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TEMPORAL DYNAMICS OF PHOSPHORUS IN TWO ALBERTA STREAMS

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled TEMPORAL PHOSPHORUS DYNAMICS FOR TWO ALBERTAN STREAMS submitted by NANCY L. MUNN in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

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Abstract

The influence of changes in discharge and season on the concentration, partitioning, and export of a limiting nutrient, phosphorus, was quantified for two streams in central Alberta from April to October, 1983. The streams, Two Creek and Sakwatamau River, flow over glacial till overlying sedimentary bedrock and are located on coniferous watersheds. Phosphorus (P) was quantified in three size fractions: 1) total dissolved phosphorus (TDP; <0.45 *u*m), 2) fine particulate phosphorus (FPP; 0.45 *u*m - 1 mm), and 3) coarse particulate phosphorus (CPP; >1 mm). Total phosphorus (TP) is the sum of TDP and FPP.

During 1983, 13.04 mg P/m² of watershed was transported past the Two Creek sampling station and 7.49 mg P/m² was transported past the Sakwatamau River sampling station; 72% of the P load was in the FPP fraction for both streams. Phosphorus export was strongly pulsed during storm events; in Two Creek, 42% of TP was exported with 19% of the water in 2% of the time. Export of FPP was more strongly pulsed than was export of TDP; in Two Creek 75% of FPP was transported within the same time period as 47% of TDP transport. Surprisingly, spring runoff was not the most significant period for P export. In fact, 65% of annual P loading was transported in June and 29% in July in Two Creek. This was probably due to low winter snowfall relative to eastern watersheds and heavy rainstorms with overland flow during late June and early July. Coarse particulate P contributed minimally to P export (0.4 mg/m² and 0.02 mg/m² for Two Creek and Sakwatamau River, respectively).

Models to predict P export were developed for the study streams. In these streams, discharge and FPP concentration were positively correlated. A nonlinear model to predict FPP concentration from discharge, which included rate of change of discharge, was significantly better than a linear model for the study streams. There were no significant differences in the relationship between FPP and discharge in different seasons. Total DP was also positively correlated to discharge in both streams although the slope of TDP concentration on discharge was significantly lower than the slope of FPP on discharge.

Stream sampling methodologies for collecting water samples were evaluated. When replicate grab samples were collected, there were no significant differences in TP and TDP concentrations in either stream. Similarly, when samples were collected across the width of either stream, there were no differences in FPP or TDP concentrations on any of the dates sampled. Thus, the grab sample technique used in this study was adequate to estimate P concentrations in streamwater. Also, there were no diel patterns in P concentrations in Two Creek and Sakwatamau River.

The results of longitudinal transport of P in Two Creek suggest seasonal trends in size of materials in transport due to significant differences in both TDP and FPP concentrations between August and October. However, TDP or FPP concentrations did not change significantly along 3390 m of Two Creek in August or in October suggesting no longitudinal trends in size of materials in transport. I postulate that in Two Creek, greater transport of particulate material during summer than autumn was primarily due to higher flows and not invertebrate processing.

This study concurs with earlier predictions that abiotic factors, such as watershed land use, bedrock geology, and climatic regimes, all influence P export patterns. However, this study suggests that P export coefficients based on watershed area may not be an appropriate export expression for forested streams overlying sedimentary bedrock.

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An undergraduate limnology course taught by my supervisor, Dr. Ellie Prepas, was the impetus for this study. I thank Dr. Prepas for her enthusiasm and support. Members of my committee, Dr. David Boag, Dr. Lynda Corkum, Dr. Richard Rothwell, and Dr. Trefor Reynoldson provided helpful advice. Dr. Rothwell kindly provided necessary sampling equipment and the Boreal Institute for Northern Studies provided the use of a field trailer which was indispensable.

