities between PR1 and PR2. This separation also occurs in CA. The analogy between the results of CA and PCA is less evident when following PC's are examined. Although PC3, PC4 and PC5 account for significant differences between PC scores, these differences do not appear to be linked in a simple way to longitudinal changes in the Lovett River or the Pembina River. The following PC's (from PC6 on) account for the remaining 48% of the sample variance. This variance relates to differences between samples rather than to differences between stations (e.g. no significant difference is shown by ANOVA in the mean scores per station).

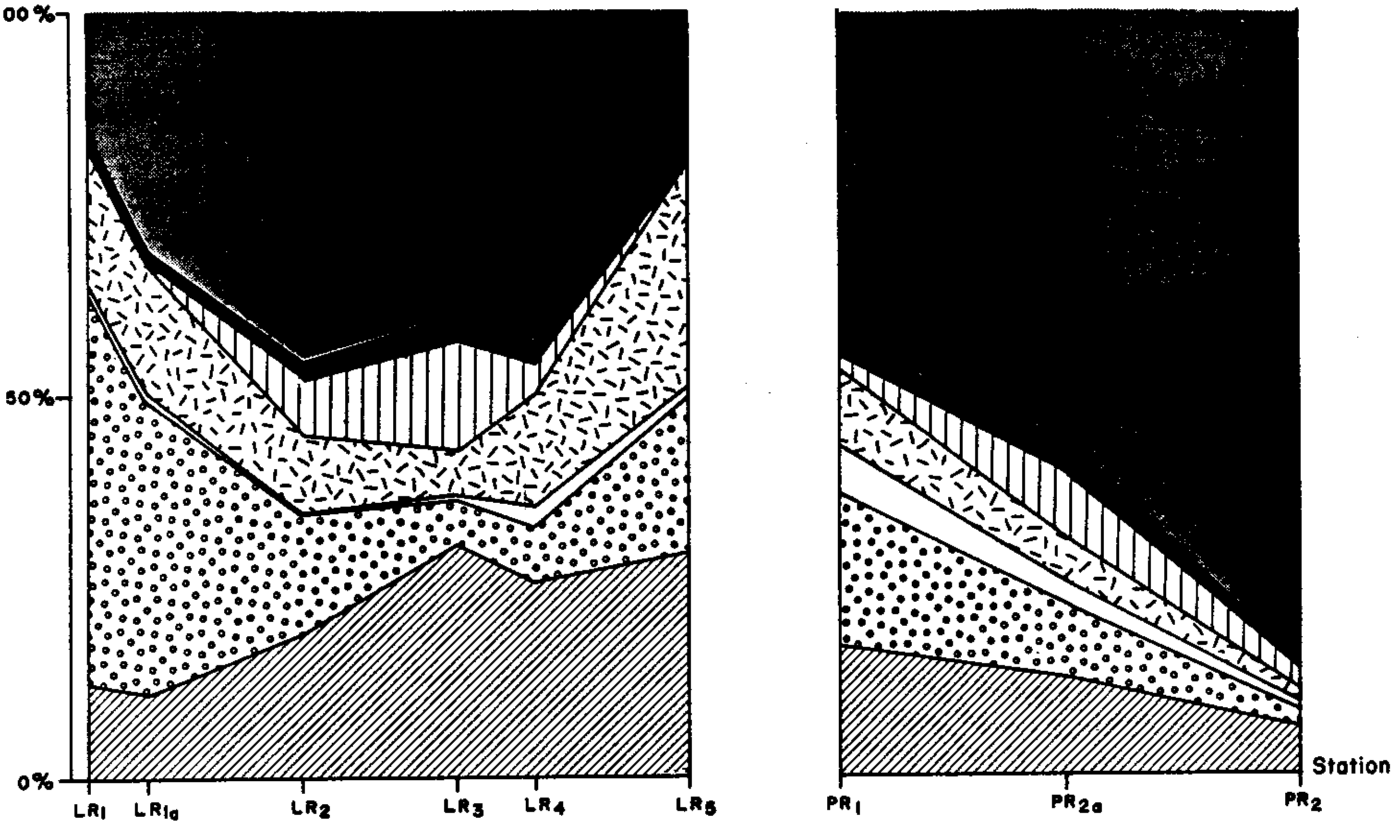
5.1.4 Major Site Classification

The site classification which is derived from the results of multivariate analysis (Figure 16 c) is mostly defined by the result of PCA. Two faunal units are distinguished in the spring survey: the first one typifies the Lovett River, the second one typifies the Pembina River. Further subdivision occurs within each unit. In the Lovett River, three site groups with different benthic invertebrate composition can be differentiated: LR1, LR2 and the 3 remaining sites LR3, LR5 and LR6. In the Pembina River the two sites PR1 and PR2 differ in their zoobenthic composition. The similarity between LR1 and PR1, the control sites on the Lovett and Pembina Rivers, is noteworthy.

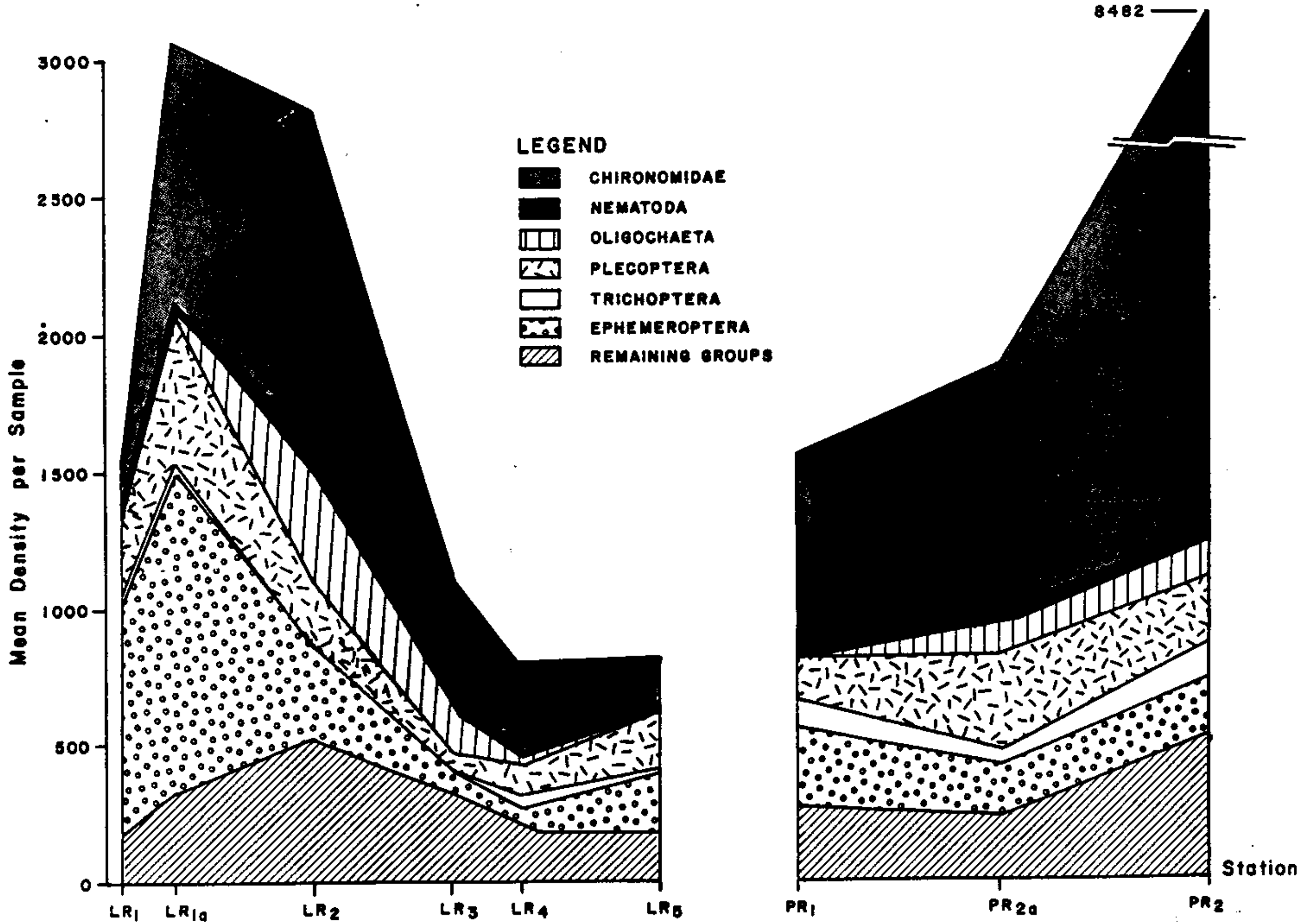
5.2 FALL SURVEYS

5.2.1 Neill Cylinder Samples - Erosional Habitat

An overview of the data pertaining to major taxonomic groups is presented in Figures 17 a and b and Table 22. Table 23 summarizes the results of ANOVA and SNK tests on these data. Total invertebrate density is significantly higher at LR1a (fine gravel substrate) than at LR1



