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WATER QUALITY STUDIES IN THE KOOTENAY RIVER BASIN

I. NUTRIENT LOADINGS TO KOOTENAY LAKE

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RESUME

Un bilan de substances nutrives a été établi pour le lac Kootenay en Colombie-britannique pour la période allant du mois d'août 1974 au mois d'août 1975. Les substances nutritives étudiées comprenaient le phosphore total, le phosphore dissous et les nitrates/nitrites.

Le phosphore et les nitrates/nitrites dans le lac Kootenay proviennent tous deux principalement de la rivière Kootenay. Les apports au lac surviennent surtout durant la crue printannière. Le déversement d'eau des barrages de Duncan et de Libby durant la période en dehors des crues fait décaler le patron de apports aux stations de Duncan et de la rivière Kootenay.

Durant les mois d'hiver, les concentrations de substances nutritives et les apports journaliers à la sortie du lac ont augmenté. Les apports maximum de substances nutritives sont survenus durant la crue alors que les déversements maximum du lac sont survenus durant l'hiver. Ainsi, l'opération des barrages de Duncan et de Libby a permis de répartir la charge de substances nutritives durant des périodes de l'année où l'utilisation des substances nutritives était plus faible.

Les estimations de l'apport annuel en phosphore total, en phosphore dissous et en nitrates/nitrites au lac sont respectivement 789 ± 14, 285 ± 54, et 1963 ± 343 tonnes (kg x 10^3). L'imprécision des estimations des apports fournis des estimations relativement médiocres du montant de matière retenue dans le lac durant la période d'étude. Les estimations de la retention dans le lac sont 156 ± 191 (kg x 10^3) en ce qui concerne le phosphore total et 210 ± 460 (kg x 10^3) en ce qui a trait aux nitrates/nitrites. Le montant de phosphate dissous émis à l'extérieur du lac était 94 ± 142 (kg x 10^3) plus grand que les charges d'entrée estimées.

ABSTRACT

A nutrient budget for Kootenay Lake in British Columbia is established for the period from August 1974 to August 1975. Those nutrients studied were total phosphorus, dissolved phosphorus and nitrate plus nitrite.

The dominant source of both phosphorus and nitrate plus nitrite to Kootenay Lake is the Kootenay River. Loadings to the lake occur predominantly during the freshet period. The discharge of water from Duncan and Libby Dams during the non-freshet period shifts the loading pattern at the Duncan and Kootenay River stations.

During the winter months the nutrient concentrations and daily loadings in the lake discharge increased. The peak inputs of nutrients occured during freshet while the highest outputs from the lake occurred during winter. In light of this, the effect of operation of the Duncan and Libby Dams was to spread the nutrient load to periods of the year when nutrient utilization was not as great.

Estimates of annual loading to the lake of total phosphorus, dissolved phosphorus, and nitrate plus nitrite are, 789 ± 14, 285 ± 54, and 1963 ± 343 tonnes (kg x 10^3) respectively. Imprecision of the estimates of the loadings provides relatively poor estimates of the amount of material retained in the lake over the study period. Estimates of the retention within the lake are, 156 ± 191 (kg x 10^3) for total phosphorus, and 210 ± 467 (kg x 10^3) for nitrate plus nitrite. Dissolved phosphate transported out of the lake was 94 ± 142 (kg x 10^3) greater than the estimated inputs.

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
STUDY AREA	3
SAMPLING SITE SELECTION	3
PARAMETER SELECTION	4
METHODS	5
1. DATA COLLECTION	5
1.1 Sample Collection	5
1.2 Total Phosphorus	5
1.3 Dissolved Phosphorus	5
1.4 Nitrate + Nitrite	6
1.5 Field Measurements	6
1.6 Flow Measurements	6
2. DATA ANALYSIS	6
2.1 Load Calculations	6
2.2 Daily Net Loadings	9
2.3 Calculation of Flows at Ungauged Stations	10
2.3.1 East and West Channel - Kootenay River	10
2.3.2 Northern and Southern Tributary Basins	10
RESULTS	12
1. SEASONAL PATTERN OF LOADINGS	12
1.1 Nutrient Contributions to Kootenay Lake	12
1.1.1 Duncan River (Figure 2)	12
1.1.2 Lardeau River (Figure 3)	12
1.1.3 Northern Tributaries (Figure 4)	12
1.1.4 Southern Tributaries (Figure 5)	16
1.1.5 East Channel of the Kootenay River (Figure 6)	16

Page

1.2 Nutrient Loadings From Kootenay Lake ---------------- 16

1.2.1 Fraser Narrows (Figure 8) ---------------------- 16

1.3 Nutrient Contributions in the Creston Valley ---------- 21

1.3.1 Goat River (Figure 9) -------------------------- 21

1.3.2 Kootenai River at Porthill (Figure 10) ---------- 21

1.4 Daily Net Loadings to Kootenay Lake (Figure 11) -------- 21

2. ANNUAL LOADINGS ------------------------------------ 25

2.1 Duncan River -- 30

2.2 Lardeau River -- 30

2.3 Northern Tributaries ---------------------------------- 30

2.4 Southern Tributaries ---------------------------------- 31

2.5 East Channel of the Kootenay River ------------------- 31

2.6 West Channel of the Kootenay River ------------------- 31

2.7 Fraser Narrows -- 31

2.8 Goat River --- 31

2.9 Kootenai River at Porthill ------------------------- 32

2.10 Net Loading to Kootenay Lake ------------------------- 32

2.11 Net Loadings Through Creston Valley ------------------ 32

DISCUSSION --- 33

1. COMMENT ON LOADING ESTIMATES ---------------------------- 33

2. UNCONTROLLED TRIBUTARIES ------------------------------- 34

3. CONTROLLED TRIBUTARIES --------------------------------- 34

3.1 Duncan River -- 34

3.2 East Channel of Kootenay River ------------------------ 34

3.3 West Channel of Kootenay River ------------------------ 35

3.4 Kootenai River at Porthill ---------------------------- 35

3.5 Fraser Narrows -- 35

Page

4. NET DAILY LOADINGS -- 36

4.1 Net Daily Loadings to Kootenay Lake ----------------- 36

5. NUTRIENT BUDGETS -- 37

CONCLUSIONS --- 38

RECOMMENDATIONS -- 38

REFERENCES --- 39

APPENDIX - CONCENTRATION DATA USED IN LOAD CALCULATIONS

INTRODUCTION

In pursuing the responsibility of the Water Quality Branch in monitoring the movement of waterborne materials across the international boundary a study of the western portion of the Kootenay River Basin was initiated. The dominant hydrological feature in this portion of the basin is Kootenay Lake (see Figure 1).

An examination of past data and a preliminary survey of the area indicated that establishing the level of inputs of primary nutrients was of major importance. Therefore, the objective defined for this study was to estimate the nutrient loadings to the lake, the relative contributions from the surrounding watersheds, and the amounts leaving the lake. This report is concerned with the transport and concentration of algal nutrients, nitrogen as nitrate or nitrite and phosphorus both total and dissolved during the period from July 1974 to July 1975. Emphasis was placed on estimating confidence levels assigned to the nutrient budget so that trends in future years might be confirmed.

It is not possible to ignore the influence of those features outside the portion of the basin under investigation, the contributions of phosphorus from the Cominco Fertilizer Plant at Kimberley in the East Kootenay, and the effect of the Libby impoundment in Montana (Lake Koocanusa) where the natural flow pattern of the Kootenai River is altered by the operation of the Libby Dam.

To avoid confusion, it is most important, to establish the working definitions of a few terms used in this report. A "loading" refers to the amount of a nutrient which is transported past a particular station. Such a loading may be expressed as an annual, monthly, or daily figure. "Nutrient budget" refers to the amount of a nutrient contributed by the input sources balanced against the amount which is discharged from the lake.

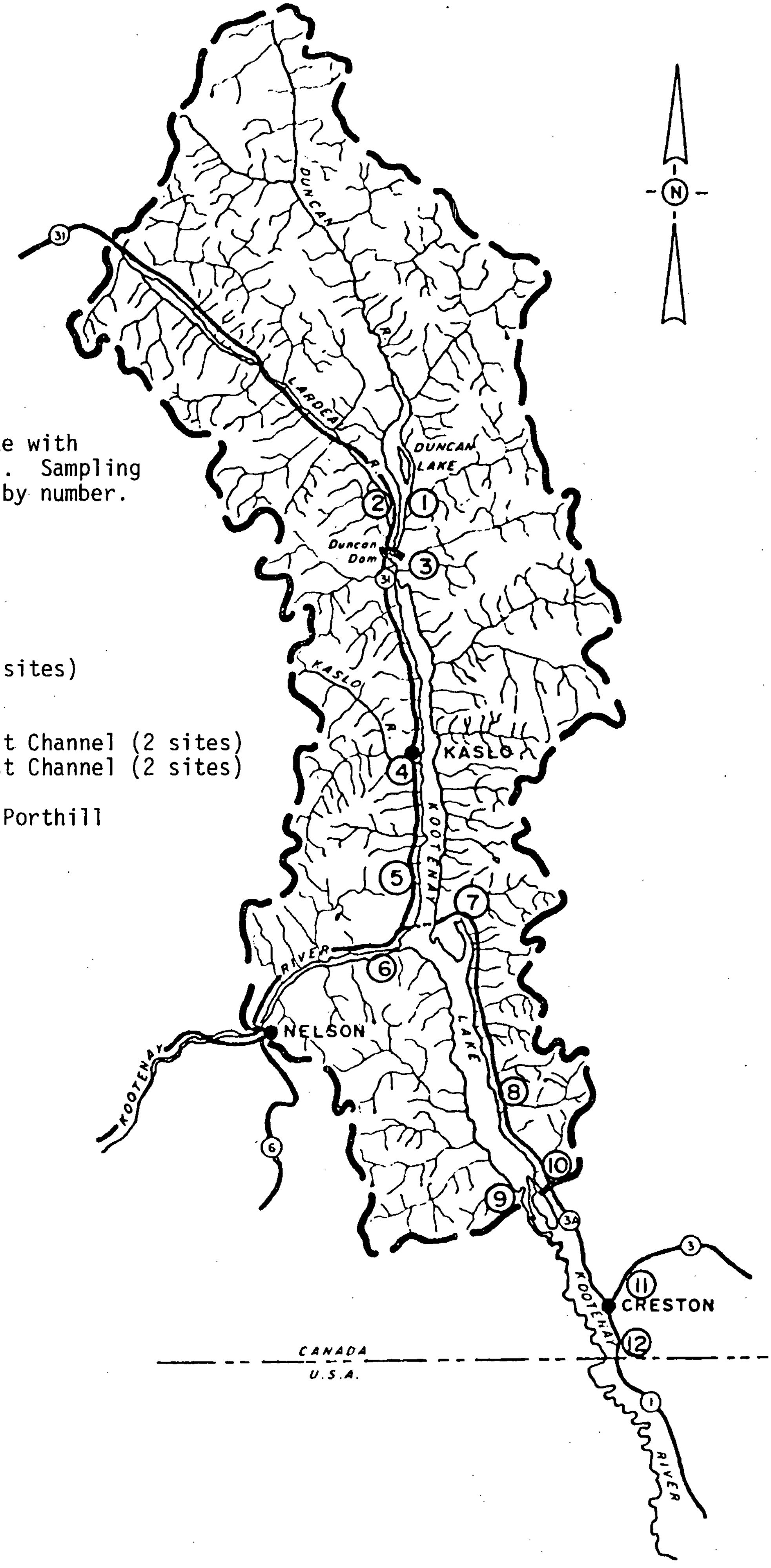


Figure 1. Kootenay Lake with adjacent drainage areas. Sampling stations are indicated by number.

1 - Duncan River
2 - Lardeau River
3 - Hamill Creek
4 - Kaslo River
5 - Coffee Creek
6 - Fraser Narrows (3 sites)
7 - Crasford Creek
8 - Sanca Creek
9 - Kootenay River West Channel (2 sites)
10- Kootenay River East Channel (2 sites)
11- Goat River
12- Kootenai River at Porthill

STUDY AREA

Kootenay Lake ia a fjord-type lake, located in southeastern British Columbia with a surface elevation of 532 m (1,745 ft.) above sea level. Its major axis has a north-south direction with a maximum length of 109.7 km (69.2 miles) with an area of 406.5 km^2 (157 square miles) (Environment Canada, 1973) and a maximum depth of 150 meters.