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Table of Contents

Chapter Page

List of Tables

List of Figures

I. General Introduction

Transfers of matter or energy involving one or more ecosystem component have been studied in attempts to understand stream ecosystem processes and functioning (e.g., Cummins 1974, Likens and Bormann 1974, MacMahon et al. 1981). Phosphorus (e.g., Hobbie and Likens 1973, Cahill et al. 1974, Johnson et al. 1976, Meyer and Likens 1979, Rigler 1979, Hill 1982) and carbon (e.g., Hobbie and Likens 1973, Wetzel and Manny 1977, Tate and Meyer 1981, Wallace et al. 1982) are two frequently studied components. Phosphorus (P) is relatively insoluble and unlike other nutrients such as carbon and nitrogen, P has no gaseous form. Although P is found in low levels in natural water, it is essential for algal and higher plant growth. The addition of P to surface waters can enhance autotrophic production and rates of detrital processing (Schindler 1977, Stockner and Shortreed 1978, Elwood et al. 1981). For these reasons, P is often considered to limit production in undisturbed aquatic systems. Thus, by defining the energy pathways of a fundamental component such as P, key processes in a stream ecosystem may be predicted from deterministic and stochastic changes in the ecosystem.

To understand the energy dynamics of an essential component, it is necessary to define the inputs and outputs to the ecosystem. Meyer and Likens (1979) present the most rigorous example of this approach at Bear Brook, an undisturbed headwater stream in the Hubbard Brook Experimental Forest, New Hampshire. A P mass balance was constructed for Bear Brook for a 13-yr period based on an empirical model of the annual budget. Nutrient inputs were quantified in three size fractions: 1) total dissolved P (<0.45 um), 2) fine particulate P (0.45 um - 1 mm), and 3) coarse particulate P (>1 mm). Phosphorus inputs to Bear Brook for all three size fractions were from precipitation, subsurface waters, tributaries, and leaf litter falling directly into the stream. The important exports were all fluvial. In Bear Brook, P accumulated and was processed in the stream ecosystem on most days of the year. Export was confined to short periods of high stream discharge, and the ratio of P outputs to inputs was directly related to annual streamflow. The net effect of ecosystem processes at Hubbard Brook was the conversion of dissolved P and coarse particulate P into fine particulate P, which was then transported downstream.

However, most studies have more limited objectives; they quantify exports to downstream water bodies (e.g., Hobbie and Likens 1973, Johnson et al. 1976, Ongley 1976, Wartiovaara 1978, Rigler 1979, Hill 1981). The "export coefficient" approach (mass per unit area of watershed) is used to study the effect of one ecosystem component on another, such as the effect of land use, pollution, and nutrient fertilization on nutrient levels in streams or lakes (e.g., Ryden et al. 1973, Dillon and Kirchner 1975, Omernik 1977, Rast and Lee 1978, Stockner and Shortreed 1978), and has influenced the development of nutrient loading calculations for eutrophication management. This approach has also been used to determine the effect of clear-cutting on P export (e.g., Bormann et al. 1968, Hornbeck 1975) and to study seasonal changes in loading. Temporal or season-related changes in the ecosystem (e.g. snowmelt and storm events) influence P export and can vary from year-to-year (Meyer and Likens 1979). Seasonal variation in P export has received increased attention in recent years because natural ecosystem variation must be understood before variation can be attributed to perturbations such as logging. I will discuss the effects of temporal changes on P export in more detail later.

Approaches that focus on nutrient inputs and outputs to streams give information only on net transfers and not on transformations within the system. For example, P in a decomposing leaf may be assimilated into fungal hyphae; both compounds are a similar size fraction (>1 mm) even though they are very different compounds (Meyer 1978). While Meyer (1978) and earlier stream biologists largely ignored this type of processing in their ecosystem studies, emphasis has recently been placed on understanding physical, chemical, and biological processes that control material cycling (e.g., Newbold et al. 1982, Minshall et al. 1983). The cycling concept (termed spiralling) theorizes that the productivity and persistence of stream ecosystems depend on the retention and recycling of nutient and energy resources from the surrounding watershed as they are transported downstream (Newbold et al. 1982). Also, the degree of retention and reutilization of nutrients in a stream is associated with the "tightness" of the spirals (Webster 1975).