A. Percentage Contribution of Major Taxonomic Groups to Total Numbers



B. Distribution of Numbers between Major Taxonomic Groups

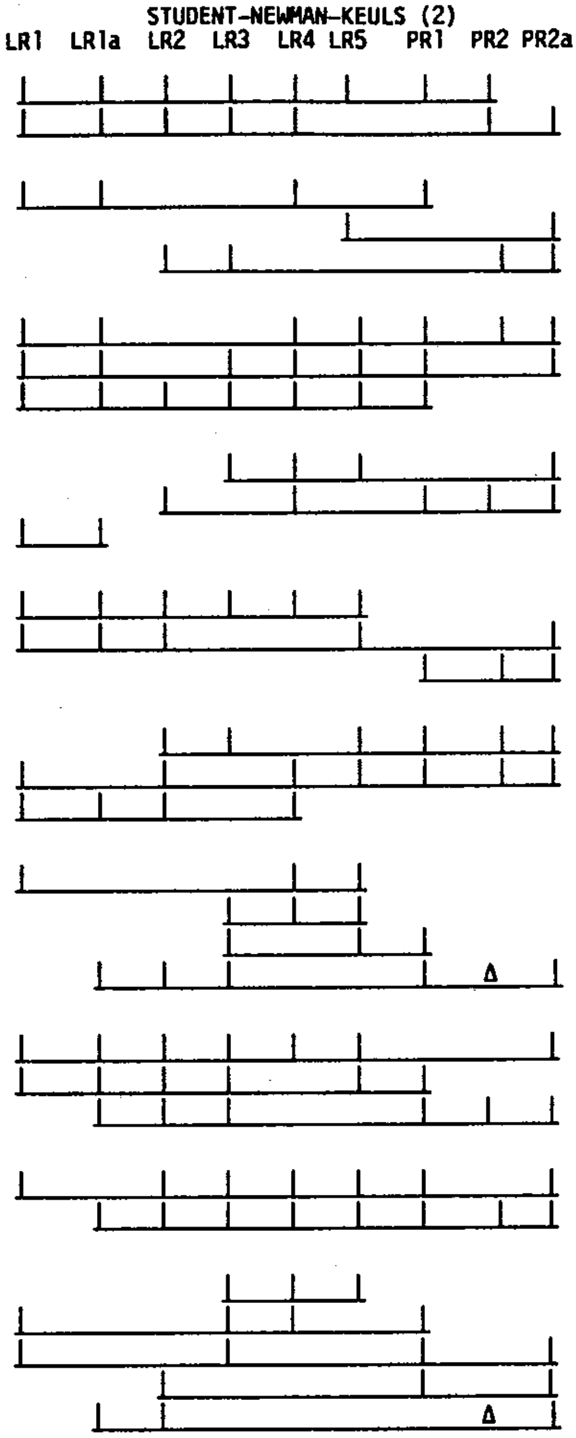
Figure 17 Fall survey (Neill cylinder samples)

Table 22 Fall survey (Neill cylinder samples) mean and standard error of major zoobenthic variables, 1984.

	LR1 x ± SE	LR1a x ± SE	LR2 x ± SE	LR3 x ± SE	LR4 x ± SE	LR5 x ± SE	PR1 x ± SE	PR2a x ± SE	PR2 x ± SE
Nematoda	42.0 ± 19.8	23.6 ± 7.0	64.2 ± 27.5	35.6 ± 7.1	11.2 ± 2.5	18.2 ± 5.4	10.4 ± 1.7	61.0 ± 11.0	29.6 ± 4.8
Oligochaeta	1.0 ± 1.0	2.4 ± 1.6	201.6 ± 86.6	169.0 ± 62.8	30.0 ± 10.2	2.0 ± 0.5	1.2 ± 0.8	110.6 ± 87.7	225.6 ± 67.2
Crustacea	96.2 ± 31.7	73.2 ± 21.9	322.2 ± 204.2	154.4 ± 41.2	53.2 ± 6.2	61.8 ± 5.9	43.4 ± 7.2	29.4 ± 7.2	43.0 ± 16.5
Ephemeroptera	831.6 ± 230.8	1179.2 ± 246.4	342.2 ± 84.4	68.6 ± 15.2	80.6 ± 23.1	164.4 ± 24.5	281.8 ± 27.9	173.4 ± 38.3	215.2 ± 27.0
Trichoptera	15.6 ± 6.8	18.6 ± 4.0	8.4 ± 1.4	8.4 ± 2.6	25.8 ± 11.0	7.4 ± 2.7	105.0 ± 27.0	54.8 ± 20.7	109.0 ± 8.9
Plecoptera	281.0 ± 77.0	556.2 ± 269.0	235.2 ± 53.0	69.6 ± 54.0	112.0 ± 39.0	225.0 ± 144.0	151.0 ± 116.0	97.4 ± 23.0	157.4 ± 131.0
Chironomidae	170.0 ± 51.7	962.0 ± 190.3	1449.6 ± 421.5	429.8 ± 44.6	340.8 ± 101.9	170.8 ± 44.4	741.6 ± 187.1	1146.4 ± 323.0	7715.4 ± 615.7
Misc. Diptera	36.4 ± 9.2	74.4 ± 16.2	47.6 ± 9.1	38.2 ± 4.3	40.4 ± 13.9	26.8 ± 8.1	81.6 ± 16.1	42.4 ± 8.5	125.6 ± 45.0
Remaing Groups	53.2 ± 8.3	179.6 ± 24.9	148.6 ± 9.5	139.8 ± 12.8	110.8 ± 38.9	142.6 ± 33.6	150.0 ± 17.5	174.6 ± 51.1	361.6 ± 102.7
Total Numbers	1528.4 ± 329.2	3074.2 ± 321.3	2819.6 ± 537.0	1113.4 ± 85.6	805.0 ± 189.5	819.0 ± 79.5	1565.2 ± 241.2	1890.0 ± 543.3	8982.4 ± 332.0
Total No. Taxa	33.6 ± 2.3	33.0 ± 1.3	35.8 ± 2.4	33.2 ± 1.6	33.6 ± 1.3	30.8 ± 1.8	35.4 ± 1.0	29.6 ± 1.2	34.0 ± 0.7

TABLE 23 Fall survey (Neill Cylinder Samples) summary of variance (ANOVA) and Student-Newman-Keuls-test (SNK) on major zoobenthic variables (1), 1984.

	ANOVA F	SIG(3)
Nematoda	2.83	*
Oligochaeta	26.44	***
Crustacea	3.03	*
Ephemeroptera	14.37	***
Trichoptera	7.28	***
Plecoptera	5.86	***
Chironomidae	16.43	***
Misc. Diptera	3.71	**
Remaining Groups	3.18	**
Total Numbers	22.36	***
Total No. Taxa	1.55	n.s.



(1) all tests were performed on log(x+1) transformed data.
(2) horizontal lines group stations which do not differ significantly in their means (P>0.05)
(3) n.s. - no significant difference ** - significant difference P<0.01
* - significant difference P<0.05 *** - significant difference P<0.001

(Cobble-pebble-gravel) (Table 23). This difference is primarily due to the significantly higher numbers of Chironomidae larvae at LR1a. Although Ephemeroptera, and Plecoptera also tend to be proportionally better represented on the finer grained substrate, the difference in absolute numbers of these two orders is not significant between the two control stations. Ephemeroptera and Plecoptera, the dominant clean water taxa, represent 50% (LR1a) to 70% (LR1) of the total invertebrate density at the control stations (Figure 17 a). There is a distinct tendency towards a decrease in the percentage contribution of these two orders at the three following stations (LR2, LR3, LR4). At LR3 for example, only 13% of the invertebrates are Ephemeroptera or Plecoptera (Figure 17 a); 39% are Chironomidae and 14% are Oligochaeta (mostly Tubificidae). There is also a tendency towards a decrease in total invertebrate density in a downstream direction (Figure 17 b). Stations LR3, LR4, and LR5 have the lowest total invertebrate density recorded in cylinder samples during the fall survey (Table 23). The percent of Ephemeroptera and Plecoptera also decreases in downstream direction in the Pembina River and coincides with an increase in the percent contribution of Chironomidae. This change in the distribution of numbers between taxa is due to the increase of Chironomidae and Oligochaeta numbers rather than to a decrease in Ephemeroptera or Plecoptera density. It is reflected in the sharp increase in total invertebrate numbers (8982 ± 332 individuals sample $^{-1}$ at PR2 with 7715 ± 616 Chironomidae sample $^{-1}$ (Table 22)).

5.2.2 Cluster Analysis

The results of CA on the fall survey Neill cylinder data are presented in the form of a dendrogram in Figure 18 a.