Major contributions to this lake are provided by the Kootenay River (annual discharge - 15.5 x 10^9 m^3) in the south and the Duncan River (4.7 x 10^9 m^3, including the Lardeau River) in the north. The remaining input (approximately 4.3 x 10^9 m^3) is provided by numerous smaller rivers and creeks draining the mountain slopes immediately east and west of the lake and feeding directly to it, including precipitation falling directly into the lake.

Impoundments on the Duncan River, above its confluence with the Lardeau River, and on the Kootenai River at Libby in Montana serve to regulate flow for the purposes of power generation and flood control. These impoundments have disturbed the natural flow regime within the region and also the associated nutrient distribution.

Under an International Joint Commission Order (1938) the level of Kootenay Lake is controlled throughout the year. This allows the storage of water for the purpose of generating power downstream of the lake by West Kootenay Power and Light Company. Corra Linn Dam, on the Kootenay River below the City of Nelson, controls levels of Kootenay Lake.

SAMPLING SITE SELECTION

Stations were selected close enough to the lake to ensure that all the input from the rivers was effectively included. The availability of discharge data which would closely approximate the discharge at the water quality sampling station was also considered.

The locations of sampling stations are shown in Figure 1. All of the major tributaries and the outflow of the lake (Fraser Narrows) immediately west of Balfour were sampled. Although this section of water is frequently referred to as the West Arm of Kootenay Lake, its characteristics support treating it as a river since high outflow velocities are evident throughout the section. The specific location of this station was above the urban development (hence urban runoff) along the north shore from Balfour to Nelson. The section chosen at Fraser Narrows also had the advantages of being relatively narrow and well mixed. Samples were collected at three points on a transection across the narrows.

With regard to the main input to Kootenay Lake by the Kootenay River, north of Creston, both the East and West Channels of the river close to the lake were sampled to include inputs from the duck habitat immediately south of the lake. Since the river divides approximately five miles upstream of the lake, possible differences in the water quality could result from local influences. In order to assess the effect of runoff from the agricultural lands in the Creston Valley, sampling was also conducted at a station near the U.S. Border (Porthill).

The remaining rivers and streams were not gauged and nutrient sampling was done on only a few (Hamill, Coffee, Sanca, Crawford and Kaslo). These streams, although minor when considered individually, in total account for 18% of the total discharge to the lake. The approximation of discharge was necessary to account for the input of additional nutrient material, from these drainage areas.

PARAMETER SELECTION

The presence of high concentrations of primary nutrients over a sustained period of time may result in accelerated eutrophication of the lake. Such a condition could affect the use of the waters of Kootenay Lake for recreation and possibly damage the economy of the area. The representative parameters were selected on the basis of their relevance as algal nutrients.

For the purpose of this study, estimates of nitrogen loadings were based on the concentration of nitrate plus nitrite ($NO_3 + NO_2$). The total amount of phosphorus which a sample contains reflects the maximum amount of phosphorus which could potentially be available to algae. The dissolved phosphorus to a certain degree reflects the amount of phosphorus which is readily available. The difference between total phosphorus and dissolved is associated with the presence of particulates.

METHODS

1. DATA COLLECTION

1.1 Sample Collection

Samples were collected at a series of stations on water entering, and leaving Kootenay Lake. These stations are identified on Figure 1. At each station at least one set of replicated samples, consisting of six total phosphorus, three dissolved phosphorus, and six nitrate plus nitrite samples, were collected during each visit. The replicate samples in each set were collected simultaneously. Two points were sampled at each of the east and west channel stations of the Kootenay River where it enters the Lake.

1.2 Total Phosphorus

Sets of six replicate samples were collected into 50 ml glass bottles using the IWD Replicate Sampler (Oguss and Erlebach, 1976). These were then returned to the Water Quality Branch laboratory in North Vancouver for determination of total phosphorus using Technicon AA II methodology (Environment Canada, 1974; Technicon AutoAnalyzer Methodology 1972).

1.3 Dissolved Phosphorus

Sets of three samples were collected using the IWD Replicate Sampler and filtered in the field through a filter (prewashed with deionized water) having a mean pore size of 0.45μm. The filtrate was collected into 50 ml glass bottles and returned to the laboratory for determination of total phosphorus content (Environment Canada, 1974; Technicon Auto Analyzer II Methodology, 1971).

1.4 Nitrate + Nitrite

Sets of six replicate samples were collected at each point for all stations, stored under ice and returned to the laboratory for analysis (Environment Canada, 1974; Technicon Auto Analyzer II Methodology, 1972).

1.5 Field Measurements

At most stations a 2-liter sample was collected. The temperature, pH and conductivity were determined immediately in the field, and the sample returned to the laboratory for major ion analysis. These data are available from NAQUADAT, the Inland Waters Directorate data file on water quality.

1.6 Flow Measurements

Discharge data were obtained from Water Survey of Canada for the following locations: Goat River, Lardeau River, Duncan River and at Corra Linn Dam site (for Fraser Narrows). Additional flow data were made available by the United States Geological Survey (Porthill). Data from other stations and groups of stations were estimated based on the available data (see 2.4, estimating flow at ungauged stations).

2. DATA ANALYSIS

2.1 Load Calculations

Daily loads as shown in Figures 2 - 12 are the product of daily mean discharges and estimates of mean daily concentration. Since concentration data were collected intermittently, it was necessary to calculate a concentration for each unsampled day. This was done by simple linear interpolation between dates which had been sampled. This linear interpolation is likely to produce a poor approximation of the concentration changes during the interval between sampling times. The unwarranted assumption that there are no substantial deviations from the linear relationship negates the validity of estimates for loading calculations based on interpolated values.

In order to calculate annual loading, it was necessary to use a more rigorous analysis.

The annual load (L) is: $L = \bar{c} \times \sum \bar{F}_i$

where $\bar{c}$ is the mean concentration and $\bar{F}_i$ is the mean daily discharge on day i.

If discharge and concentration are independent then the variance associated with the load (V_L) should fit the model:

$$V_L = \bar{c}^2 \times V_{\Sigma\bar{F}_i} + \sum \bar{F}_i^2 \times V_{\bar{c}}$$

Where $V_{\bar{c}}$ and $V_{\Sigma\bar{F}_i}$ and the variances associated with mean concentrations and annual discharge respectively.

Daily discharge data obtained from Water Survey of Canada is assumed to have a 5% error. Estimates of the variance of total discharge were obtained by:

$$V_{\Sigma\bar{F}_i} = \sum_{i=i}^{365} \left(\frac{.05\ \bar{F}_i}{t_{\infty,\ .95}} \right)^2$$

Derivation of the variance of annual mean concentration is based on an analysis of variance (ANOVA).

MODEL SOURCE	DEGREES OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE
GROUPS*	G-1	$\dfrac{\Sigma \dfrac{(\Sigma c)^2}{n_i} - \dfrac{(\Sigma\Sigma c)^2}{\Sigma n_i}}{G-1}$	$\hat{\sigma}_r^2 + n_o\hat{\sigma}_g^2$
REPLICATES	Σn_i-G	$\dfrac{\Sigma\Sigma c^2 - \Sigma \dfrac{(\Sigma c)^2}{\Sigma n_i}}{\Sigma n_i - G}$	$\hat{\sigma}_r^2$

*(GROUPS INCLUDES BOTH SAMPLING TIMES AND SITES AT A STATION)

$$n_o = \frac{\Sigma n_i - \dfrac{\Sigma n_i^2}{\Sigma n_i}}{G-1}$$

The mean concentration ($\bar{c}$) is calculated by:

$$\bar{c} = \frac{\Sigma\Sigma c}{\Sigma n_i}$$

and the variance of the mean concentration $V\bar{c}$ is:

$$V\bar{c} = \hat{\sigma}_g^2 \times \frac{\Sigma n_i 2}{(\Sigma n_i)2} + \hat{\sigma}r^2 \times \frac{1}{n_i}$$

The 95% confidence limit about a load is:

$$CL = \pm\ t^* \sqrt{V_L}$$

Where t* is the weighted average of t values for degrees of freedom for concentration measurements and discharge as:

$$t^* = \frac{(\Sigma\bar{F}_i)^2 \times t_{(n_i,.05)} + (\bar{c})^2 \times t_{[\infty,.05]}}{(\Sigma\bar{F}_i)^2 + (\bar{c})^2}$$

In certain situations it is necessary to estimate net or total loadings by difference or summation. In these cases the confidence limits associated with the load have been estimated by:

$$CL_{est} = \pm \sqrt{\Sigma(CL_i)^2}$$

This analysis is entirely dependent upon the lack of covariance between concentration and discharge. As such it is a good model in situations where discharge patterns are altered or materials are introduced to the system through mechanisms independent of discharge.

Mean concentrations for the study period with their variances are included as appendex I. Also given in the appendix are the number of actual measurements made and the total number of replicate samples involved in estimating $\bar{c}$ and $V_{\bar{c}}$.

For the purpose of calculating $\bar{c}$ and $V_{\bar{c}}$ the data from Kaslo River, Hamill Creek, and Coffee Creek were combined and considered to be representative of all northern ungauged tributaries. Similarly this data from Sanca and Coffee Creeks were combined to represent the southern tributaries.

2.2 Daily Net Loadings

Net loadings on a daily basis are the difference between inputs and outputs. When the outputs exceed the inputs, negative values are obtained. This type of data evaluation is used for graphic purpose, since it reflects patterns of loadings to and from the system under consideration.

2.3 Calculation of Flows at Ungauged Stations

2.3.1 East and West Channel - Kootenay River

The available supply of water to the two channels which enter Kootenay Lake was determined as the sum of the measured flows at Porthill and the Goat River, assuming no significant groundwater inflow. On the basis of historical records made available by Water Survey of Canada, and some metering of flows during August, 1975, a division of the input flow between the two channels was approximated. During the low flow conditions the East Channel carried only 2% of the discharge to the lake. During the greatest portion of the year, combined flows were maintained at a relatively high flow (greater than 600 m^3/sec) during which time the East Channel carried approximately 13% of the flow. It was decided to use the 13:87 split of the input flow for the for the calculation of daily loads. The result of this was an overestimate of the annual loading of nutrients in the East Channel and a similar underestimate of loadings in the West Channel. This disparity of esitmates should be less than 5% on the annual loads. This estimate could be improved in the future, if necessary, by additional measurements of the discharge in the two channels at a variety of stages.

2.3.2 Northern and Southern Tributary Basins

The 30-year annual mean precipitation records of Environment Canada (1973) indicate that the northern portion of the Kootenay Lake Drainage Basin is characterized by higher annual mean precipitation than the southern portion of the basin. The boundaries of these sub-basins were delineated on maps and their areas estimated by planimeter. The annual mean discharge per square mile from those contained or adjacent watersheds for which streamflow data are reported by Water Survey of Canada, was used to estimate the annual discharges from the two sub-basins. The discharge per square mile for the Kaslo River was used as the representative for the northern tributaries, while the discharge per square mile data from the Goat River watershed was felt to be representative of the southern tributaries. The total ungauged input was then estimated for the entire basin. The northern tributaries were found to contribute approximately 55% of this total ungauged contribution on the basis of these calculations and assumptions. A limitation in expanding this procedure to calculate ungauged inputs for the study year was the absence of any data on a contained tributary for that year. Consequently historical data was used to determine the ratios of discharges and a total water balance using lake level changes was used.

The ungauged contribution was calculated on a daily basis from the sum of the gauged input less the discharge from the lake, less any changes in storage in the lake as the result of the control of the discharge from the lake. This provided a record of discharge to the lake which, when divided between the northern and southern basins, was remarkably similar in shape to the other uncontrolled inputs (the Lardeau River and the Goat River). There was, however, a considerable amount of variation present in the discharge estimates, including a number of negative values for flow. This was a recognizable problem which resulted from a number of physical factors which were not considered in the daily estimates but which would be significant in a cumulative loading for a longer period. These include wind-induced seiches, evaporation, and time delays in level changes at metering equipment. As an example, the operation of the Duncan Dam can produce very drastic changes in the flow of the Duncan River, but the effect of this is not measured at Corra Linn Dam site within the same time period.