Newbold and his colleagues (1982) at the Oak Ridge National Laboratory in Tennessee constructed a steady-state model to predict spiralling length of a limiting nutrient. A complete cycle was considered to consist of biotic uptake of a nutrient atom from an available dissolved state, subsequent passage through the food chain, and ultimate return to the water in an available dissolved form. Soluble reactive P (SRP) was measured as an estimate of biologically available dissolved P. The model was based on five assumptions: (1) the system is in steady-state, (2) microbial growth and algal photosynthesis are limited through a concentration limitation on nutrient uptake kinetics, (3) all available P is within the SRP form, (4) all SRP is available, and (5) soluble unreactive P is not important. The model predicts that most downstream transport of the nutrient occurs in an unavailable particulate form when nutrient limitation is severe but when "nutrient limitation is moderate", transport in the dissolved phase dominates and how well particles are transported has little influence on spiralling length. However, the terms "moderate" and "severe" nutrient limitation have never been operationally defined. The nutrient spiralling model is important theoretically because it can incorporate the potential role of invertebrate consumers on nutrient dynamics and could be elaborated to incorporate other levels of the food web (e.g. fish). In a recent study, radioactive P was released into a woodland stream in Tennessee and its uptake from water to coarse particulate organic matter (CPOM), fine particulate organic matter (FPOM), aufwuchs, grazers, etc., was measured (Newbold et al. 1983). In this study, the average velocity of P travelling downstream was 10.4 m/d and P completed the cycle once every 18.4 d. The average downstream distance associated with one cycle, defined as spiralling length, was therefore 190 m (10.4 m/d X 18.4 d). Coarse particulate organic matter accounted for 60% of the uptake although FPOM transport accounted for 99% of the particulate turnover length due to a slow turnover time (99 d). As well, P retention within the stream community was high; Newbold and his colleagues attribute this to low drift rates of consumers and a long turnover time for P (152 d) within the consumer community.

Another approach for defining stream ecosystem processes is the river continuum concept. It was developed to describe gradual changes in ecosystem structure, function, and stability along the length of a stream (Vannote et al. 1980). This concept predicts that as stream size increases, the reduced importance of allochthonous organic input coincides with the enhanced significance of autochthonous primary production and organic transport from upstream; the latter is reflected by an increase in the ratio of gross primary productivity to community respiration (see Vannote et al. 1980). Unlike the nutrient spiralling model, the river continuum concept is based on a dynamic equilibrium whereby producer and consumer communities characteristic of a river reach become established in harmony with dynamic physical conditions of the channel. However, the river continuum concept is too general, and deviations from expected patterns are too easily explained (e.g. Minshall et al. 1983).

It is apparent that stream ecosystem studies are elaborate and time consuming. Thus, it is important to have well defined goals within budget and time constraints. A decade ago, many studies were conducted to evaluate the effect of land use on P loading in different biomes (e.g. Dillon and Kirchner 1975, Omernik 1977, Rast and Lee 1978). Most of these projects were government directed with eutrophication-control goals. In these projects, many different streams were sampled once every two to three weeks. Dillon and Kirchner (1975) listed annual P export values for streams situated in watersheds with different geology and land use from all over the world. The most widely used theoretical export coefficients for nutrient budgets were based on data from 34 watersheds in southern Ontario (Dillon and Kirchner 1975) or on data from all across the United States (Rast and Lee 1978). More recently, Meyer and Likens (1979) and Rigler (1979) demonstrated that most P export values reported in the literature are underestimates of actual loading because the data are derived from inadequate sampling regimes (2-3 wk intervals) which neglected short-term changes resulting from storm runoff (see Table 1.1). Stevens and Smith (1978) made a comparison between loading values obtained from 2-8 h sampling intervals versus 8 d sampling intervals over a 102 d period. They found particulate P was underestimated by 43% with 8 d as compared to 2-8 h sampling intervals; elevated particulate P concentrations during short periods of high discharge were missed with the 8 d routine. Also, soluble reactive P (potentially, the fraction of dissolved phosphorus that is available for uptake) was overestimated by 12% with the 8 d routine because soluble reactive P concentration decreased at high discharge due to dilution by rainwater. A similar comparison was done for a moorland stream in England; annual export was recalculated as if the samples had been only collected on a weekly or monthly basis (Rigler 1979). Both weekly and monthly export calculations were significantly less than 'true annual export' based on an intensive sampling program. Thus, loading values in empirical models based on a 1-2 wk sampling interval are poor estimates and require refinements.