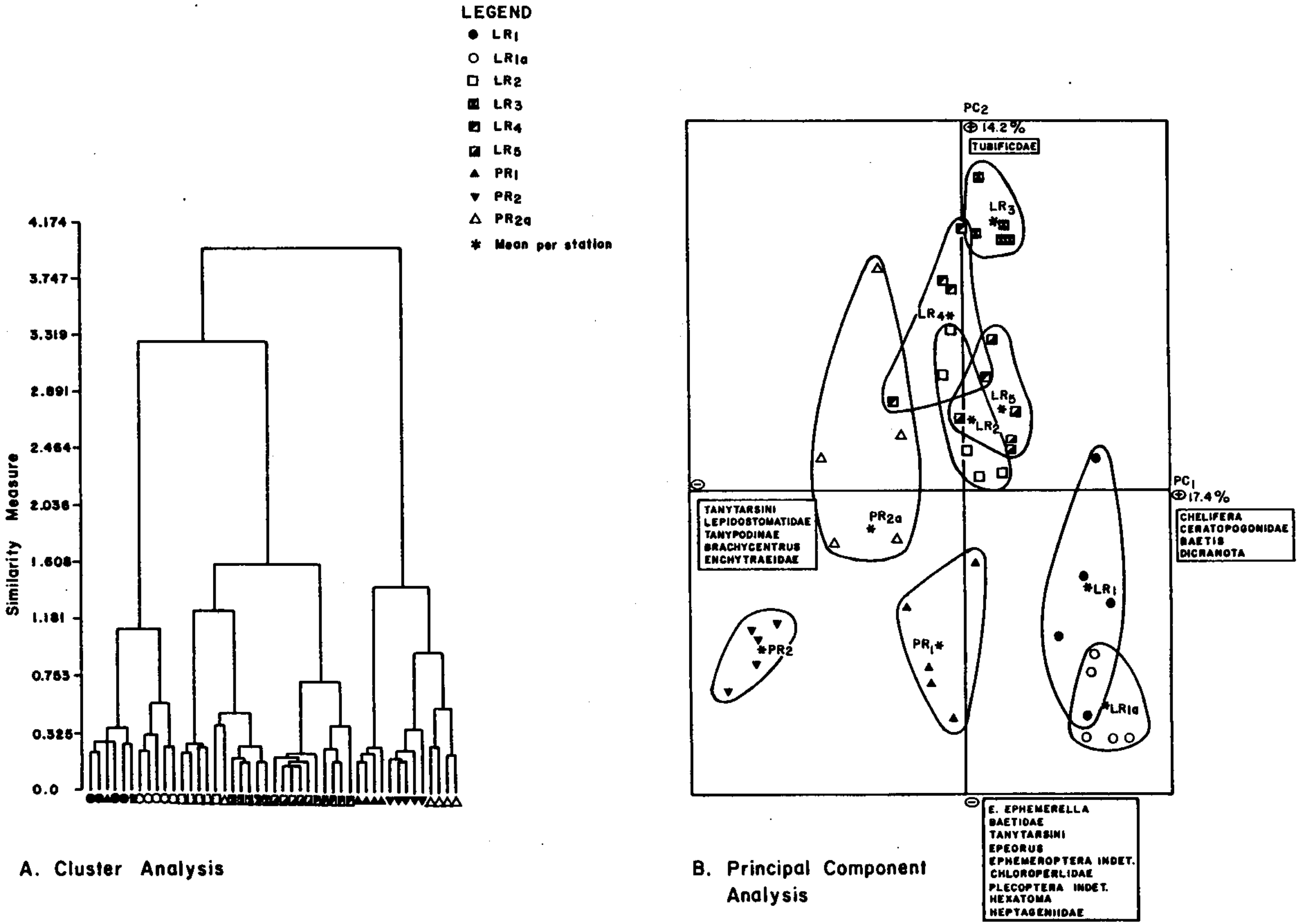
Like the CA in the spring survey, the CA in the fall survey shows a large degree of similarity between replicates of the same station (intra-station similarity), and sharp dissimilarities between samples from different stations (inter-station dissimilarity). There are two exceptions: one sample from station PR1 and one sample from PR2a, which do not cluster with the other replicates from their respective stations.

CA divides the 45 samples into two major groups. The first cluster contains samples from the Pembina River and splits further into one group which contains samples from the control station and another group which contains samples from the two stations below the confluence with the Lovett River (PR2a and PR2). There is a further distinction between the samples of these two stations.

The second cluster contains all Lovett River samples. The first split in this large sample group occurs between samples from the two control stations and samples from the remaining stations. The five replicates from each control station form two distinct units. The remaining four stations on the Lovett River separate into one group which contains the two mine stations (LR2 and LR3) and another group which contains the two stations below the mine (LR4 and LR5). Samples from each of these four stations form separate groups.

5.2.3 Principal Component Analysis

The results of PCA on fall cylinder samples are summarized in Table 24. The results of the ANOVA and SNK tests on factor scores are also given in the Table. Figure 18b represents the projection of



A. Cluster Analysis

B. Principal Component Analysis

Figure 18 Fall survey (Neill cylinder samples) : Multivariate analysis

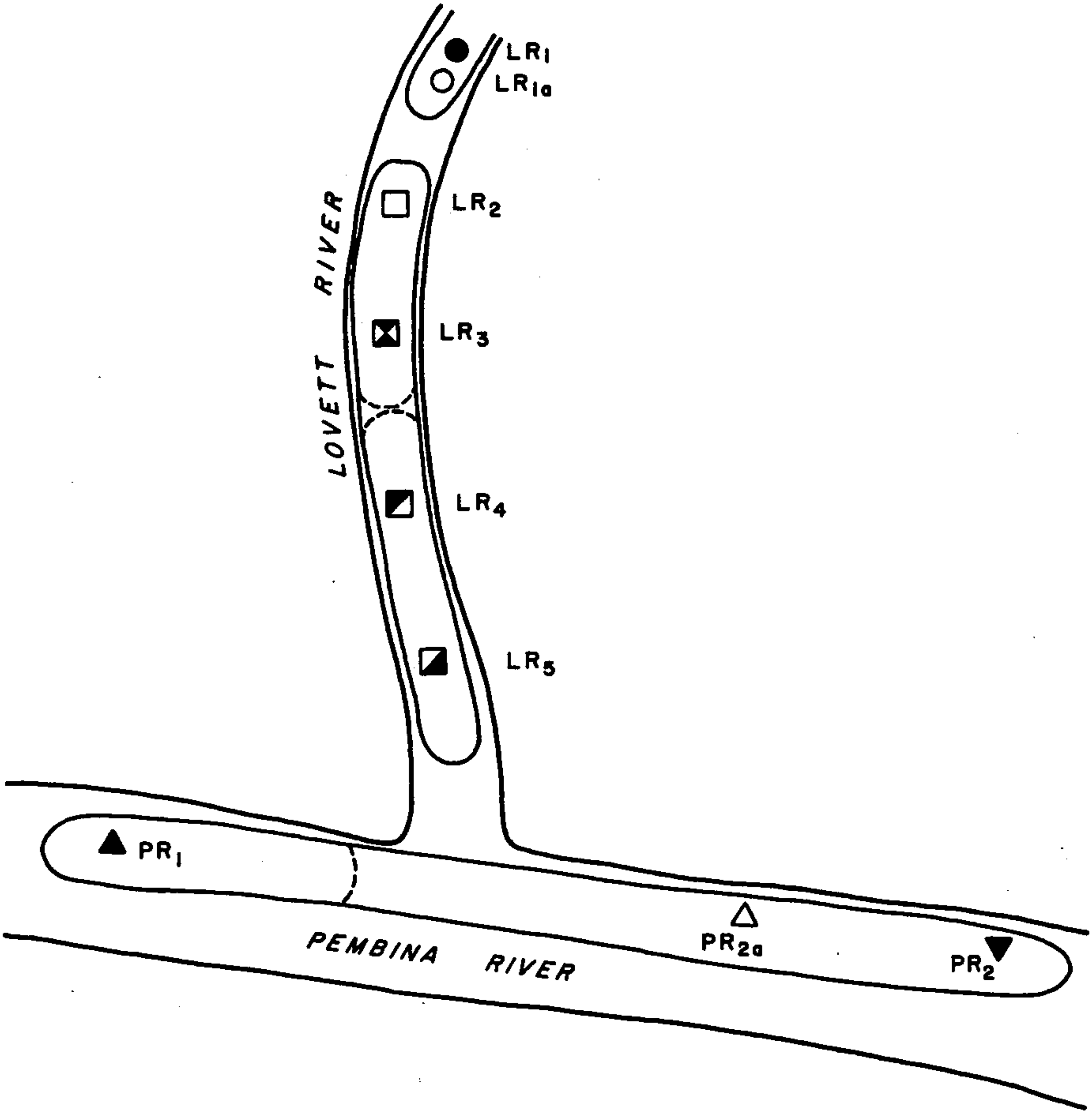


Figure 18 C. Fall Survey (Neill Cylinder) .
Schematic presentation of site classification derived from the results of multivariate analyses on benthic invertebrate data .

Table 24 Fall survey (Neill cylinder samples): summary of principal component analysis (PCA) on zoobenthic data and of analysis of variance (ANOVA) and Student-Newman-Keuls (SNK) test on principal component scores, 1984.

PRINCIPAL COMPONENT	1	2	3	4	5	6	7	8
EIGENVALUES	8.87	7.22	5.09	3.97	2.78	2.70	2.44	1.97
% VARIANCE	17.39	14.16	9.99	7.79	5.46	5.28	4.79	3.86
EIGENVECTORS ≥ 0.200	Chelifera 0.257 Ceratopogonidae 0.233 Baetis 0.209 Dicranota 0.206 Tanytarsini -0.200 Lepidostomatidae -0.240 Tanypodinae -0.241 Brachycentrus -0.244 Enchytraeidae -0.264	Tubificidae 0.261 E. Ephemerella -0.203 Baetidae -0.205 Tanytarsini -0.206 Epeorus -0.226 Ephemeroptera 0.233 Chloroperlidae -0.250 Plecoptera -0.257 Hexatoma -0.272 Heptageniidae -0.287	Arctopsyche 0.250 Rhithrogena 0.218 Tubificidae -0.240 Chironomini -0.270 Orthocladiinae -0.270 Paraleptophlebia 0.302 Tipula -0.334	Nemouridae 0.411 Perlidae 0.293 Diamesinae 0.272 Perlodidae 0.257 Hydroptila 0.244 Glossosoma 0.223 Rhithrogena 0.220 Hydropsyche 0.203	Chloroperlidae 0.254 Perlodidae 0.223 Antocha -0.202 Brachycentrus -0.217 Dicranota -0.265 Glossosoma -0.355 E. Drunella -0.401	Nematoda 0.321 Hesperoconopa 0.302 Elmidae 0.250 Baetis 0.243 Simuliidae -0.231 Rhithrogena -0.286 Leptophlebiidae -0.307	Mermithoidea 0.324 Pericoma 0.310 Himalopsyche 0.306 Hydropsyche 0.223 Hesperoconopa -0.202 Acari -0.205 Capniidae -0.229 Wiedemannia -0.379	Hydropsyche 0.331 Siphlonuridae 0.276 Epeorus 0.232 Diamesinae 0.212 Baetidae 0.200 Antocha -0.259
MEAN FACTOR SCORES AND SUMMARY OF SNK (1)								
STATION LR1	3.555	-1.686	1.699	-1.002	0.333	-2.140	0.712	0.580
STATION LR1a	3.993	-3.419	-1.659	-0.897	0.618	1.998	0.333	0.196
STATION LR2	0.199	1.110	-3.790 ◄	2.718	-0.456	-0.690	0.483	-0.138
STATION LR3	0.961	4.234 ◄	-0.625	-0.545	-0.964	0.643	-1.308	-1.049
STATION LR4	-0.395	2.780 ◄	2.243	0.745	0.413	1.397	1.087	0.319
STATION LR5	1.062	1.251	1.627	0.531	1.962	-0.225	-0.799	0.594
STATION PR1	-0.680	-2.466	1.693	0.631	-3.192 ◄	-0.267	-1.247	-0.101
STATION PR2a	-2.714 ◄	0.678	-1.660	-1.850	-0.087	-0.904	0.621	-0.709
STATION PR2	-5.981 ◄	-2.482	0.470	-0.332	1.373	0.184	0.119	0.309
SUMMARY OF ANOVA								
F-ratio (df = 29)	92.93	31.86	14.00	3.1	11.78	4.91	1.88	0.78
F-probability	***	***	***	***	***	***	n.s.	n.s.