RESULTS

1. SEASONAL PATTERN OF LOADINGS

1.1 Nutrient Contributions to Kootenay Lake

1.1.1 Duncan River (Figure 2)

Peak loadings of nutrients passing through Duncan Dam occurred at two periods in the year. The first of these was during the late summer (from the beginning of August to the end of September) when Duncan Lake had nearly reached its maximum holding capacity. The second period, during which loadings were relatively constant and maintained at a high level, occurred from the beginning of December through to the end of February. This pattern of loading was established as the result of discharge from the reservoir, as evidenced by the high sustained flow during this same period.

1.1.2 Lardeau River (Figure 3)

Nearly all loading of nutrients occurred during the freshet period from the beginning of May through to mid-August. This was evidenced by the dominance of the flow patterns on the loading curves.

1.1.3 Northern Tributaries (Figure 4)

The significant loadings of nutrients occur from mid-May through mid-July. The magnitude of the peaks of nutrient loadings were substantially higher than either the Duncan River or the Lardeau River. The appearance of negative peaks in both the flow and the loading curves was the result of the method of estimation of the flow contribution of this area and also applies to the southern tributaries. The response time of the lake to incoming flow was of a magnitude greater than one day which was the interval of measurement. Sudden changes of incoming flow may have produced the negative peaks. This, however, averaged out over the period of a year as the estimates of negative loads were followed by overestimates of positive loads. Hence, over the year for which totals have been calculated the net result is felt to be accurate.

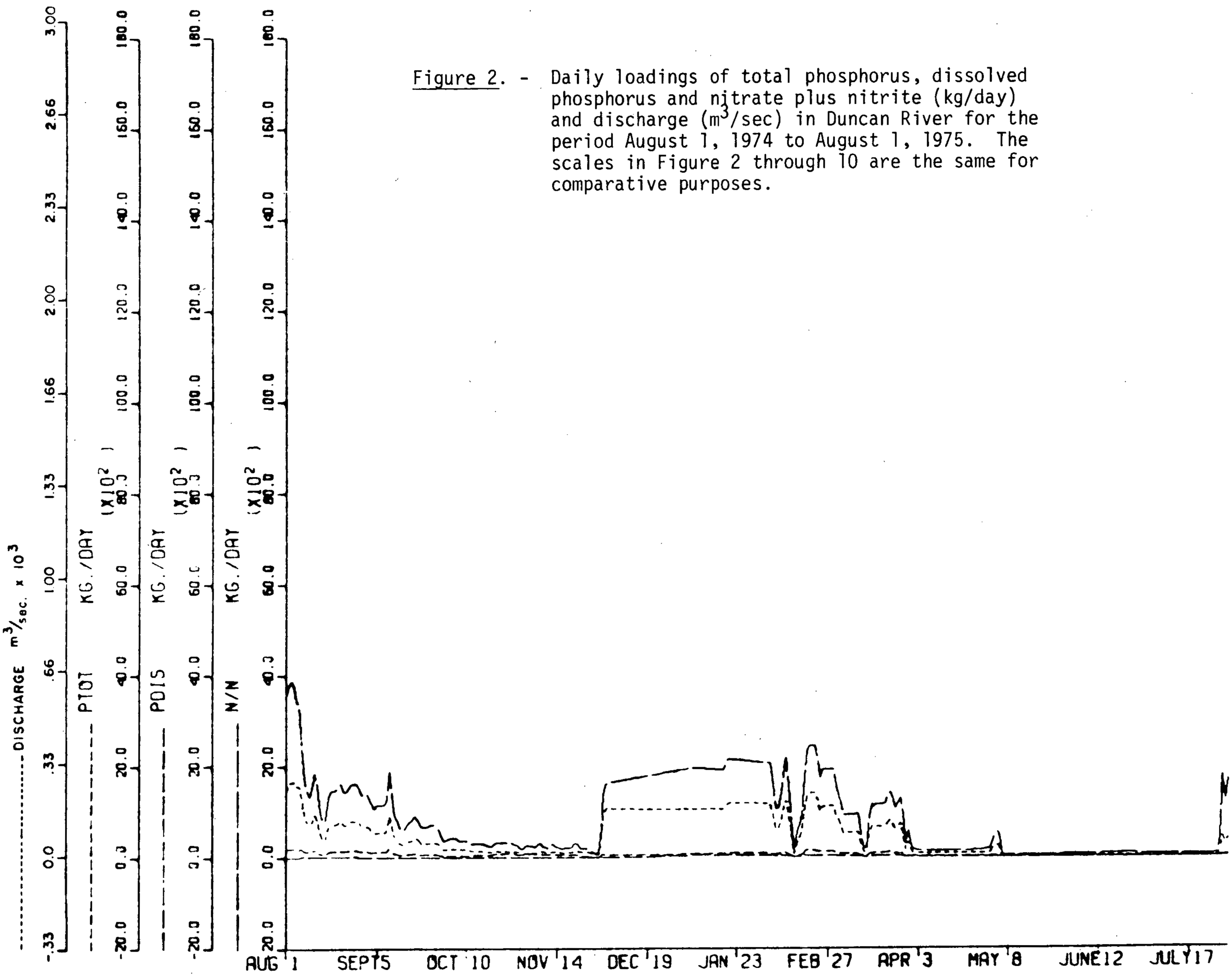


Figure 2. - Daily loadings of total phosphorus, dissolved phosphorus and nitrate plus nitrite (kg/day) and discharge (m^3/sec) in Duncan River for the period August 1, 1974 to August 1, 1975. The scales in Figure 2 through 10 are the same for comparative purposes.

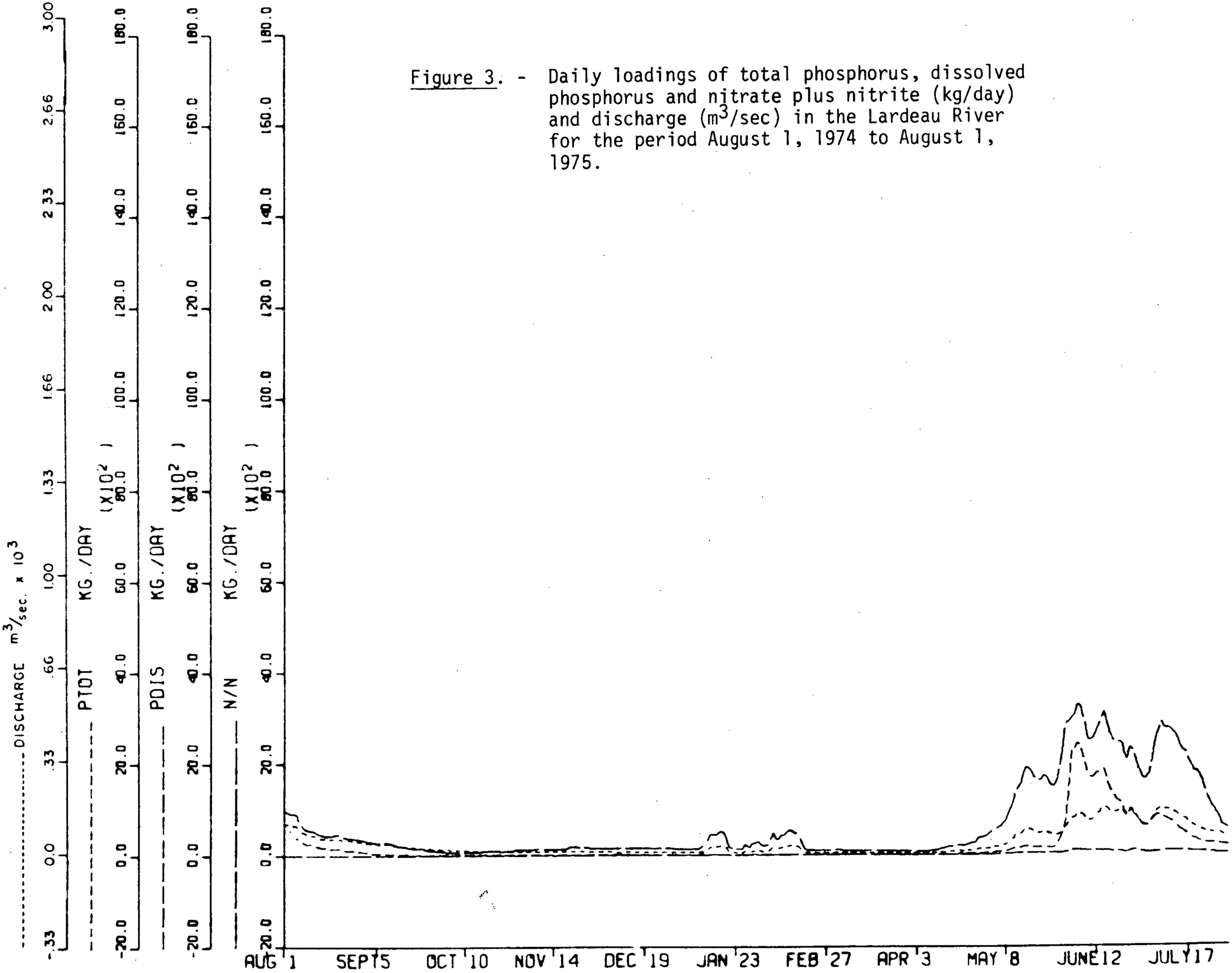


Figure 3. - Daily loadings of total phosphorus, dissolved phosphorus and nitrate plus nitrite (kg/day) and discharge (m^3/sec) in the Lardeau River for the period August 1, 1974 to August 1, 1975.

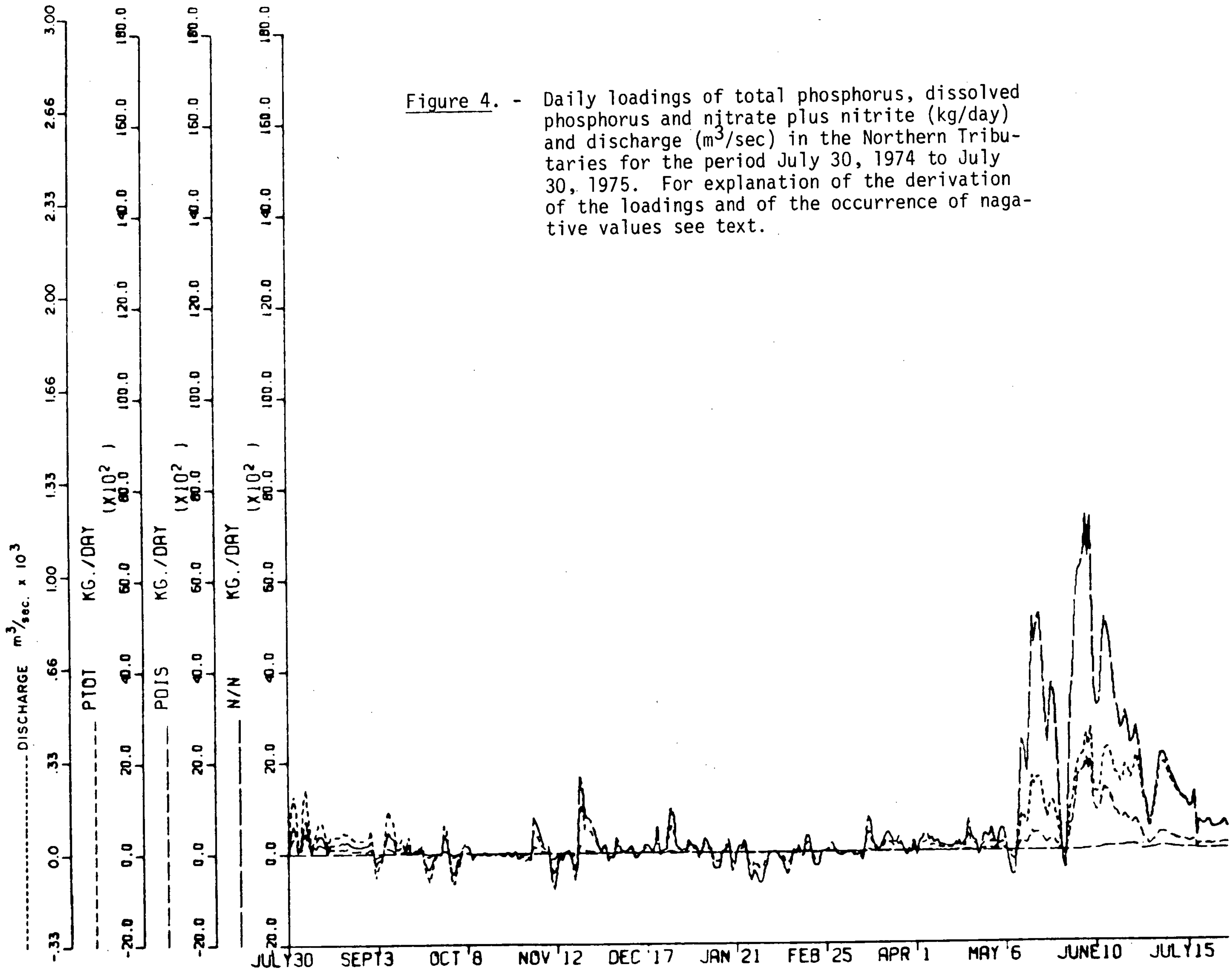


Figure 4. - Daily loadings of total phosphorus, dissolved phosphorus and nitrate plus nitrite (kg/day) and discharge (m^3/sec) in the Northern Tributaries for the period July 30, 1974 to July 30, 1975. For explanation of the derivation of the loadings and of the occurrence of nagative values see text.