Regional variations in general ecosystem characteristics (e.g. geology, slope), timing of seasonal events, and stochasticity of storms result in a variety of loading patterns. A stream in rural New York (43% agricultural land) exported 75% of annual P during highest flows which covered only 10% of the time (Johnson et al. 1976). During snowmelt runoff, 50% of total annual P export was transported from two contour-farmed Iowa watersheds (Alberts et al. 1978). In only 10 days, 67% of the annual P export was transported from a forested stream in New Hampshire (Meyer and Likens 1979). A large portion of annual stream P inputs can occur within the first few days or hours of spring runoff in Arctic streams (de March 1975, H.E. Welch, Freshwater Institute, pers. comm.). Thus, P loading data exhibit strong temporal and seasonal trends, generally with peaks during snowmelt and storm events.

Regional variations exist in the relationship between P concentration and discharge. Increasing discharge resulted in marked increases in total P concentration, especially in the fine particulate fraction, for: (1) a forested stream (Bear Brook) on the Precambrian Shield (Meyer and Likens 1979), (2) grazed moorland streams of Dartmoor, England (Rigler 1979), and (3) arctic streams entering Char Lake (de March 1975). In Bear Brook and the Dartmoor streams, increases in P concentration during floods were larger during ascending than descending stage of the hydrograph, and P increases were greater in summer than winter

(Meyer and Likens 1979, Rigler 1979). In these two streams, most of the P increase during flooding was in the particulate fraction; Rigler (1979) postulated that these increases could be explained if P accumulated on the stream bed during periods of base flow and was resuspended as particulate P during floods. In Bear Brook, the relationship between fine particulate P and discharge varied with season, position of hydrograph, and watershed area. In the moorland streams, dissolved P concentrations increased slightly with an increase in discharge whereas in Bear Brook, there was no significant change in dissolved P concentration when discharge increased. In streams draining Ohio woodlands (Taylor et al. 1971) and in two rivers draining disturbed watersheds in southern Alberta (Bow River and Oldman River), dissolved P concentration and discharge were not related (Ongley and Blachford 1982).

Studies conducted in the larger rivers in western Canada have concentrated primarily on longitudinal trends in P concentration; year-to-year variation was monitored, and effects of dumping urban effluents into the river evaluated (Paterson and Nursall 1975, Tones et al. 1980, Ongley and Blachford 1982). Studies on small streams entering lakes have been conducted for Lake Wabamun (Mitchell et al. 1981), Baptiste Lake (Trew et al. 1978), Cold Lake (Trew et al. 1981), and Nakamun Lake (Riley and Prepas 1984) as part of lake nutrient budgets. Most streams were intermittent. Trew and his colleagues at Alberta Environment (1978) concluded that Rast and Lee's (1978) export coefficients were adequate for streams draining into Baptiste Lake. However, P loading data for both Baptiste Lake and Rast and Lee's loading coefficients were based on inadequate sampling regimes.