(1) horizontal lines join score means which are not significantly different (P>0.05)
*** significant difference between stations (P<0.001)
n.s. no significant difference between stations (P>0.05)

stations in a two-dimensional space defined by PC1 and PC2. PC1 identifies differences between the two control stations on the Lovett River and the other stations. It also points to differences between the Lovett River stations and the Pembina River Stations, but the separation is not well defined (Table 24). Inter-station differences are the result of density differences between stations for the taxa listed for PC1 in Table 24. The control stations on the Lovett River are typified by higher numbers of Chelifera, Ceratopogonidae, Baetis, and Dicranota, while the PR2 and PR2a Pembina River stations are characterized by Enchytraeidae, Brachycentrus, Tanypodinae, Lepidostomatidae and Tanytarsini. The remaining stations contain varying, usually low, numbers of these taxa.

PC2 makes a sharp separation between the control stations on the Lovett River, the stations on the Pembina River and the remaining stations. The PC scores of the latter stations are strongly influenced by the density of tubificid worms, while higher densities of Heptageniidae, Epeorus, immature Ephemeroptera and Plecoptera, Chloroperlidae, Hexatoma, and Tanytarsini are generally more typical of the Lovett River control stations and Pembina River stations.

PC3 has two features of interest: 1. it separates station LR2 from other stations, primarily because of higher densities of Paraleptophlebia, Tipula, Orthocladiinae, and Chironomini; 2. it points to differences between the two control stations (LR1 has a denser population of Arctopsyche than LR1a, but LR1a has higher numbers of Paraleptophlebia, Orthocladiinae and Chironomini).

The first three PC's explain approximately 42% of the sample variance. Although PC4 and PC6 account for an additional 18% of the sample variance and although their mean PC scores show statistically significant differences between stations, they do not appear to yield ecologically interpretable information which could aid in explaining inter-station differences.

5.2.4 Major Site Classification

The overall results of CA and PCA are similar and lead to the site classification shown in Figure 18c. As in spring, invertebrate associations in the Pembina River are different from those in the Lovett River. The two control sites, in the Lovett River, form one site group which is distinct from other Lovett River sites in its zoobenthos composition. Although the four remaining Lovett River sites have rather similar zoobenthic associations they split further into two groups. LR2 and LR3 which are located immediately below point source discharges from the Luscar-Coal Valley Mine have a different invertebrate composition form LR4 and LR5, the sites farthest downstream. In the Pembina River, the control site PR1 differs from the two sites below the confluence with the Lovett River. These two sites (PR2a and PR2b) have some features in common with the Lovett River sites within and below the mine (LR2 to LR6).

5.3 EKMAN SAMPLES - DEPOSITIONAL HABITAT

5.3.1 Major Zoobenthic Variables

Data pertaining to major taxonomic groups are presented in Figures 19 a and b and Table 25. The results of ANOVA and SNK tests are

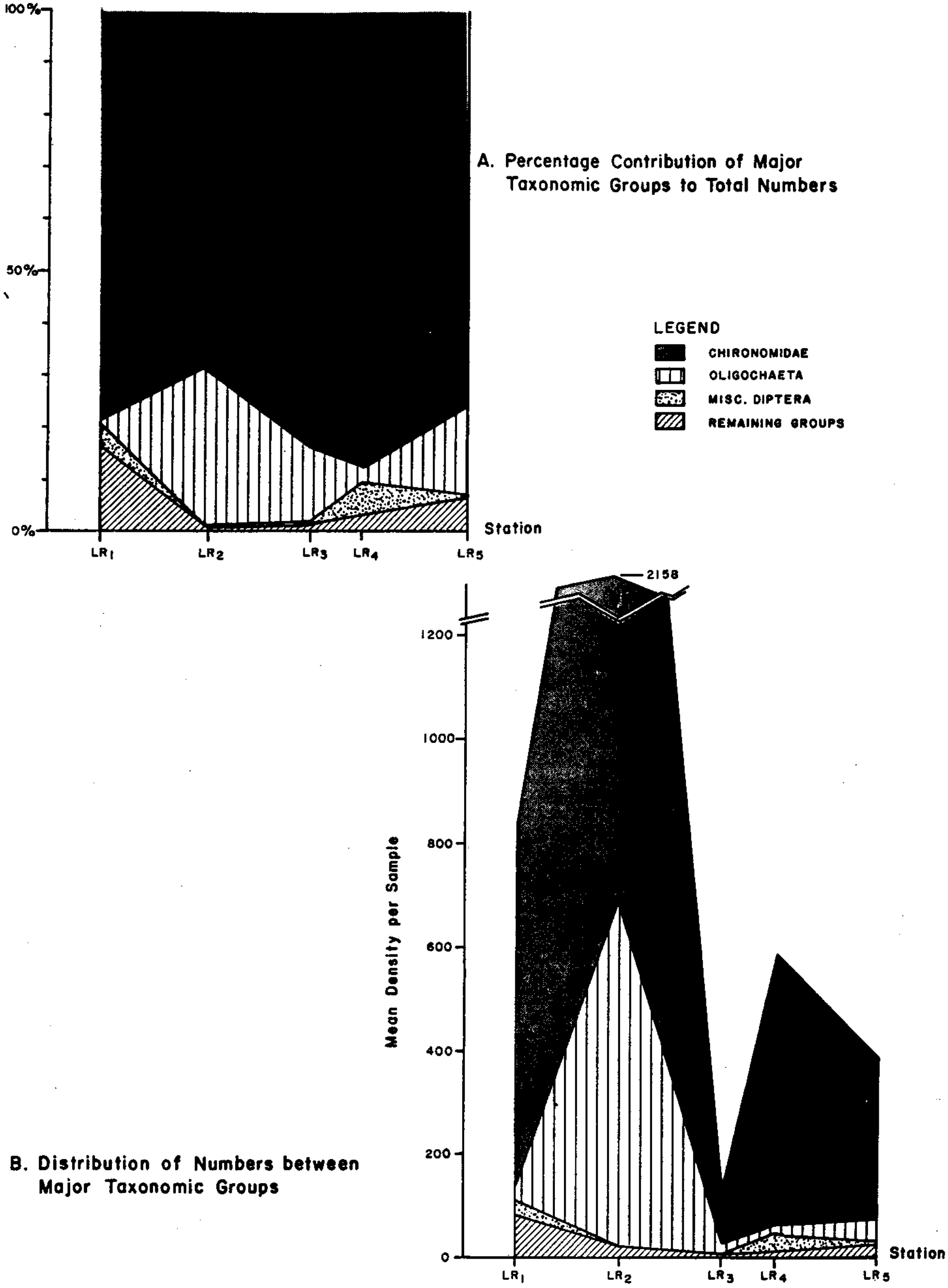


Figure 19 Fall survey (Ekman samples)

Table 25 Fall survey (Ekman samples): mean and standard error of major zoobenthic variables, 1984.

	LR1 x ± SE	LR2 x ± SE	LR3 x ± SE	LR4 x ± SE	LR5 x ± SE
Nematoda	6.8 ± 2.1	0.7 ± 0.7	0.2 ± 0.2	0.2 ± 0.2	0.5 ± 0.3
Oligochaeta	6.8 ± 3.9	668.5 ± 169.9	21.2 ± 5.5	20.7 ± 8.6	58.7 ± 20.9
Ephemeroptera	1.5 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0
Plecoptera	0.8 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Trichoptera	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0
Chironomidae	771.0 ± 226.8	1469.0 ± 452.4	111.8 ± 27.3	522.8 ± 265.9	301.3 ± 117.5
Misc. Diptera	33.7 ± 8.3	1.3 ± 0.7	0.7 ± 0.3	23.8 ± 8.3	3.3 ± 1.3
Crustacea	75.8 ± 15.4	14.8 ± 4.6	1.5 ± 0.6	11.7 ± 5.9	13.8 ± 5.0
Remaing Groups	3.0 ± 0.7	3.7 ± 2.7	0.3 ± 0.2	5.0 ± 1.5	11.5 ± 3.7
Total Numbers	839. ± 242.7	2158. ± 552.9	135.7 ± 23.4	584.3 ± 278.9	389.3 ± 108.9
Total No. Taxa	21.0 ± 1.7	16.3 ± 1.1	10.2 ± 1.2	21.3 ± 1.6	14.2 ± 2.0
Tubificidae	0.2 ± 0.2	667.2 ± 170.0	21.0 ± 5.3	13.5 ± 3.0	57.8 ± 21.0
Chironomus	0.0 ± 0.0	25.5 ± 21.2	0.0 ± 0.0	0.5 ± 0.5	10.5 ± 3.2
Chironomini	85.8 ± 32.6	316.7 ± 150.0	85.0 ± 23.5	74.5 ± 34.1	158.0 ± 65.5
Tanytarsini	468.3 ± 142.9	627.3 ± 181.7	2.7 ± 1.9	56.3 ± 27.8	62.3 ± 49.8
Orthocladiinae	229.9 ± 71.2	781.9 ± 204.8	90.1 ± 23.4	378.3 ± 180.0	212.3 ± 65.2
Tanypodinae	3.3 ± 3.0	6.5 ± 3.1	0.0 ± 0.0	1.0 ± 1.0	2.7 ± 2.7
Prodiamesinae	9.5 ± 3.5	53.3 ± 6.73	18.7 ± 5.0	86.7 ± 24.8	24.0 ± 6.2
Diamesinae	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2	0.5 ± 0.3	0.0 ± 0.0