1.1.4 Southern Tributaries (Figure 5)

The same pattern of loadings was found for southern tributaries; however, the peaks of the loadings were not as large as for the northern tributaries. This results in part from lower discharges because of the manner of calculation (Methods Section 2.4.2). The reservations regarding negative peaks applied to the northern tributaries also apply to the southern tributaries.

1.1.5 East Channel of the Kootenay River (Figure 6)

Loadings of nutrients occurred throughout the entire year at a fairly constant low level.

1.1.6 West Channel of the Kootenay River (Figure 7)

The most substantial loadings to the lake occurred in this the main source of water to the lake. The loading curves for total and dissolved phosphorus follow the pattern of the discharge curve during the entire year. The pattern of the nitrate loading cruve follows the discharge curve for most of the year but an independent peak with a high nitrate concentration occurred at the beginning of March and another at the end of June. There was some evidence of the March peak in the East Channel and at Porthill.

1.2 Nutrient Loadings From Kootenay Lake

1.2.1 Fraser Narrows (Figure 8)

Nutrients are transported from Kootenay Lake through Fraser Narrows. Nutrient transport parallelled discharge during most of the year. There were two major peaks of nutrient discharges from the Lake. The first occurred during sustained high discharge between mid-October and the end of March. The second occurred during the natural freshet period between April and September.

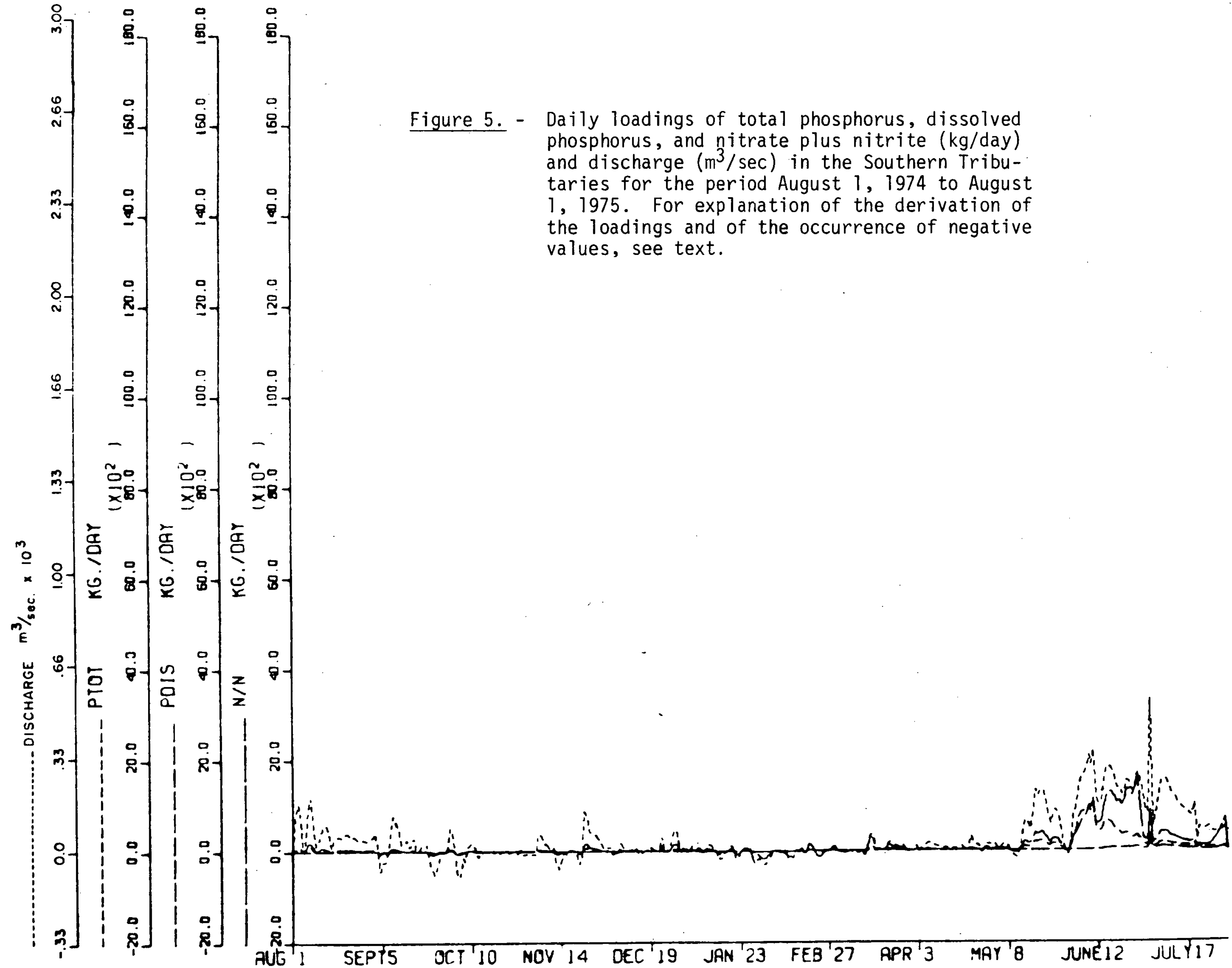


Figure 5. - Daily loadings of total phosphorus, dissolved phosphorus, and nitrate plus nitrite (kg/day) and discharge (m^3/sec) in the Southern Tributaries for the period August 1, 1974 to August 1, 1975. For explanation of the derivation of the loadings and of the occurrence of negative values, see text.

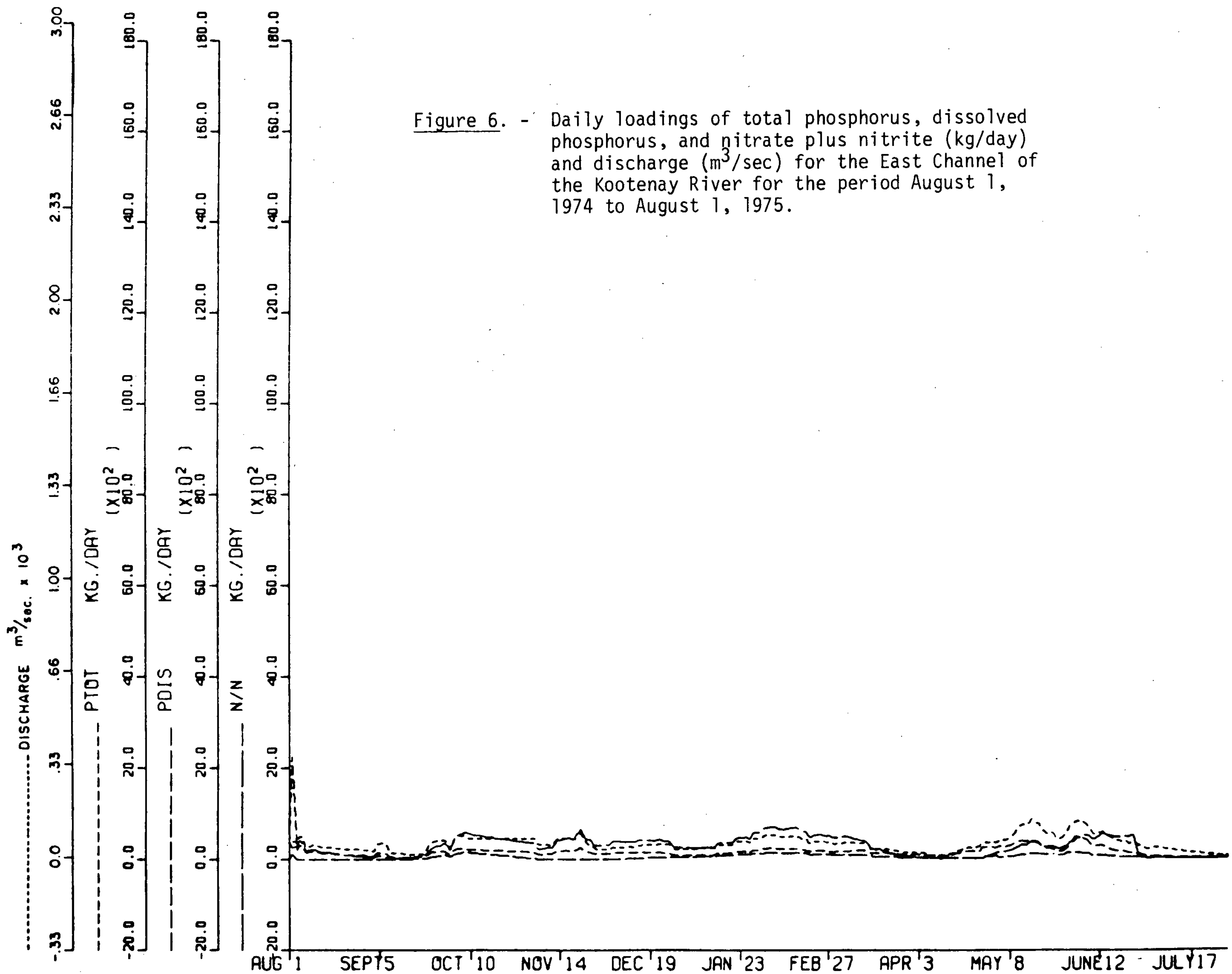


Figure 6. - Daily loadings of total phosphorus, dissolved phosphorus, and nitrate plus nitrite (kg/day) and discharge (m^3/sec) for the East Channel of the Kootenay River for the period August 1, 1974 to August 1, 1975.