Many gaps exist in our knowledge of patterns in stream phosphorus. Good export coefficients have yet to be developed for watersheds on glacial till. Loading values have never been presented on a seasonal basis for non-shield streams and this may be important in the design of monitoring programs. As well, the relationship between P concentration and discharge has never been adequately tested for undisturbed streams on glacial till. The contribution of coarse particulate P to P loading has been investigated for only one stream, Bear Brook, which is in a deciduous forest and flows over igneous bedrock (Meyer and Likens 1979). Also, the standard approach for sampling stream water, the grab sampling technique, has never been tested for adequacy in estimating P concentration in streamwater. In other words, horizontal heterogeneity in stream P concentration at one location has not been evaluated. In this study, I investigated these questions in two undisturbed streams located in a boreal mixed-wood biome in central Alberta; I: (1) investigated the influence of season on P loading, (2) examined the influence of deterministic (e.g. spring runoff) and stochastic (e.g. storm events) changes in the ecosystem on P concentration and partitioning, (3) evaluated the grab sample technique, and (4) developed a model to predict P loading in headwater streams flowing over 3-5 m of glacial till overlying sedimentary bedrock.

A. References

Alberts, E.E., G.E. Schuman, and R.E. Burwell. 1978. Seasonal runoff losses of nitrogen and phosphorus from Missouri Valley Loess watersheds. Journal of Environmental Quality 7:203-208.

Bormann, F.H., G.E. Likens, D.W. Fisher, and R.S. Pierce. 1968. Nutrient loss accelerated by clear-cutting of a forest ecosystem. Science **159**:882-884.

Cahill, T.H., P. Imperato, and F.H. Verhoff. 1974. Evaluation of phosphorus dynamics in a watershed. Journal of the Environmental Engineering Division, American Society of Civil Engineers **100**:439-458.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bioscience **24**:631-641.

de March, L. 1975. Nutrient budgets for a high arctic lake (Char Lake, N.W.T.). Verhandlungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie **19**:496-503.

Dillon, P.J., and W.B. Kirchner. 1975. The effects of geology and land use on the export of phosphorus from watersheds. Water Research **9**:135-148.

Elwood, J.W., J.D. Newbold, A.F. Trimble, and R.W. Stark. 1981. The limiting role of phosphorus in a woodland stream ecosystem: effects of P enrichment on leaf decomposition and primary producers. Ecology **62**:146-158.

Hill, A.R. 1981. Stream phosphorus exports from watersheds with contrasting land uses in southern Ontario. Water Resources Bulletin **17**:627-634.

Hill, A.R. 1982. Phosphorus and major cation mass balances for two rivers during low summer flows. Freshwater Biology **12**:293-304.

Hobbie, J.E., and G.E. Likens. 1973. Output of phosphorus, dissolved organic carbon, and fine particulate carbon from Hubbard Brook watersheds. Limnology and Oceanography **18**:734-742.

Hornbeck, J.W. 1975. Streamflow response to forest cutting and revegetation. Water Resources Bulletin **11**:1257-1260.

Johnson, A.H., D.R. Bouldin, E.A. Goyette, and A.M. Hedges. 1976. Phosphorus loss by stream transport from a rural watershed: quantities, processes, and sources. Journal of Environmental Quality 5:148-157.

Likens, G.E., and F.H. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. BioScience 24:447-456.

MacMahon, J.A., D.J. Schimpf, D.C. Anderson, K.G. Smith, and R.L. Bayn, Jr. 1981. An organism-centered approach to some community and ecosystem concepts. Journal of Theoretical Biology 88:287-307.

Meyer, J.L. 1978. Transport and transformation of phosphorus in a forest stream ecosystem. Dissertation. Cornell University, Ithaca, New York, USA.

Meyer, J.L., and G.E. Likens. 1979. Transport and transformation of phosphorus in a forest stream ecosystem. Ecology 60:1255-1269.

Minshall, G.W., R.C. Patersen, K.W. Cummins, T.L. Bott, J.R. Sedell, C.E. Cushing, and R.L. Vannote. 1983. Interbiome comparison of stream ecosystem dynamics. Ecological Monographs 53:1-25.