summarized in Table 26. Total invertebrate numbers fluctuate greatly from station to station. These fluctuations are primarily due to density changes in the Chironomidae larvae and Oligochaeta worms. Chironomidae larvae are the numerical dominant in all Ekman samples (Table 25). Although the density fluctuation is large (Figure 19b), their percent contribution to total numbers changes relatively little between stations (maximum 88% at LR4, minimum 68% at LR2). The most noticeable change in the percent composition is due to fluctuations in numbers of Oligochaeta. Oligochaeta represent less than 1% of the invertebrates at LR1; 31% at LR2, and an average of 11% at the three stations further downstream. Although numbers of Oligochaeta are not significantly different between stations LR1, LR3, LR4, and LR5 (Table 26); there is a tendency towards an increase in their numbers in a downstream direction. This tendency is attributable to members of the family Tubificidae (Table 25). Miscellaneous Diptera (i.e. non-chironomid Diptera, primarily Tipulidae) also account for differences between stations: these larvae are more numerous at LR1 and LR4 but they are virtually absent from the other three stations (Table 25 and Table 26). Crustacea (i.e. Ostracoda, Copepoda, and Cladocera), Ephemeroptera, and Plecoptera are significantly more abundant at LR1 (Table 26). However, it should be noted that the densities of Ephemeroptera and Plecoptera are extremely low in Ekman samples (Table 25) and that an ecological interpretation of these differences would have limited validity.

5.3.2 Cluster Analysis

The dendrogram summarizing the results of CA on invertebrate

TABLE 26 Fall survey (Ekman samples) summary of analysis of variance (ANOVA) and Student-Newman-Keuls-test (SNK) on major zoobenthic variables (1), 1984.

	ANOVA		STUDENT-NEWMAN-KEULS (2)				
	F	SIG(3)	LR1	LR2	LR3	LR4	LR5
Nematoda	10.85	***	Δ	|	|	|	|
Oligochaeta	14.23	***	|		|	|	
				Δ	|	|	|
Crustacea	9.36	***			|	|	|
			Δ	|		|	|
Ephemeroptera	10.57	***	Δ	|	|	|	|
Plecoptera	8.72	***	Δ	|	|	|	|
Trichoptera	1.00	n.s.					
Chironomidae	5.31	**			|	|	|
			|			|	|
			|	|		|	
Misc. Diptera	24.56	***		|	|		|
			|			|	
Remaining Groups	5.46	**	|	|	|		
			|	|		|	|
Total Numbers	11.39	***	|	Δ	Δ	|	|
Total No. Taxa	9.51	***		|	Δ		|
			|	|		|	

(1) all tests were performed on log(x+1) transformed data.

(2) horizontal lines group stations which do not differ significantly in their means (P>0.05)

(3) n.s. - no significant difference ** - significant difference P<0.01
* - significant difference P<0.05 *** - significant difference P<0.001

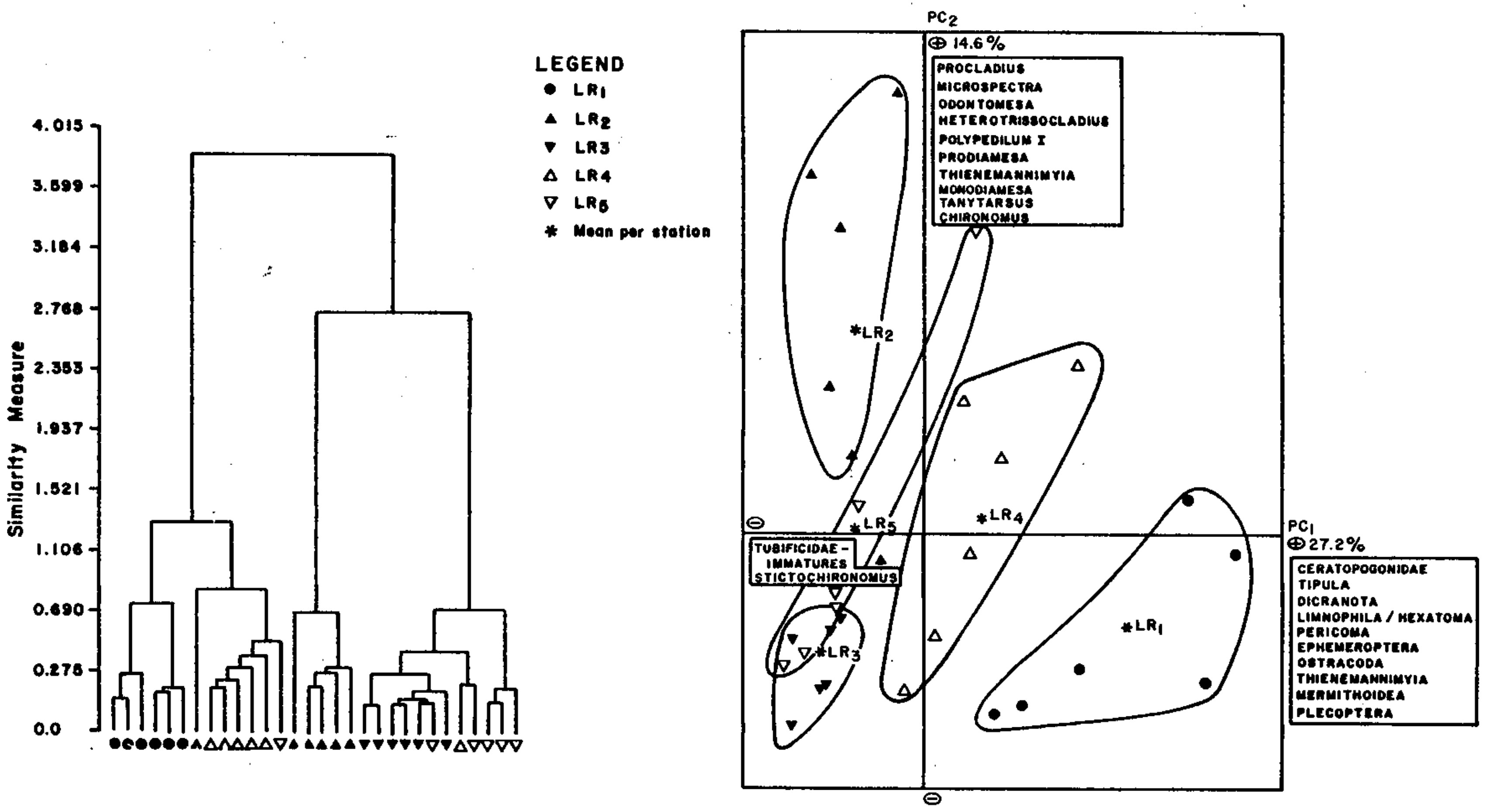
data from the Ekman samples is presented in Figure 20.

In most cases replicate samples from individual stations cluster together; this reflects a relatively high level of intra-station similarity. Inter-station dissimilarity is also evident. Two clusters are formed. The first one groups station LR1 samples and all except one LR4 sample. This cluster also contains one LR2 and one LR5 sample. LR1 and LR4 form distinct clusters. The second cluster splits in two sub-clusters: one sub-cluster isolates LR2 samples, the other groups LR3 and LR5 samples without actually separating the two stations.

5.3.3 Principal Component Analysis

A summary of the results of PCA is given in Table 27. The results of ANOVA and SNK tests on PC scores are also highlighted in this table. A two-dimensional projection defined by PC1 and PC2 of the samples and mean station scores is shown in Figure 20b.

The first three PC's explain 53% of the sample variance. PC1 shows that there are common traits between LR1 and LR4. Both stations have high numbers of tipulid larvae (i.e. *Tipula*, *Dicranota*, *Hexatoma*/*Limnophila*) and Ceratopogonidae larvae. However, these two stations remain significantly different from each other, primarily because PR1 has some Ephemeroptera, Plecoptera, Mermithoidea, and fairly high numbers of *Pericoma*, which LR4 lacks. Instead, LR4 has Tubificidae and *Stictochironomus*. The later two taxa are also typical of LR2, LR3, and LR5. This feature suggests a degree of similarity between LR4 and these stations.