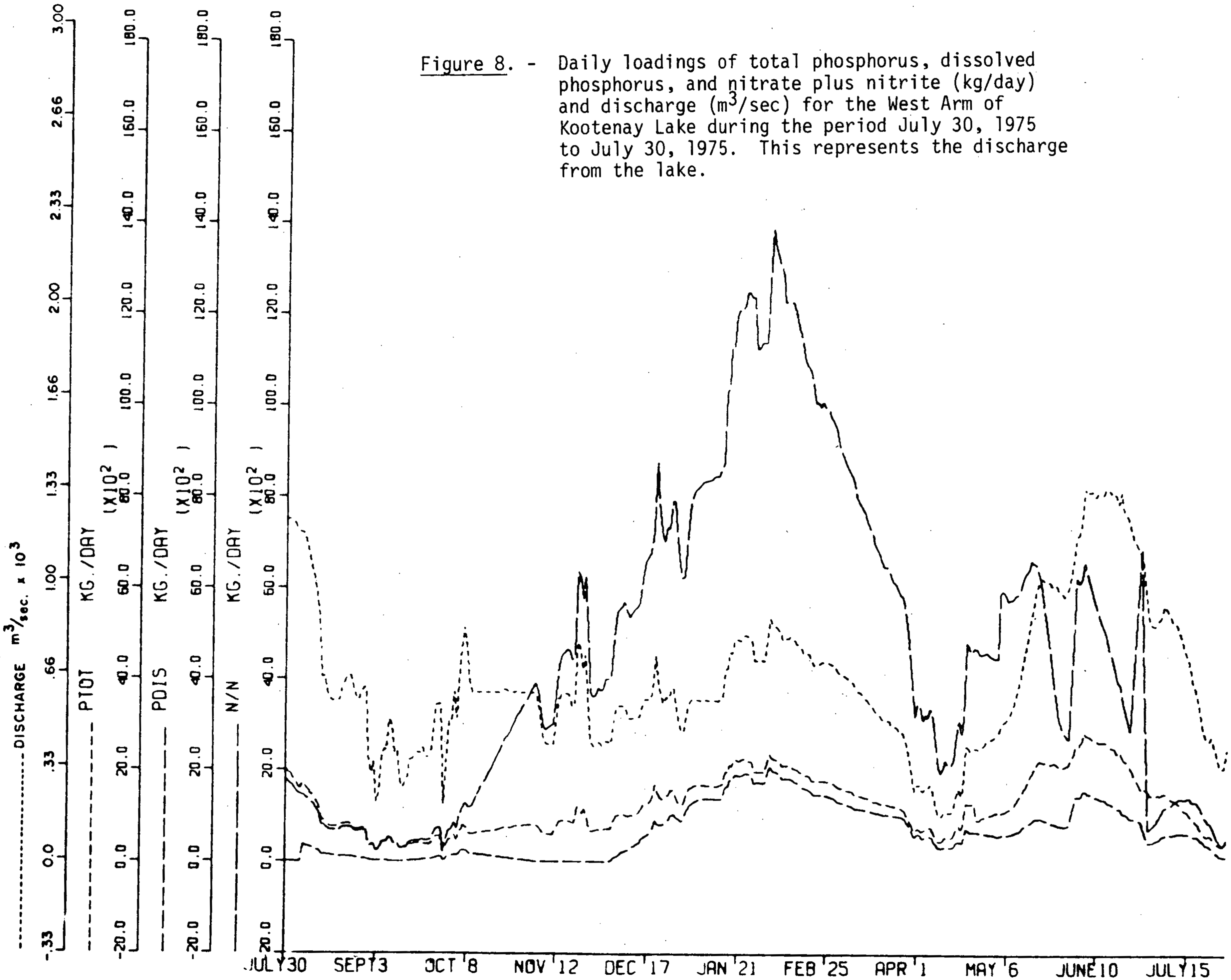


Figure 8. - Daily loadings of total phosphorus, dissolved phosphorus, and nitrate plus nitrite (kg/day) and discharge (m^3/sec) for the West Arm of Kootenay Lake during the period July 30, 1975 to July 30, 1975. This represents the discharge from the lake.

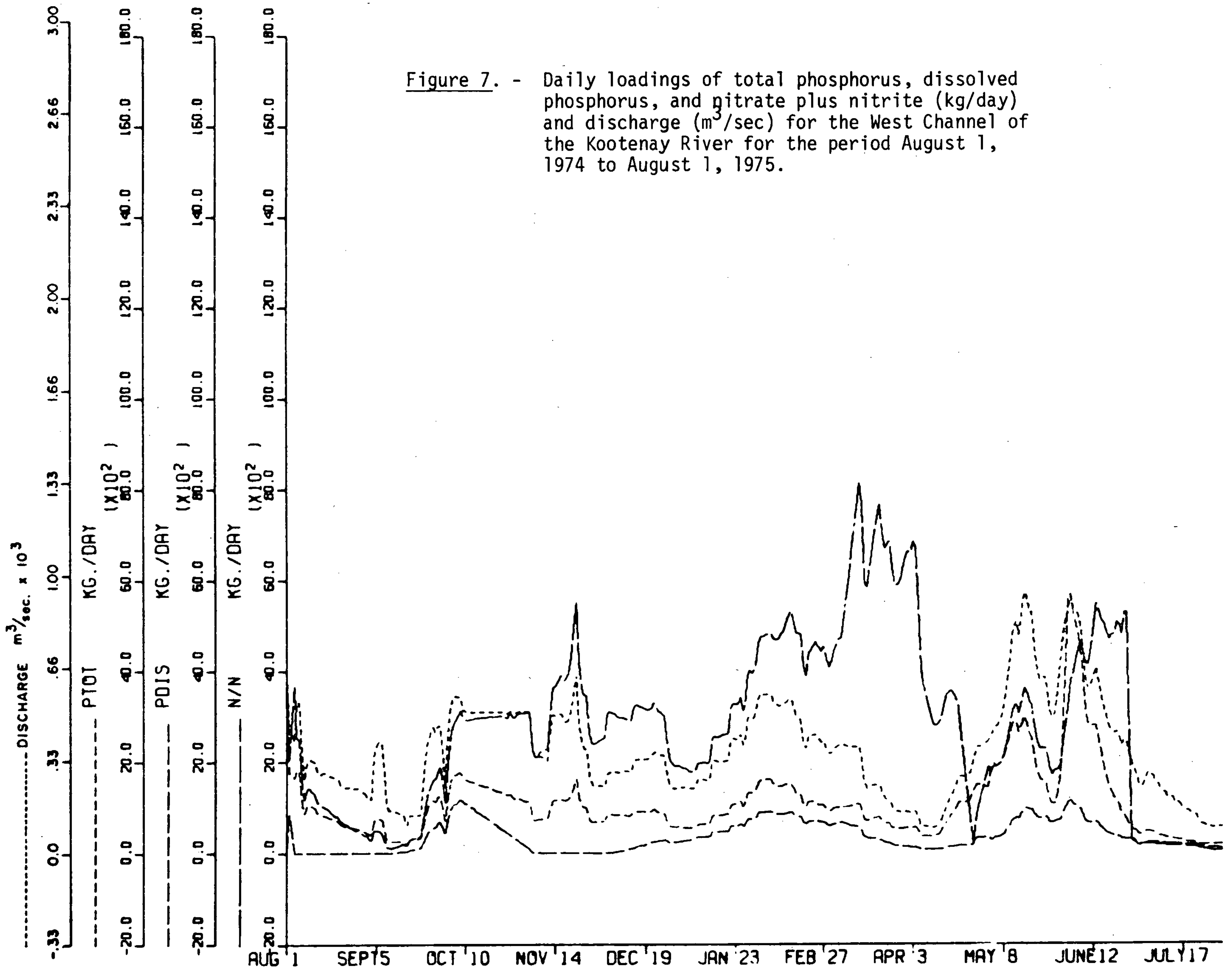


Figure 7. - Daily loadings of total phosphorus, dissolved phosphorus, and nitrate plus nitrite (kg/day) and discharge (m^3/sec) for the West Channel of the Kootenay River for the period August 1, 1974 to August 1, 1975.

At all times the output of nutrients from the lake exceeded any of the individual inputs, but not always the sum of the inputs. The high nitrate + nitrite peak, evident at Fraser Narrows in late January, occurred before this nutrient showed any substantial loadings into the lake.

1.3 Nutrient Contributions in the Creston Valley

1.3.1 Goat River (Figure 9)

The loading of nutrients from this source reached its maximum during a brief period in May and June. The Goat River had only a small contribution of nutrients throughout this study.

1.3.2 Kootenai River at Porthill (Figure 10)

The pattern of nutrient contributions which occurred at this station, where the Kootenai River re-enters Canada, was similar to that in the West Channel. The magnitude of loadings, however, were slightly lower.

1.4 Daily Net Loadings to Kootenay Lake (Figure 11)

Positive net loading of phosphorus occurred primarily during the period of freshet (Figure 11). During winter there was a net loss of total phosphorus, the major portion of which appeared to be in a dissolved form. The fluctuations shown in Figure 11 reflect net changes in storage of water on the lake.

The pattern of net loading of dissolved phosphorus followed the pattern exhibited for total phosphorus during most of the year except during the period of massive total phosphorus loading during freshet.

Nitrate + nitrite loadings to the lake followed a pattern similar to that of total phosphorus except for a few slight variations. The net loss of nitrate + nitrite which occurred during the winter months was very dramatic, reaching nearly 8,000 kg/day. There was an isolated, very distinct peak of positive net loading which occurred during April.

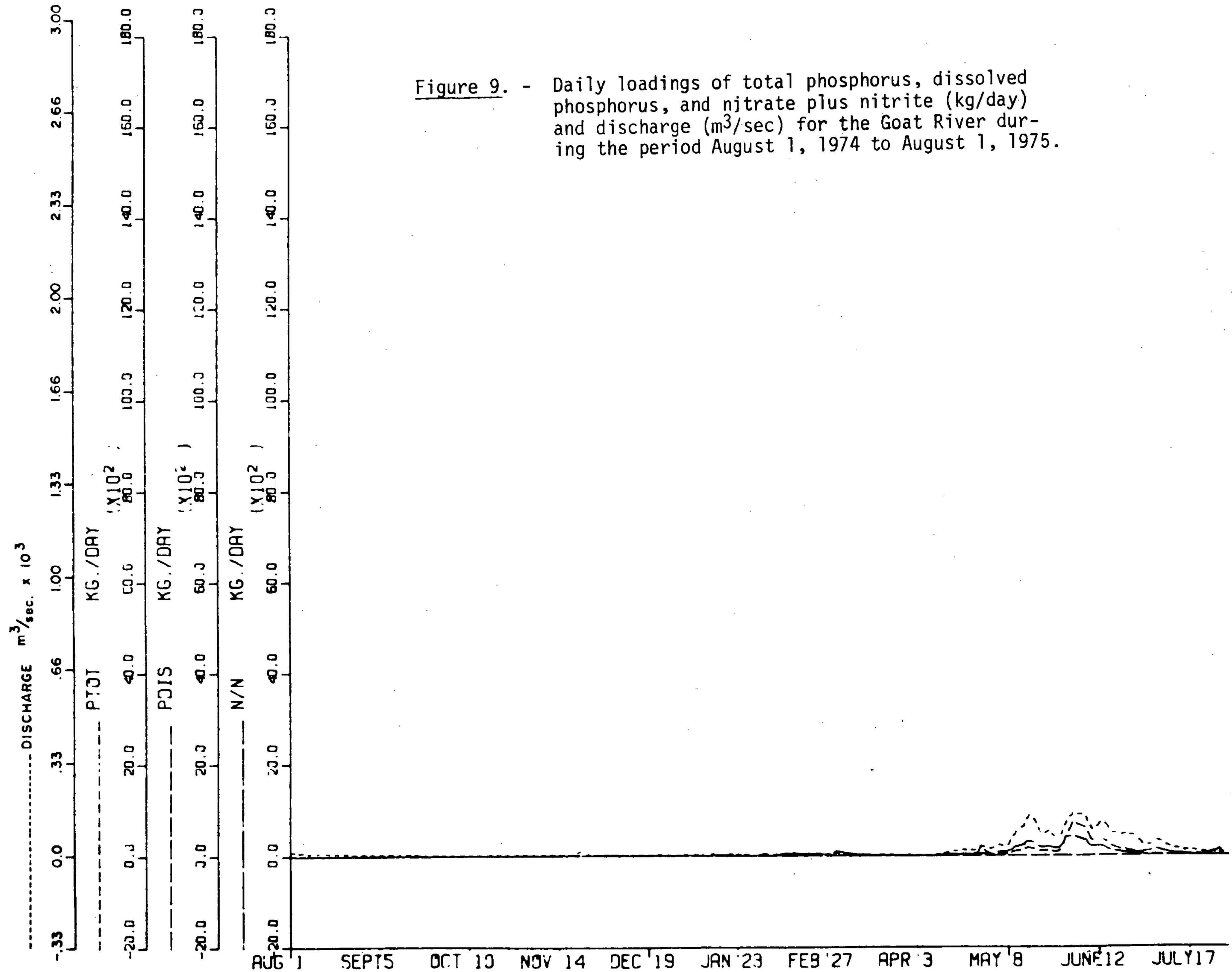


Figure 9. - Daily loadings of total phosphorus, dissolved phosphorus, and nitrate plus nitrite (kg/day) and discharge (m^3/sec) for the Goat River during the period August 1, 1974 to August 1, 1975.