Mitchell, P., H. Hamilton, S. Livingstone, B. Rippon, and D. Prosser. 1981. Lake Wabamun eutrophication study-interim report. Alberta Environment, Pollution Control Division. 46p.

Newbold, J.D., J.W. Elwood, R.V. O'Neill, and A.L. Sheldon. 1983. Phosphorus dynamics in a woodland stream ecosystem: a study of nutrient spiralling. Ecology 64:1249-1269.

Newbold, J.D., R.V. O'Neill, J.W. Elwood, and W. Van Winkle. 1982. Nutrient spiralling in streams: implications for nutrient limitation and invertebrate activity. American Naturalist 120:628-652.

Omernik, J.M. 1977. Nonpoint source-stream nutrient level relationships: a nationwide study. EPA-600/3-77-105, United States Environmental Protection Agency, Corvallis, Oregon, USA. 106p.

Ongley, E.D. 1976. Sediment yields and nutrient loadings from Canadian watersheds tributary to Lake Erie: an overview. Journal of the Fisheries Research Board of Canada 33:471-484.

Ongley, E.D., and D.P. Blachford. 1982. Nutrient and contaminant pathways in the Bow and Oldman Rivers, Alberta 1980-1981. Final Report to Environment Canada, Contract OSU80-00056. 107p.

Paterson, C.G., and J.R. Nursall. 1975. The effects of domestic and industrial effluents on a large turbulent river. Water Research **9**:425-435.

Rast, W., and G.F Lee. 1978. Summary analysis of the North American (U.S. portion) OECD Eutrophication Project: nutrient loading-lake response relationships and trophic state indices. U.S. EPA-600/3-78-008. 455p.

Rigler, F.H. 1979. The export of phosphorus from Dartmoor catchments: a model to explain variations of phosphorus concentrations in stream water. Journal of Marine Biology Association of the United Kingdom **59**:659-687.

Riley, E.T., and Prepas, E.E. 1984. The role of internal phosphorus loading in two shallow, productive lakes in Alberta, Canada. Canadian Journal of Fisheries and Aquatic Sciences **41**:(in press).

Ryden, J.C., J.K. Syers, amd R.F. Harris. 1973. Phosphorus in runoff and streams. Advances in Agronomy **25**:1-45.

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes. Science **195**:260-262.

Stevens, R.J., and R.V. Smith. 1978. A comparison of discrete and intensive sampling for measuring the loads of nitrogen and phosphorus in the River Main, County Antrim. Water Research **12**:823-830.

Stockner, J.G., and K.R.S. Shortreed. 1978. Enhancement of autotrophic production by nutrient addition in a coastal rainforest stream on Vancouver Island. Journal of the Fisheries Research Board of Canada **35**:28-34.

Tate, C.M., and J.L. Meyer. 1981. The influence of hydrologic conditions and successional state on dissolved organic carbon export from forested watersheds. Ecology **64**:25-32.

Taylor, A.W., W.M. Edwards, and E.C. Simpson. 1971. Nutrients in streams draining woodland and farmland near Coshocton, Ohio. Water Resources Research 7:81-89.

Tones, P.I., D.T. Waite, and D.A. Fast. 1980. Report on nutrient impact on the South Saskatchewan River. WPC 25A+25B. Saskatchewan Environment, Water Pollution Control Branch. 419p.

Trew, D.O., D.J. Beliveau, and E.I. Yonge. 1978. The Baptiste Lake study summary report. Alberta Environment, Pollution Control Division. 105p.

Trew, D.O., E.I. Yonge, and R.P. Kaminiski. 1981. A trophic assessmetn of nine lakes in the Cold Lake region interim report. Alberta Environment, Pollution Control Division. 70p.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Wallace, J.B., D.H. Ross, and J.L. Meyer. 1982. Seston and dissolved organic carbon dynamics in a southern Appalachian stream. Ecology 63:824-838.