A. Cluster Analysis

B. Principal Component Analysis

Figure 20 Fall survey (Ekman samples) : Multivariate analysis

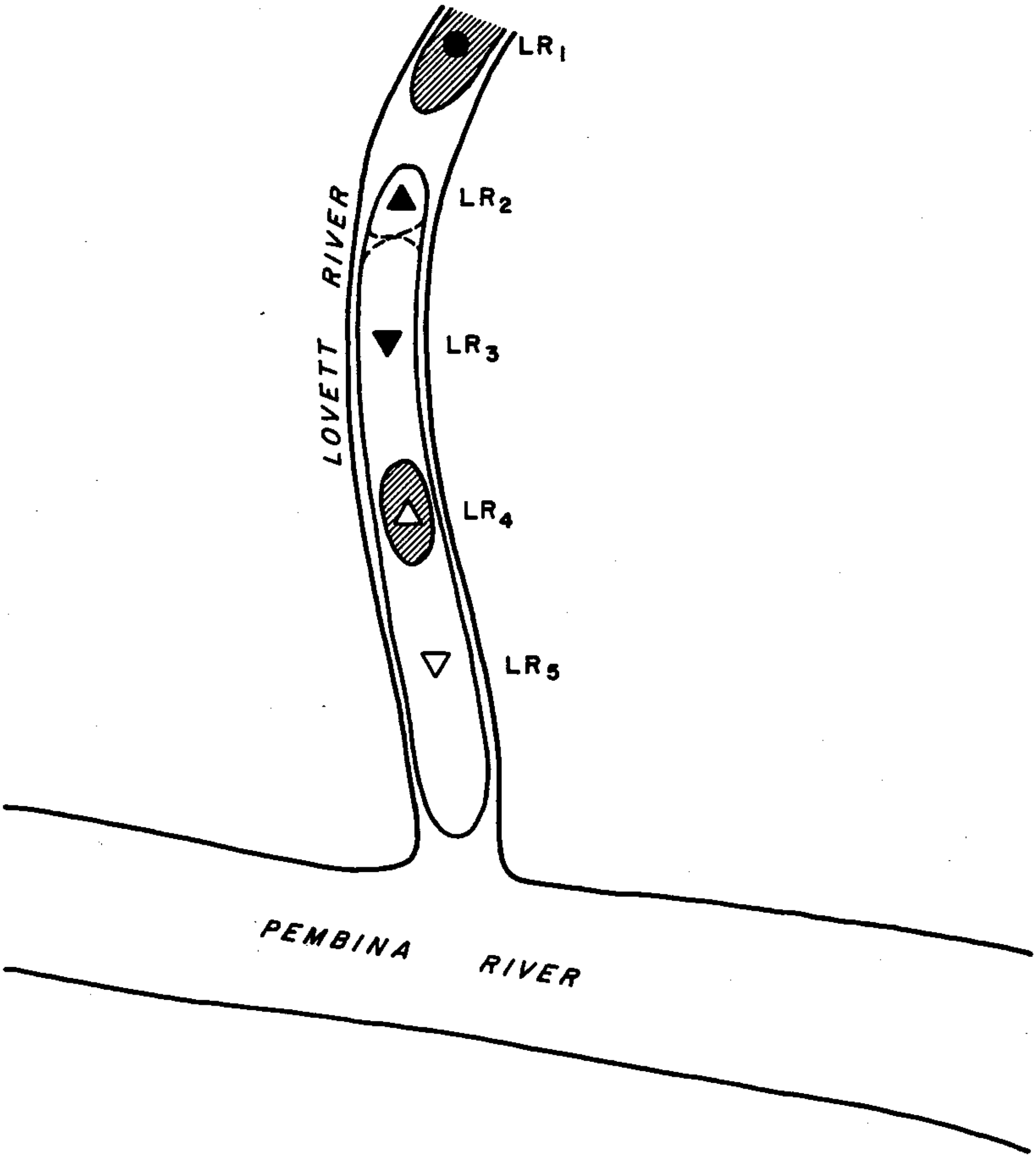


Figure 20C. Fall Survey (Ekman Samples). Schematic presentation of site classification derived from the results of multivariate analyses on benthic invertebrate data.

Table 27 Fall survey (Ekman Samples): summary of principal component analysis (PCA) on zoobenthic data and of analysis of variance (ANOVA) and Student-Newman-Keuls test (SNK) on principal component scores, 1984.

PRINCIPAL COMPONENT	1	2	3	4	5	6	7	8
EIGENVALUES	10.06	5.40	3.98	2.63	2.10	1.81	1.69	1.30
% VARIANCE	27.20	14.60	10.76	7.12	5.69	4.88	4.57	3.52
EIGENVECTORS ≥ 0.200	Ceratopogonidae 0.273 Tipula 0.260 Dicranota 0.257 Limnophila/ Hexatoma 0.250 Pericoma 0.243 Ephemeroptera 0.241 Ostracoda 0.223 Thienemannimyia 0.209 Hermithoidea 0.209 Plecoptera 0.204 Tubificidae immature -0.220 Stictochironomus -0.226	Procladius 0.336 Microspectra 0.304 Odontomesa 0.304 Heterotrissocladius 0.294 Polypedilum I 0.288 Prodiamesa 0.255 Thienemannimyia 0.242 Monodiamesa 0.232 Tanytarsus 0.223 Chironomus 0.226	Naididae 0.328 Monodiamesa 0.312 Ormosia 0.301 Cladotanytarsus 0.260 Chelifera 0.245 Parakiefferiella 0.240 Pisidium 0.232 Chrysops 0.220 Pericoma -0.242	Thienemannimyia 0.328 Polypedilum II 0.280 Paralauterborniella 0.385 Plecoptera 0.211 Stictochiromus -0.204 Enchytraeidae -0.299	Polypedilum I 0.304 Clinocera 0.294 Polypedilum II 0.261 Chironomus 0.251 Ormosia 0.247 Tubificidae 0.237 Nematoda -0.220 Ostracoda -0.247 Pisidium -0.484	Clinocera 0.404 Tubificidae 0.293 Parakiefferiella 0.247 Tubificidae immatures Polypedilum II 0.216 Tanytarsus 0.208 Enchytraeidae 0.203 Chelifera -0.283 Paracladopelma -0.325	Cladotanytarsus 0.483 Chelifera 0.287 Limnophila/ Hexatoma 0.206 Ephemeroptera -0.238 Ormosia -0.322 Chrysops -0.509	Clinocera 0.326 Pisidium 0.304 Acari 0.280 Chrysops 0.269 Plecoptera 0.234 Enchytraeidae -0.220 Nematoda -0.246 Parakiefferiella -0.260 Odontomesa -0.308
MEAN FACTOR SCORES AND SUMMARY OF SNK (1)								
STATION LR1	4.863 ◄	-1.342	-1.895	0.145	-0.301	-0.024	-0.212	-0.017
STATION LR2	-1.742	2.910 ◄	-1.288	1.030	0.328	0.684	-0.297	-0.645
STATION LR3	-2.625	-1.721	-0.140	0.489	0.608	-1.060	0.264	-0.197
STATION LR4	1.325 ◄	0.228	3.105 ◄	-0.013	0.819	0.440	0.505	-0.049
STATION LR5	-1.821	-0.074	0.220	-0.673	-1.454	-0.041	-0.260	0.810
SUMMARY OF ANOVA								
F-ratio (df = 29)	24.18	6.48	21.79	1.01	3.07	1.61	0.43	1.34
F-probability	***	***	***	n.s.	***	n.s.	n.s.	n.s.

(1) horizontal lines join score means which are not significantly different (P>0.05)
*** significant difference between stations (P<0.001)
* significant difference between stations (P<0.05)
n.s. no significant difference between stations (P>0.05)

PC2 singles LR2 out for its greater overall density of Chironomidae larvae (i.e. genera such as Procladius, Microspectra, Odontomesa, Heterotrissocladius, Polypedilum, Prodiamesa, Thienemannimyia, Monodiamesa, Tanytarsus, and Chironomus) but does not differentiate other stations from one another.

The third PC singles station LR4 out which is the only station where moderate numbers of the tipulid Ormosia are found, and which also carries larger populations of Monodiamesa, Parakiefferiella, Cladotanytarsus, and naidid oligochaetes.

The factor scores of PC4, PC6, PC7,and PC8 do not account for inter-station differences. Both CA and PCA identify similarities but also dissimilarities between LR1 and LR4. LR2 is separated from the remaining stations.

5.3.4 Major Site Classification

Figure 20c shows the site classification which is derived from multivariate analysis on invertebrate data from depositional areas. Ekman samples fall into two major groups with different zoobenthic associations: the control site and the sites located within and below the mine. The latter group is not homogenous: the invertebrate fauna at LR4 resembles that of the control site LR1, and the zoobenthos of LR2 is different from that of all other Lovett River sites.

6.0 DISCUSSION

6.1 WATER QUALITY

The increased sediment load to surface waters is one of the chief water quality concerns in coal mining areas in the western portion of North America (e.g. Ward et al. 1978, MacDonald & McDonald 1987). Measures of sediment inputs such as NFR, turbidity and estimates of suspended solids loadings can be used to quantify the relative contributions from various sources and to assess the efficiency of settling ponds (e.g. McDonald 1982).

Despite the use of polymer flocculants in an extensive suspended solids control program practiced by Luscar Coal Valley Mine in its impoundments, levels of suspended solids, NFR, turbidity and sediment loads were often elevated in the river below impoundment discharge, especially below CC-IM. However, increases in sediment loads were sometimes well in excess of loads predicted from background and impoundment inputs suggesting that non-point sources of anthropogenic (e.g. erosion from road crossing, disturbance of overburden) or natural origin (e.g. riverbank slumping) may contribute to the loads. High turbidity in the Lovett River and in the impoundments was associated with heavy rain storms suggesting that runoff and increased river flow are important vectors of sediment transport.

The differences between instantaneous measurements of turbidity and NFR at the background site (LR1) and at the downstream site (LR5) exceeded ASWQO mainly during peak discharge events which followed heavy rain storms. NFR data from time- integrated composite samples exceeded the ASWQO considerably more frequently than NFR from instantaneous samples. This illustrates the episodic nature of sediment flux in disturbed, foothills watersheds and emphasizes the importance of a comprehensive sampling design.