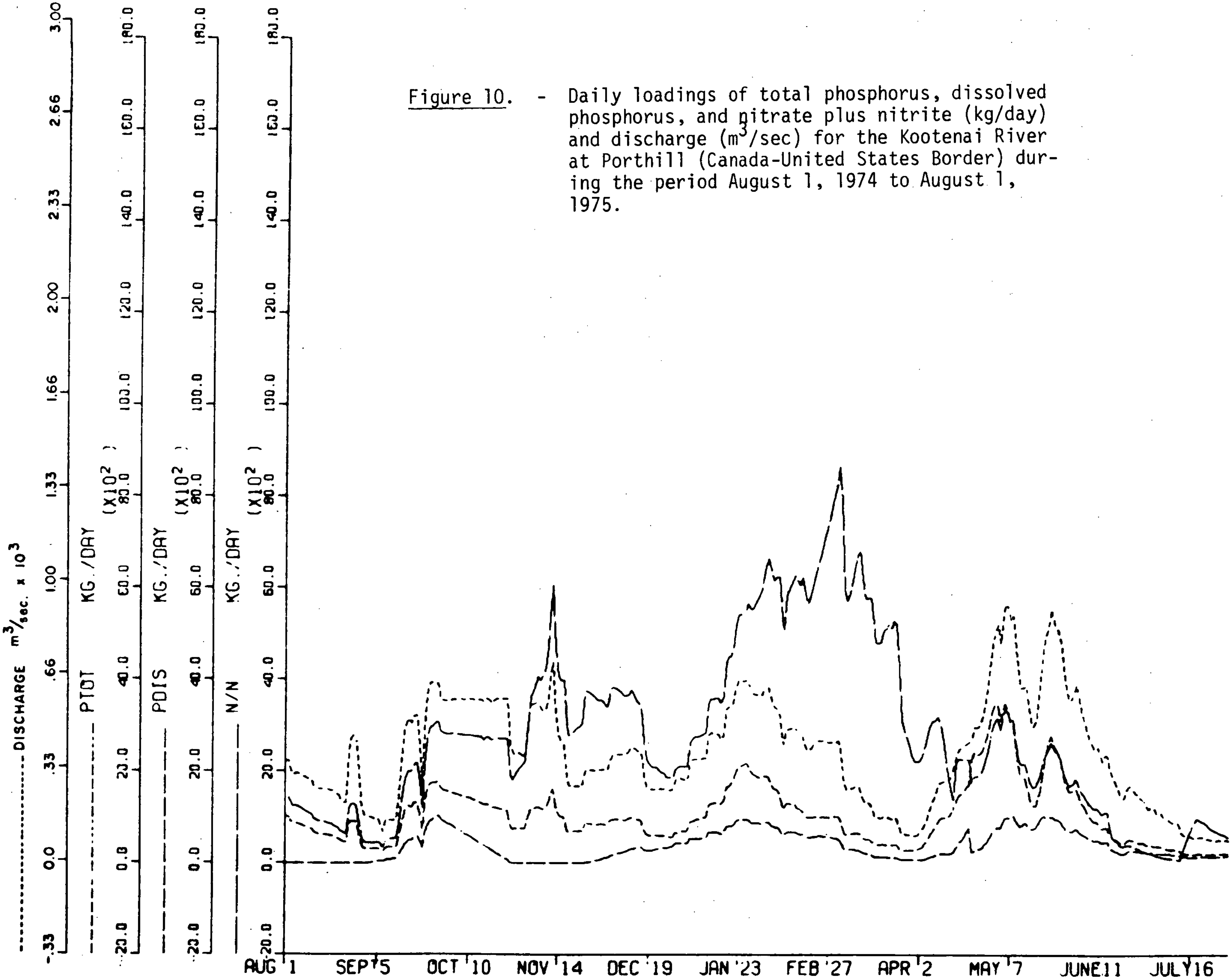


Figure 10. - Daily loadings of total phosphorus, dissolved phosphorus, and nitrate plus nitrite (kg/day) and discharge (m^3/sec) for the Kootenai River at Porthill (Canada-United States Border) during the period August 1, 1974 to August 1, 1975.

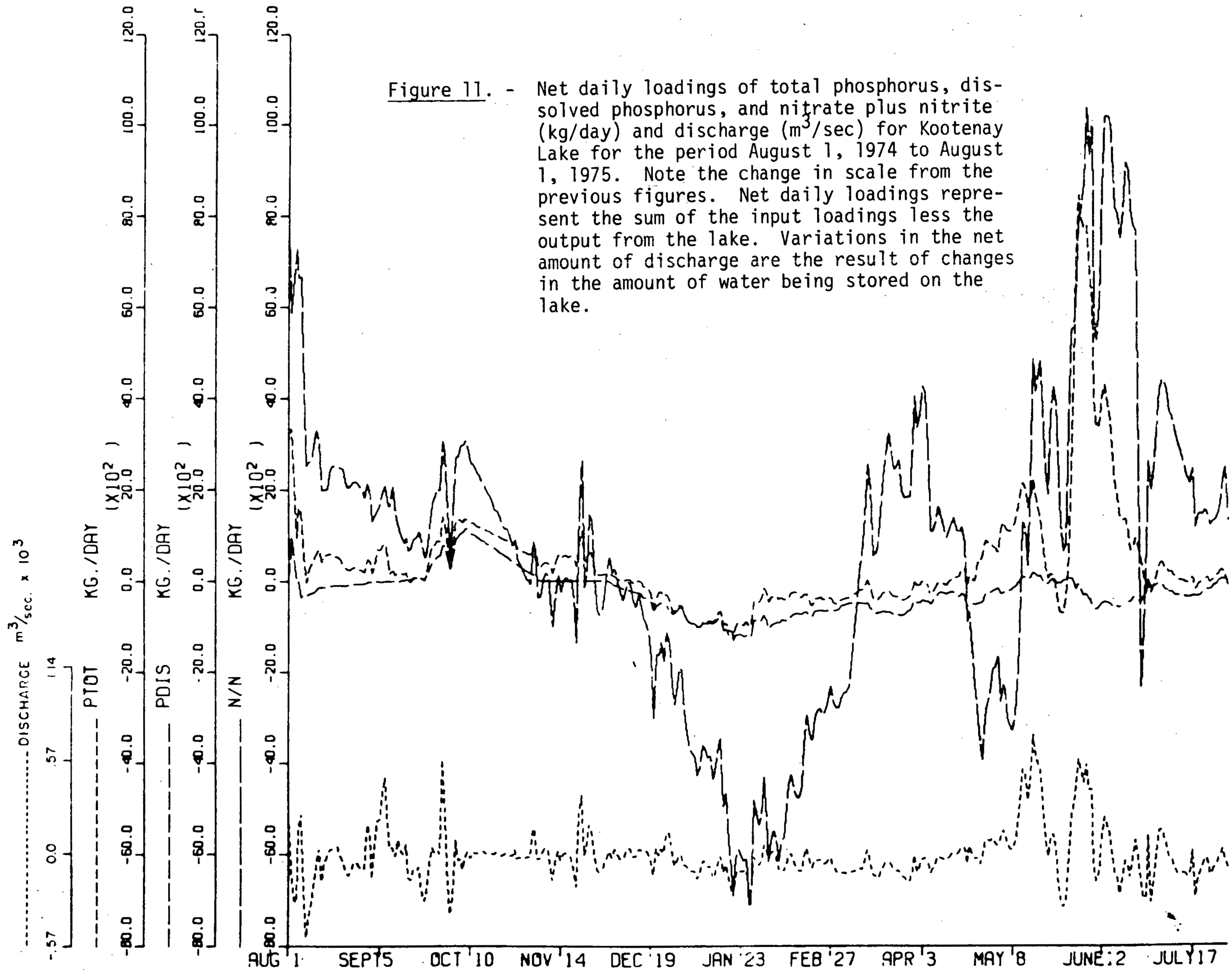


Figure 11. - Net daily loadings of total phosphorus, dissolved phosphorus, and nitrate plus nitrite (kg/day) and discharge (m^3/sec) for Kootenay Lake for the period August 1, 1974 to August 1, 1975. Note the change in scale from the previous figures. Net daily loadings represent the sum of the input loadings less the output from the lake. Variations in the net amount of discharge are the result of changes in the amount of water being stored on the lake.

This peak was reflected in the net loadings to Creston. Again this pattern reflects the massive loading of material which occurred during freshet and the subsequent winter, discharge.

2. ANNUAL LOADINGS

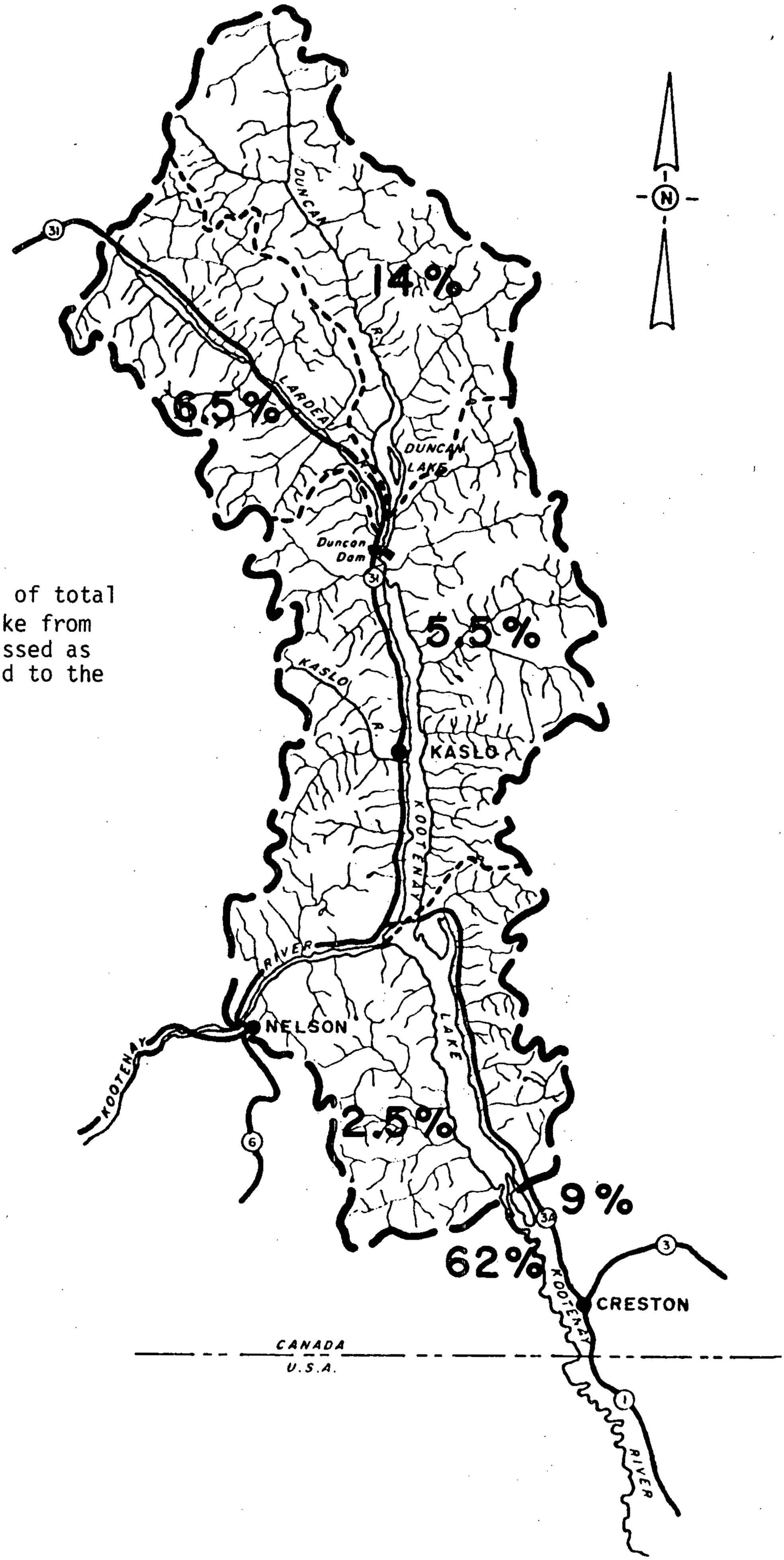
The numbers discussed in this section are the totals of the daily loadings for the period beginning July 31, 1974 and ending July 31, 1975. The yearly totals with 95% confidence intervals are given in Table 1.