Suspended sediments at the mouth of the Lovett River contained considerably more clay than similar foothill streams with undisturbed watersheds. The high proportion of very fine particles in the Lovett River could reflect the selective retention of larger size fractions in the impoundments.

Mining activity in a watershed alters not only normal patterns of sediment transport, but can also result in measurable changes in surface water chemistry.

According to McWhorter et al. (1975), soluble salts are the most significant potential pollutant of streams from strip mines. Indeed, the discharges from the Luscar Coal Valley impoundments to the Lovett River caused an increase in major ion concentration (particularly sodium and sulphate) which resulted in a shift in ion dominance. The increase in ionic concentration was associated with a significant increase in TDS. Ward et al. (1978) also observed an increase in TDS in Trout Creek (upper Colorado River basin) which receives groundwater and surface runoff from a strip coal mine. They attributed the increase in TDS to the leaching of soluble salts from surfaces recently exposed by mining. There are no ASWQO for major ions because their concentration varies considerably in surface waters. The changes observed in the Lovett River are within the range expected for surface waters.

In the western part of North America coal seams contain primarily coal with a low sulfur content and surface waters generally have a high buffering capacity. Consequently, acid mine drainage is less likely to become the problem it represents in eastern parts of the continent. Actually, pH increases rather than decreases were recorded in the Lovett and Pembina rivers and these were related to the discharge of alkaline water from the impoundments.

IEC Beak (1985) reported that raw wastewater from western coal mines are characterized by low concentrations of metals although iron concentrations are often high in southwestern Alberta mines.

This was confirmed in this study for the Lovett River area. Regular exceedances of the ASWQO or CCREM guidelines were recorded at all sites for Fe and Al, only. Although metal levels were usually moderate, Al, Mo, Mn, As, Zn, Cr and Se showed significant concentration increases downstream of impoundments.

Discharges from the impoundments have been shown to increase the concentration of nitrogen fractions in the Lovett River considerably. Mine discharges commonly contain high concentrations of nitrogen which are a result of disturbance (weathering of fragmented rock and ammonium nitrate residue from explosives Plass 1975; Jackson 1983). On a study in the Grande Cache region, Hackbarth (1981) found that virtually all the nitrate in streams affected by mining activity was from blasting materials. The concentrations in the streams ranged from 10 to 100 mg $N \bullet L^{-1}$ during seven years of monitoring.

In 1979-80, the British Columbia Ministry of Environment studied the effects of using explosives in the Fording Coal mine (southeast British Columbia) on the water quality of the Fording River. The study revealed that approximately 95% of the nitrogen discharged from the mine was derived from explosives (Pommen 1983). The author reported that the nitrogen discharge from the mine was mainly nitrate with relatively small amounts of ammonia and nitrite. The nitrate concentrations in the river increased from less than 0.1 mg•L^{-1} above the minesite to as high as 10 mg•L^{-1} within the minesite during low flow. Furthermore, it was found that nitrogen discharged from the mine in surface water was equivalent to 6% of the nitrogen used in the explosives. The other 94% of the nitrogen was released to the atmosphere as nitrogenous gases.

As part of the same study, Nagpal (1982) found the spoil piles were highly permeable. The permeability was conducive to high nitrogen leaching rates. He estimated that the impact of spoil nitrogen, due to explosives, on the Fording River water quality would be short-lived following the cessation of mining.

Nitrogen and phosphorus are plant nutrients which control algal growth in surface waters. Phosphorus at very low concentrations tends to limit plant growth even if nitrogen concentrations are high. However, at higher phosphorus levels, algal growth may become a problem. An illustration of this phenomenon is given by McDonald (1984) for Elk River (British Columbia). Elk River receives nitrogen-enriched effluent from surface coal mines and phosphorus-rich wastewater from municipalities. Downstream of the town of Fernie where both nitrogen and phosphorus are plentiful, algal growth reaches nuisance levels.

McDonald believes that nitrate from surface coal mining operations produced a much stronger phosphorus limitation downstream and increased the potential maximum level of algal growth. The algal growth in the lower Lovett River did not reach the nuisance levels reported in the British Columbian stream. However, considering that nitrogen enrichment already occurs in the Lovett River it is probable that any further phosphorus enrichment would result in enhanced algal biomass production.

6.2 ZOOBENTHOS

The environmental effects of coal mining activity on aquatic biota have long been a serious source of concern in the eastern part of North America (e.g. Lackey 1939, Parsons 1968, Warner 1971). Acidification of stream water due to strip mining activity is the chief cause of distress to the aquatic biota. Some benthic invertebrate taxa are very intolerant of acidification, whereas other taxa have a wider tolerance range. Despite this inter-specific variability, a reduction in total density and a reduction in species diversity are commonly reported phenomena at the community level (e.g. Roback and Richardson 1969, Dills and Rogers 1974, Scullion and Edwards 1980).

The effects of coal mining activity on aquatic biota have received less attention in the western part of the continent. Part of the reason for this is that the combination of low sulfur content in western coal seams and higher buffering capacity of receiving waters are less likely to result in acidification. Ward et al. (1978) concluded that increases in salinity, sedimentation, and water depletion are the major problems related to coal mining activity in the West. The authors observed that invertebrate population density increased below a coal mine station in Trout Creek, a Colorado stream, although the invertebrate community structure was not altered notably. They attributed this invertebrate response to the moderate increase in soluble salts. Coal mine drainage can also result in the production of ferric hydroxide, which can form a yellow-orange precipitate on the stream bed (e.g. Wentz, 1974). Benthic invertebrates are usually greatly reduced in numbers in areas where this precipitate forms (e.g. Radford and Graveland 1978, Scullion and Edwards 1980). Increases in suspended solid loads and in sedimentation, can definitely result in the disruption of invertebrate communities. The principal ways in which the fauna of streams and rivers may be affected by suspended solids are described in Hynes (1960) and illustrated in a review paper by Chutter (1969). The reduction of light penetration may inhibit the growth of primary producers and result in the decline in invertebrate food resources. The deposition of inert solids (silt) may smother attached algae, clog interstices between stones, and cover the substrate of erosional habitats. The result is not only a reduction in food availability but also the obliteration of habitat for many aquatic invertebrates. Taxa typical of erosional habitats (such as Ephemeroptera, Plecoptera, Trichoptera) are most affected and tend to be replaced by taxa which are more typical of depositional areas (such as Tubificidae, Chironomidae) (e.g. Nuttall 1972, Cordone and Kelly 1961).

The effect of suspended solids on aquatic biota occasionally deviates from the expected pattern. Hamilton (1961) found that the high turbidity produced by finely divided inorganic matter did not adversely affect the bottom fauna in a shallow, lotic environment, nor did it seem to inhibit primary producers as abundant growth of filamentous algae was observed. Bergstrom and Jablonski (1977) have also reported the growth of filamentous algae in Luscar Creek, below the settling ponds of the Cardinal-Luscar mine. Mosses can also be very tolerant of high suspended solid loads. Lewis (1973 a, b) determined that Eurhynchium riparioides is capable of living below the discharge of coal washery effluents. This moss survived in levels of suspended coal dust as high as 5000 $mg \bullet l^{-1}$ even though the percentage germination of the spores was reduced by 42% at this concentration.

The examples cited above indicate that in some instances the suspended solids in the water phase are less detrimental to benthic life forms than the sediment that settles to the bottom. Because sedimentation is likely to be greater in depositional areas than in erosional areas where it is reduced by swift currents, it is probable that benthic invertebrates exhibit different responses in each habitat. In an extreme situation, benthic invertebrates could appear to be unaffected in erosional areas whereas they could be impacted in depositional areas. In order to obtain an unbiased overall assessment of water quality conditions, as experienced by benthic invertebrates, it is desirable to examine the community of both types of habitats.

Benthic invertebrate communities exhibit some degree of tolerance to environmental disturbances. However, even relatively mild environmental disturbances may induce measurable changes at one or more levels. The number of organisms of certain taxa may decrease (sensitive taxa) or increase (tolerant taxa); the total invertebrate density or the number of individual taxa may change; the proportion of numbers between taxa may be altered.

Cluster analysis consistently separates control stations on the Lovett River from stations below the mine, and also consistently distinguishes LR2 (the first mine station) from the remaining stations at or below the mine. On the Pembina River, the control station is always separated from stations below the confluence with the Lovett River. This clustering pattern identifies the existence of different invertebrate associations upstream and downstream of the mine.

An apparent deviation from this typical clustering pattern in the survey on depositional areas (Ekman samples) needs to be clarified. The clustering of samples from LR4 with LR1 is considered to be an aberration in the data set. The similarity between these two stations is primarily attributable to the presence of various Tipulidae; these larvae are absent from all other samples collected in depositional areas. The distribution of tipulid larvae in these samples is not thought to be related to an improvement of the water quality but rather is an artifact caused by the specific sampling location. Ekman samples were collected in an area where the river has steep, unstable banks. Ormosia, which only occurs at station LR4, is one example among several of tipulids with semi-aquatic habitats (e.g. Johannsen 1934, Merritt and Cummins 1978, McAlpine et al. 1981). The presence of these larvae, which tend to live in moist soil, could be indicative of the fact that bank erosion had influenced the fauna at LR4.

The appraisal of major zoobenthic variables show that the decrease in the proportion and number of Ephemeroptera and Plecoptera in favour of an increase in the proportion and number of Chironomidae and Oligochaeta is a feature common to both seasonal surveys of erosional habitats. In depositional areas, an increase in the proportion and numbers of Chironomidae and Oligochaeta was also observed. The decline of clean water taxa in favour of tolerant taxa is commonly regarded as a typical benthic invertebrate response to the deterioration of environmental conditions (e.g. Gaufin 1957, Hynes 1960, 1965).