TABLE 1

Estimated annual loadings at various stations (kg x 10^3). Confidence intervals are 95%.

	TOTAL - PHOSPHORUS	DISSOLVED PHOSPHORUS	$NO_3 + NO_2$
DUNCAN RIVER	112.25 ± 116.05	11.89 ± 7.00	418.19 ± 47.03
LARDEAU RIVER	51.43 ± 19.01	21.83 ± 33.58	203.50 ± 30.01
NORTHERN TRIBUTARIES	43.32 ± 22.50	8.43 ± 1.95	203.59 ± 33.57
SOUTHERN TRIBUTARIES	19.79 ± 5.54	9.07 ± 2.51	109.63 ± 39.29
KOOTENAY RIVER - EAST CHANNEL	72.00 ± 8.56	28.03 ± 7.35	83.88 ± 15.93
KOOTENAY RIVER - WEST CHANNEL	490.48 ± 74.36	179.40 ± 41.53	944.71 ± 333.73
TOTAL TO LAKE	789.27 ± 141.31	258.65 ± 54.46	1963.50 ± 342.66
OUTPUT AT FRASER NARROWS	633.25 ± 128.35	352.171 ± 131.02	1753.70 ± 317.52
NET DIFFERENCE	-156.02 ± 190.90	93.52 ± 141.88	-209.80 ± 467.16
KOOTENAI RIVER - AT PORTHILL	492.30 ± 65.90	341.70 ± 260.90	1035.20 ± 353.90
GOAT RIVER	17.73 ± 8.34	4.46 ± 1.56	27.36 ± 14.34
PORTHILL + GOAT	510.03 ± 66.43	346.16 ± 260.90	1062.56 ± 354.20
EAST CHANNEL & WEST CHANNEL	562.48 ± 74.85	207.43 ± 42.17	1028.59 ± 334.11
DIFFERENCE	+ 52.45 ± 100.07	-138.73 ± 264.30	- 33.97 ± 486.91

Figure 12. Contribution of total phosphorus to Kootenay Lake from each of the inputs, expressed as percent of the annual load to the lake from all sources.



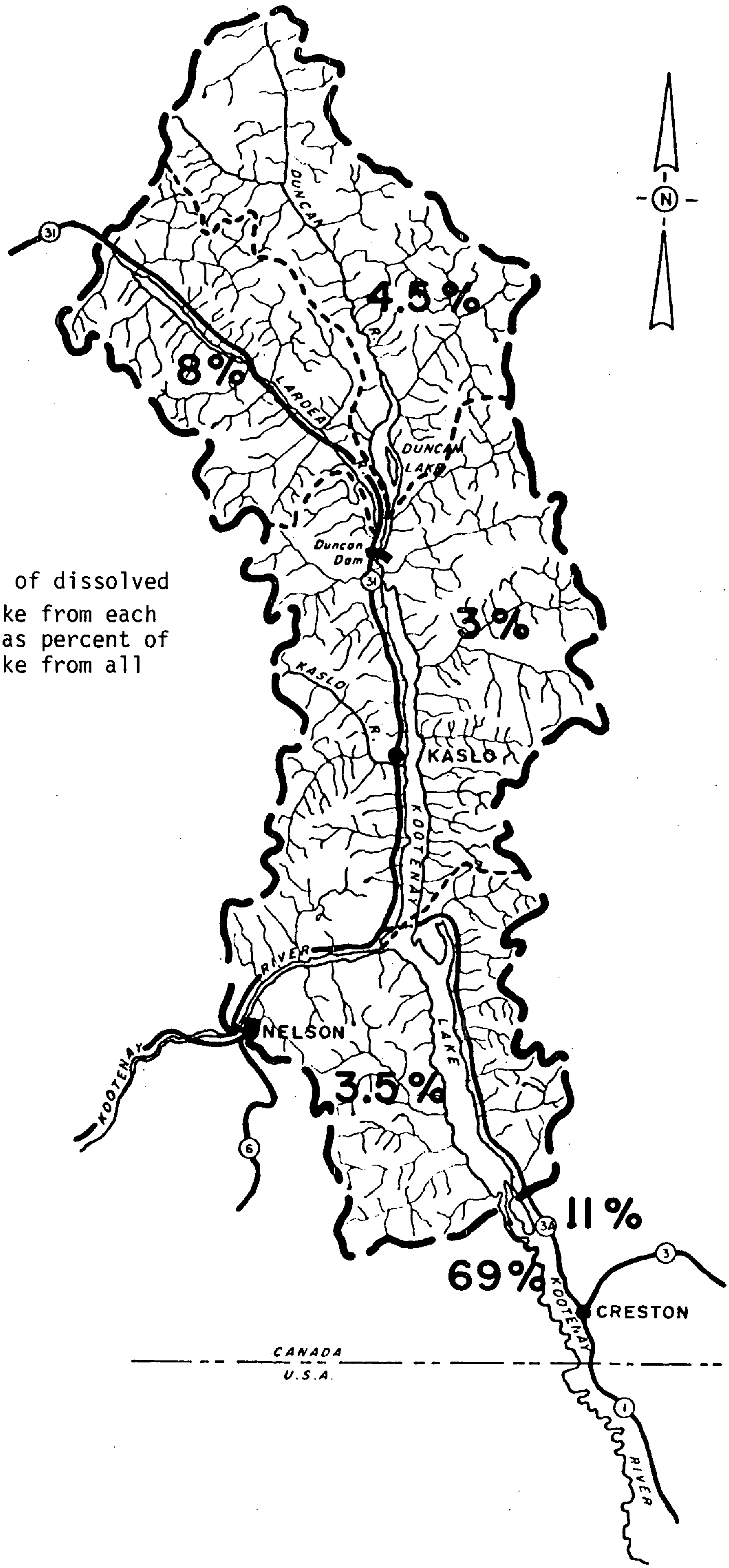


Figure 13. Contribution of dissolved phosphorus to Kootenay Lake from each of the inputs, expressed as percent of the annual load to the lake from all sources.

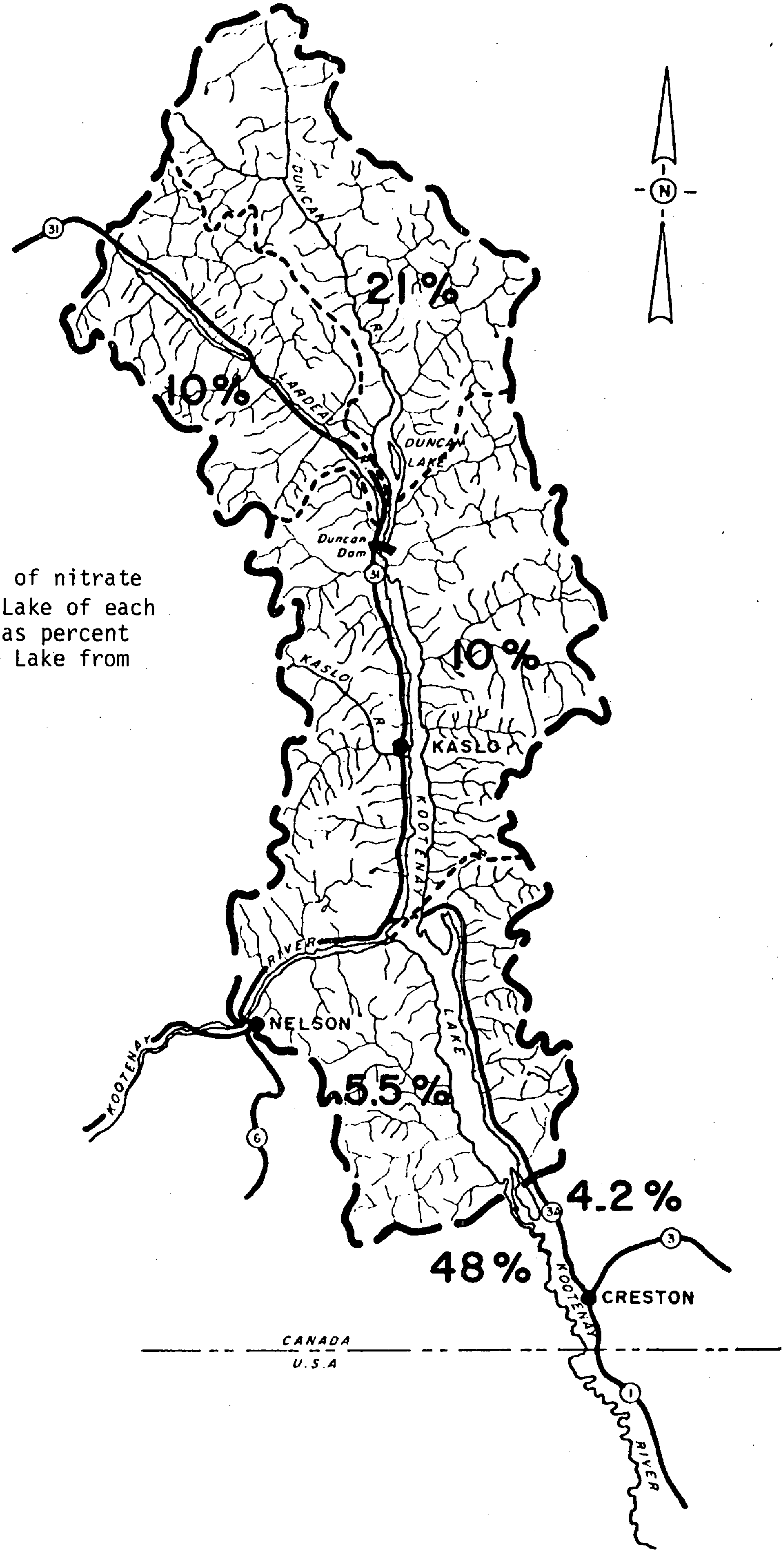


Figure 14. Contribution of nitrate plus nitrite to Kootenay Lake of each of the inputs, expressed as percent of the annual load to the Lake from all sources

2.1 Duncan River

Estimates of total phosphorus loading in the Duncan River are imprecise. The confidence limits associated with the estimate reflect a high frequency of the occurrence of outliers. Hence the estimate of 112.25×10^3 kg is expected to be high. This represents 14% of the total phosphorus entering the lake. (Figure 12). Dissolved phosphorus loading in the Duncan River represents 4% of the total input to the lake. (Figure 13). Nitrate nitrite contribution to the lake was quite substantial, being 21% of the total to the lake. (Figure 14).

2.2 Lardeau River

A second estimate of loading of total phosphorus was obtained for the Lardeau River. This was the only station at which total phosphorus concentration was found to be related to discharge. The regression equation determined was:

$$[P]_{\mu g/l} = 3.32 + 0.463 \times \text{Flow } (m^3/sec)$$

with $F_b = 28.55$ ($p < .01$) with F_b being the ratio of the error explained by the regression to the unexplained error.

This equation was then used to calculate the loading of total phosphorus. A loading of total phosphorus estimated by this method was 81×10^3 kg/year. The higher values associated with the regression estimates have been observed elsewhere (Kleiber and Erlebach, 1977). In undertaking of studies of this type the statistical model chosen can have a large effect on the estimates made.

The 81 tonnes of total phosphorus represents 10% of the total phosphorus entering the lake. Dissolved phosphorus and nitrate plus nitrite represent 8% and 10% respectively.

2.3 Northern Tributaries

Of the total contributions to the lake of total phosphorus, dissolved phosphorus and nitrate plus nitrite for the collective northern tributaries was 5%, 3% and 10% respectively.

2.4 Southern Tributaries

Loadings of total phosphorus and nitrate plus nitrite for the southern tributaries were much less than the northern tributaries. Here total phosphorus was 2.5% of the total to the lake, dissolved phosphorus 3% and nitrate plus nitrite 6%.

2.5 East Channel of the Kootenay River

Contribution of total phosphorus to the lake by the East Channel of the Kootenay River was 9% of the total. Dissolved phosphorus and nitrate plus nitrite account for 11% and 4% respectively.