The appraisal of detailed taxonomic data (PCA) confirms the importance of individual Ephemeroptera, Plecoptera, Chironomidae, and Oligochaeta taxa in the comparison of control stations and stressed stations. In addition, a number of taxa which do not belong to these major groups, but which exhibit sharp density differences between stations, are also important.

Longitudinal changes in the benthic invertebrate associations are indicative of a deterioration of environmental conditions in the lower reaches of the Lovett River. However, the benthic invertebrate response appears to be complex and suggests the possibility of more than one cause of environmental stress.

Tubificid worms are of particular significance in this study. In fall, Tubificidae are virtually absent from the control stations, but they appear suddenly and in considerable numbers at the first mine station (LR2) in samples taken from riffles (Neill cylinder) and depositional areas (Ekman samples). They are encountered in nearly every sample collected further downstream in the Lovett River and also downstream in the Pembina River. Although this distribution pattern is only pronounced in the fall surveys, when tubificid density is high, it is also discernable in the spring survey notwithstanding the low tubificid population densities. Tubificid worms are common in unpolluted habitats, but the presence of Tubifex tubifex, which was identified in Ekman samples, has frequently been associated with organic enrichment (e.g. Goodnight and Whitley 1960, Brinkhurst 1965, 1966, 1972, Aston 1973).

Because Tubificidae are detritivorous, bacteria are an important constituent of their diet (Brinkhurst and Chua 1969, Wavre and Brinkhurst 1971, Brinkhurst _et al_. 1972). McMurty _et al_. (1983) determined that the microbial constituents were more important than either organic contents or particle size in determining substrate selection by tubificid worms. Bergstrom and Jablonski (1977) reported extensive algal and bacterial growths in Luscar Creek below the settling ponds of the Cardinal River coal mine. Although such phenomena were not observed below the impoundments of the Luscar-Coal Valley mine in the Lovett River, it is possible that bacterial growth was enhanced as a result of the increased nutrient concentration (see section 4.3). The occurrence of tubificid worms at station LR2 could be related to a mild enrichment of the Lovett River and could be encouraged by the settling of fine particulate sediments.

The occurrence of two chironomid genera, _Chironomus_ and _Stictochironomus_, suggests a similar explanation. These members of the tribe Chironomini are generally regarded as tolerant of eutrophication in lakes (Brinkhurst 1974, Saether 1975, 1979, 1980). However, enrichment is not necessarily the only explanation for the occurrence of these three taxa below the first mine effluent, a point which will be discussed at more length below.

The information provided by other benthic taxa suggests that enrichment is not the only cause of stress in the Lovett River. In a case of mild enrichment alone, one would not expect a decline of

Ephemeroptera, and Plecoptera as seen in the spring and fall surveys of erosional habitats, nor would one expect total invertebrate numbers to decrease below background levels (fall surveys) or to remain virtually unchanged (spring survey). These observations raise the suspicion of the existence of inhibitory effects in the Lovett River.

An appraisal of the results of physical and chemical water quality (Section 4.0) suggests that sedimentation is the most likely cause of benthic invertebrate inhibition in the Lovett River. Sedimentation of suspended sediment (non-filterable residue) is one of the main results of coal mining activity in Western North America (Ward _et al_. 1978). Coal fines can represent a large fraction of the suspended sediments transported by rivers and the sedimentation of these particles can cover the bottom with a black layer (e.g. Bergstrom and Jablonski 1977). In the Lovett River, where the presence of coal fines was not apparent, the suspended sediment load originating from soil perturbation due to mining operations increased significantly downstream of the Luscar Coal Valley mine (see section 4.1.5).

Siltation can be a very dynamic process in mountain or foothill streams. For example, Bergstrom and Jablonski (1977) described how extensive deposition beds of coal fines, below the Cardinal River Coal settling pond, were washed out by sudden increases in river discharge resulting from storm events. In the Lovett River, benthic invertebrate samples contained considerable amounts of fine sediment. It was evident that this fine sediment filled gaps between rocks, but at the time of sampling, silt deposition on top of the substrate was not excessive.

The response of benthic invertebrates to high loads of suspended sediments can vary. Some authors (e.g. Hamilton 1961) are of the opinion that deposition of a thick layer of fine particulate material is necessary to eliminate the normal fauna. In contrast, most studies have shown a reduction in abundance and diversity of zoobenthos under much less severe conditions. For example, Nuttall and Bielby (1973) reported that even relatively small amounts of sediments can induce changes in the invertebrate associations when deposition is between stones. The major effect is to reduce the habitat available to taxa which live under or between stones. Ephemeroptera, Plecoptera, and Trichoptera are generally replaced by burrowing forms such as Tubificidae, and Chironomidae. In erosional habitats of the Lovett and Pembina rivers most Ephemeroptera (e.g. _Epeorus_/Heptageniidae, _E._ (_Ephemerella_), _Baetis_/Baetidae, _Ameletus_) and most Plecoptera (e.g. Chloroperlidae, Taeniopterigidae) which have clinging or sprawling habits (Merritt and Cummins 1978) are more numerous above the mine effluents. Although the pattern is not nearly as consistent as that of Ephemeroptera, other taxa (such as Ceratopogonidae, _Chelifera_ and _Dicranota_, all with sprawling habits - see Merritt and Cummins, 1978) tend to be better represented at the control stations. High loads of fine suspended solids can interfere directly with invertebrates by abrading soft tissues or by clogging filter apparatus. For example, Simuliidae, filter feeders which cling to clean substrates, are known to be negatively influenced by sedimentation and by high suspended sediment loads (Hamilton 1961, Nuttall and Bielby 1973, Rosenberg and Wiens 1978). The occurrence of Simuliidae in the Lovett and Pembina rivers was restricted to sites located upstream of important increases in suspended solids.

The tolerance of Chironomidae and Oligochaeta to siltation is well documented (Hamilton 1961, Nuttall 1972, Nuttall and Bielby 1973, Scullion and Edwards 1980). In this study, sedimentation could certainly explain the distribution pattern of certain chironomids, and especially tubificids. Sedimentation and enrichment tend to favour burrowing forms. Consequently, it is difficult to determine which effect prevails in the study area, although it is probable that both sedimentation and mild enrichment affect the invertebrate associations. In depositional areas, the distribution pattern of Odontomesa supports the thesis that sedimentation is more important below than above the impoundments. This member of the sub-family Prodiamesinae, which shows a definite preference for the lightly silted sediments of slow moving waters (Saether 1983), was absent from the Ekman samples collected at the control station, but was common at all stations influenced by the Luscar Coal Valley mine discharges.

6.2.1 Comparison of Present and Pre-Impact Conditions

In 1974-1975, EPEC Consulting Western Ltd. (1976) conducted an impact assessment study on the Lovett River, some of its tributaries, and the Pembina River. The invertebrate data collected in riffles on several occasions during this study provided a valuable basis for the comparison of longitudinal and temporal trends in the benthic invertebrate distribution of the Lovett and the Pembina rivers. Because of differences in methodology between the studies conducted in 1974-1975 and 1984 (e.g. sampler, sieve mesh size, level of taxonomic identification) the comparison of density data for individual taxa may not always be justified or possible. However, even a rather cursory examination of both data sets is informative. Table 28 compares the percentage distribution of major taxonomic groups to total numbers for spring and fall data from both surveys. In 1974-1975 Ephemeroptera were the dominant fauna element at all stations in the Lovett River; usually, they represented more than 30% of the total invertebrate density. Chironomids were common, but their percentage contribution seldom exceeded 20%. Oligochaetes were of minor importance (<0.5%).

In 1984 a definite change is apparent. Although the percentage distribution of numbers between taxa is still comparable to that in 1974-1975 at the control stations, the proportion of Ephemeroptera is much lower (<15%) below the mine; chironomids are now dominant (approximately 40%), and Oligochaeta have become important (1 to 5%). Data from the Pembina River in 1984 also show clearly that the clean water taxa which dominate undisturbed reaches of the river are much reduced below the confluence with the Lovett River.

From the examination of 1984 and pre-impact (i.e. pre-Luscar Coal Valley Mine) zoobenthic data, it is apparent that the composition of the zoobenthic community has deteriorated at sites downstream of the influence of the mine. The invertebrate associations of the Pembina River have also changed noticeably below its confluence with the Lovett River.

Table 28 Comparison of the percentage contribution of major zoobenthic groups to the total number of benthic invertebrates collected in 1974-1975 (EPEC 1976) and in 1984 (WQCB).

LOVETT RIVER

	Spring				Fall			
	Control Station at or near LR1		Station Below Mine Area at or near LR5		Control Station at or near LR5		Station Below Mine Area at or near LR4	
	1975	1984	1975	1984	1974	1984	1974	1984
Ephemeroptera	36.0	39.0	49.0	13.5	N/A	51.7	56.4	9.4
Plecoptera	11.7	5.1	15.4	11.5		17.6	18.7	14.1
Trichoptera	6.4	2.7	3.6	1.9		1.0	7.8	13.1
Chironomidae	29.2	32.6	17.0	47.9		13.6	2.7	38.6
Oligochaeta	0.3	0.5	0.5	1.1		0.1	0.2	4.1

PEMBINA RIVER

FALL

	Control Station at or near PR1		Below Confluence with Lovett River At or near PR2b	
	1975	1984	1975	1984
Ephemeroptera	43.8	51.7	55.9	9.6
Plecoptera	12.0	17.6	16.9	5.6
Trichoptera	37.0	1.0	14.7	2.8
Chironomidae	2.6	13.6	1.8	56.5
Oligochaeta	1.4	0.1	1.8	8.8

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