2.6 West Channel of the Kootenay River

The major contributor of material to Kootenay Lake was the West Channel of the Kootenay River. Total phosphorus contribution was 62% of the total to the lake. Similarly dissolved phosphorus contribution was 69% and nitrate plus nitrite was 48%.

2.7 Fraser Narrows

The magnitude of the loadings was greater in the outlet from the lake than in any one of the contributors. It should be noted that the confidence limits about the loadings are quite large. This is attributable to the same mechanism as in the Duncan River, that is the frequency of outliers among the concentration measurements.

2.8 Goat River

The contributions of nutrients from the Goat River were very small. Of the contribution to the lake through the East and West Channels of Kootenay Lake total phosphorus from the Goat River represents 3%, dissolved phosphorus 1% and nitrate plus nitrite 2%.

2.9 Kootenai River at Porthill

Total phosphorus loading at Porthill was 97% of the combined east and west channel loads. Dissolved phosphorus loading exceeds that of the combined east and west channels, as does nitrate plus nitrite. Associated with these two are broad confidence limits. Again, these are the result of the random occurrence of outliers in the concentration measurements.

2.10 Net Loading to Kootenay Lake

The results of this study suggest that there is not a significant difference between the loadings of the inputs to the lake and the output from the lake. (Table 1). The results do suggest the following. Total phosphorus and nitrate plus nitrite are retained in the lake, while some conversion to dissolved phosphorus may occur. The retention of phosphorus may be on the order of 10% of the total input to the lake, and 11% of the nitrate plus nitrite.

2.11 Net Loadings through Creston Valley

There are apparent discrepancies which exist between the sum of the inputs to the Creston Valley (i.e. Kootenai River at Porthill + Goat River) and the sum of the loads from the East and West Channel. It is felt that these differences result because of overestimates of loadings of dissolved phosphorus and nitrate plus nitrite, as was noted in section (2.9). These apparent discrepancies are not significant at the 95 percent confidence level.

DISCUSSION

Damming rivers alters their natural flow but provides some beneficial effects such as flood control and power generation. The effect of dams, however, on ecosystems is not well understood. The creation of an impoundment which alters the natural flows may produce changes in biota. One concern in this respect could be the alteration of the supply and retention period of primary nutrients reaching the waters of the lake and their retention over a period of time.

An impoundment can alter the pattern of loading in a variety of ways. The creation of an impoundment or reservoir reduces water velocity which allows materials which would normally be suspended to settle out. This would reduce the concentrations of particulate nutrients in the water leaving the impoundment. A reservoir which stores water during freshet and is drawn down during the period of normally low-flow conditions, will change the normal pattern of nutrient transport.

1. COMMENT ON LOADING ESTIMATES

Loadings of materials which have wide confidence limits tend to be overestimated. This results from the occurrence among the concentration measurements of "outliers". Outliers occur randomly throughout all data. In the measurements used, outliers are always "high". This affects the mean concentration with an increase in magnitude proportional to the magnitude of the outliers and to the frequency with which they occur.

There is no basis for removing outliers from the data set since they occur at all stations in a random manner. The effect of outliers on estimates of the mean concentration and its variance is reduced by increasing the number of samples taken at stations where the frequency of outliers is high.

2. UNCONTROLLED TRIBUTARIES

All of the uncontrolled tributaries contributed the most significant portion of their annual load to Kootenay Lake during freshet. In general the total loadings contributed by individual streams and rivers was relatively minor. The contribution by all the uncontrolled tributaries of total phosphorus was 17% of the total to the lake. Similarly dissolved phosphorus contribution was 15% and nitrate plus nitrite 20%.

In these (Lardeau River, Northern and Southern Tributaries) the magnitude and duration of the freshet were the most significant factors affecting the loading of materials to Kootenay Lake.

3. CONTROLLED TRIBUTARIES

3.1 Duncan River

The Duncan River contributes significant amounts of both total phosphorus and nitrate plus nitrite to Kootenay Lake. (Figure 12, Figure 14). Contribution of dissolved phosphorus was small.

The operation of Duncan Dam disturbs the natural seasonal pattern of nutrient loading to Kootenay Lake. The most significant feature is the enhancement of winter loadings at a time when algal growth is minimal. Other parameters such as temperature and quality of light are likely to be limiting factors during the winter months.

3.2 East Channel of Kootenay River

The loading of nutrients to Kootenay Lake occurred at a minimal level throughout the year. When compared to the West Channel both forms of phosphorus approximated the 13:87 flow ratio used. However, the loading of nitrate plus nitrite represents only 8% of the total contribution of the two channels.

Possibly the reduction in the nitrate plus nitrite loading may be attributed to utilization during the period of residence in this reach. Interchange of water associated with Duck Lake ponding, and reported blooms of blue-green algae (Ennis, personal communication) may have played a role in the reduction of nitrate plus nitrite concentrations during certain periods of the year.

3.3 West Channel of Kootenay River

The nutrients which entered Kootenay Lake by way of the West Channel of the Kootenay River represented the largest percentage of the total input. The nitrate plus nitrite contribution represents 53% of the yearly total. In any future monitoring this station should be studied most intensively.

The seasonal pattern of nutrient loadings to Kootenay Lake were affected by the operation of the Libby Dam. The fluctuation in the volume of water released at the Libby Dam was substantially reduced by the time it reached the entrance to Kootenay Lake. The effect of the Libby Dam on the loading of nutrients to Kootenay Lake through the West Channel of the Kootenay River was to act in a pattern similar to that described for the Duncan Dam. That is the storage of water in the reservoir behind the dam at different periods of the year with subsequent drawdown lowered the peak of flow and altered the seasonal pattern of the loading pattern of nutrients. This pattern was complicated by the addition of water from a series of tributaries such as the Moyie, Yahk and Fisher Rivers.

3.4 Kootenai River at Porthill

Loadings of nutrients in the Kootenai River at Porthill were very similar to that which was found in the West Channel both in seasonal pattern and magnitude. The Goat River falls in the same category as the other uncontrolled rivers. There was a substantial increase in flow and magnitude of the nutrient loadings.

3.5 Fraser Narrows

The net loss of the nutrients from the lake occurred to the greatest degree during the winter months (Figure 11). This likely reflects the vertical mxing of the lake which was highly stratified during the late summer. The vertical mixing resulted in bringing to the surface of water which was much higher in nutrient concentrations. This was reflected in the concentration measurements (see Appendix). This was especially noticeable for nitrate, and suggests that nitrate was accumulated at a certain depth or high nitrate water from the northern tributaries entered the lake and proceeded to sink to a depth based on the density regime present.

4. NET DAILY LOADINGS

4.1 Net Daily Loadings to Kootenay Lake

The pattern of net loadings as shown in Figure 11 reflects the net occurrence of the inputs and the discharge from the lake. This was very important when the loading to the lake was considered. Massive amounts of both phosphorus and nitrate were added to the waters of the lake during freshet. The freshet loading accounted for 85 - 90% of the total annual loading. This material was retained within the lake until the following winter when the greatest portion of the nutrient discharge occurred. Almost all of the total loadings reported in Table 1 entered the lake during the early months of the summer. The loadings represent the amount which remained subsequent to winter discharge. Subsequent studies should be designed to reflect this situation, the loadings being established in connection with the following winter. In this respect the estimates in Table 1 may be quite erroneous as they reflect the discharge from the lake after a freshet which was not the one which had been monitored. Future studies should be established to ensure that, in the case of reservoirs, impoundments and lakes where this situation might arise, the study commences prior to the freshet period rather than beginning and ending during freshet. Studies of this nature should also be extended for a period of time which covers the effective residence time of the lake.

5. NUTRIENT BUDGETS

Kootenay Lake appeared to be acting as a sink for nutrients, with the above reservations, since annual input exceeded annual output. It was estimated that Kootenay Lake retains 156 ± 191 tonnes of total phosphorus and 210 ± 467 tonnes of nitrate plus nitrite.

Although these estimates were relatively large, it was most important to consider these values in relation to all the available information. Since these were annual values they reflected the total input less the total output. When the timing of the loadings to and from the lake (as shown in Figure 11) was considered it was noted that the net loading to the lake occurred to the largest degree during freshet while the largest output from the lake occurred during the following winter, presumably when the stratification of the lake was broken down.

The major portion of nutrient loadings occurred during the productive summer months, increasing the amounts available for algal growth and maintenance. High levels of suspended solids in the East and West Channels may limit the amount of light available for algal growth. The discharge of nutrients through Fraser Narrows during late winter coincided with the breakdown of stratification of the lake. This may explain why the nutrients which were loaded into the lake did not create algal blooms.

CONCLUSIONS

1. Kootenay Lake received the bulk of its nutrient load during the period of freshet with the notable exception of the Duncan River where operation of the reservoir shifted the nitrate plus nitrite loading to the winter drawdown period.

2. The source of highest input of nutrients to Kootenay Lake was the West Channel of the Kootenay River which accounted for an estimated 62% of the total phosphorus, 69% of the dissolved phosphorus, and 48% of the nitrate plus nitrite that entered the lake. Future estimates of the loadings for this area should be based on the largest number of samples possible.

3. The concentration of nitrate plus nitrite was found to be substantially higher in the Duncan and Lardeau Rivers than in the others. (Appendix) This phenomenon might be related to logging practices in these two watersheds, atmospheric contributions or to the mineralogy of the area. This phenomenon warrants further consideration.

RECOMMENDATIONS

1. Studies of this nature should begin during the stable low-flow conditions which exist during the winter months and continue throughout the effective residence time of the system being assessed.

2. When outliers are found to exist in the concentration measurements, efforts should be made to increase the intensity of sampling. This will reduce the relative impact of outliers in mean concentration and on its variance, if the frequency of the occurrence of outliers does not increase in proportion to the number of samples.

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APPENDIX - Concentration data used in load calculations

STATION	PARAMETER	$\bar{C}$ (mg/l)	$V\bar{c}$	N^1	G^2
DUNCAN RIVER	TOTAL PHOSPHORUS	.03834	.00040336	172	29
	DISSOLVED PHOSPHORUS	.00406	.00000143	58	19
	$NO_2 + NO_3$	.14285	.00006623	184	31
LARDEAU RIVER	TOTAL PHOSPHORUS	.03063	.00003327	192	32
	DISSOLVED PHOSPHORUS	.01300	.00010000	60	18
	$NO_2 + NO_3$	.12120	.00008214	202	33
NORTHERN TRIBUTARIES	TOTAL PHOSPHORUS	.02008	.00002815	441	74
	DISSOLVED PHOSPHORUS	.00390	.00000019	35	12
	$NO_2 + NO_3$	.09438	.00006263	439	74
SOUTHERN TRIBUTARIES	TOTAL PHOSPHORUS	.01090	.0000024	275	46
	DISSOLVED PHOSPHORUS	.00499	.0000004	24	8
	$NO_2 + NO_3$	.06039	.0001208	247	46
KOOTENAY RIVER EAST CHANNEL	TOTAL PHOSPHORUS	.03446	.00000705	310	52
	DISSOLVED PHOSPHORUS	.01260	.00000212	56	17
	$NO_2 + NO_3$	.06639	.00014209	320	54
KOOTENAY RIVER WEST CHANNEL	TOTAL PHOSPHORUS	.03386	.00000418	309	52
	DISSOLVED PHOSPHORUS	.01318	.00000298	60	18
	$NO_2 + NO_3$	.03945	.00001450	319	54
FRASER NARROWS	TOTAL PHOSPHORUS	.02131	.0000048	461	76
	DISSOLVED PHOSPHORUS	.01185	.0000048	62	18
	$NO_2 + NO_3$	.05903	.0000295	465	77
GOAT RIVER	TOTAL PHOSPHORUS	.02086	.00002447	100	17
	DISSOLVED PHOSPHORUS	.00525	.00000071	12	4
	$NO_2 + NO_3$	.03220	.00007244	102	17
KOOTENAI RIVER AT PORTHILL	TOTAL PHOSPHORUS	.03175	.00000464	161	27
	DISSOLVED PHOSPHORUS	.02203	.00007077	57	17
	$NO_2 + NO_3$	.06676	.00013376	174	28

1 - Total number of concentration measurements.
2 - Total number of replicate samplings (includes different days and different sites at station).