Watriovaara, J.V. 1978. Amount of phosphorus and organic substances discharged by rivers off the coast of Finland. Verhandlungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie. 20:1478.

Webster, J.R. 1975. Analysis of potassium and calcium dynamics in stream ecosystems on three southern Appalachian watersheds of contrasting vegetation. Dissertation. University of Georgia, Athens, Georgia, USA.

Wetzel, R.G., and A. Manny. 1977. Seasonal changes in particulate and dissolved organic carbon and nitrogen in a hardwater stream. Archiv fur Hydrobiologia 80:20-39.

TABLE 1.1. Annual phosphorus (P) loading for various watersheds in north temperate zones. Data are divided into two groups based on whether the sampling regime was sufficiently frequent (adequate) or not sufficiently frequent (inadequate) to produce accurate loading coefficients. Location, geology, and land use are indicated.

AUTHORS	LOCATION	GEOLOGY	LAND USE	P EXPORT (mg/m^2)
INADEQUATE SAMPLING REGIMES				
Hobbie and Likens (1973)	Hubbard Brook, N.H.	igneous	forested	1.9
			disturbed	3.6
Dillon and Kirchner (1975)	Southern Ontario	igneous	forested	4.8
			forested/grazed	10.2
		sedimentary	forested	11.7
			forested/grazed	23.3
Rast and Lee (1978)	all over USA	varied	forested	10
			rural/agriculture	50
Hill (1981)	Southern Ontario	igneous	disturbed	2.7-211
ADEQUATE SAMPLING REGIMES				
Stevens and Smith (1978)	Ireland	igneous	grazed	25.1
Rigler (1979)	England	igneous	grazed	19.9
Meyer and Likens (1979)	Hubbard Brook, N.H.	igneous	forested	7.3

II. Seasonal dynamics of phosphorus partitioning and export in two headwater streams in central Alberta

A. Abstract

In 1983, phosphorus (P) export was quantified for two undisturbed headwater streams in central Alberta, Canada. These streams flow over 3-5 m of glacial till overlying sedimentary bedrock and are located in boreal mixed-wood watersheds. In these streams, the influence of changes in discharge on P concentration and partitioning was examined on an annual and seasonal basis and compared with streams on granitic bedrock with disturbed or hardwood forested watersheds. The relationship between P concentration and discharge was used to develop models to predict P concentration in the forested Albertan streams. Unlike previous studies where P export was maximum in the spring or autumn, P export in the study streams peaked during summer storm events; 68% of total P loading was transported during 12 days in early summer. In the study streams, hysteresis effects were not observed during the early summer storms but were observed during later summer storms. Phosphorus export was primarily in the fine particulate fraction (0.45 um - 1 mm; 72%). Coarse particulate P was the least important fraction (> 1 mm; 3% and 0.3% for the two streams) possibly due to the absence of an autumn deciduous leaffall. There were strong positive correlations between discharge and both fine particulate P and total dissolved P (< 0.45 um); the correlations were nonlinear and linear, respectively. Models presented are the first based on detailed data from watersheds with the following characteristics: (1) coniferous trees, (2) 3-5 m of glacial till overlying sedimentary bedrock, and (3) climatic regime where summer storms are a dominant influence on P export.

B. Introduction

A decade ago, many studies were conducted to evaluate the effect of land use on phosphorus (P) loading in different biomes (e.g. Dillon and Kirchner 1975, Rast and Lee 1978). Most of these projects were government directed with eutrophication-control goals. In these projects, many different streams were sampled once every two to three weeks. More recently, Stevens and Smith (1978), Meyer and Likens (1979), and Rigler (1979) demonstrated that most P export values reported in the literature are underestimates of actual loading; data derived from sampling regimes of 2-to-3 wk intervals are inadequate because they miss dramatic short-term changes during storm runoff. For example, in only 10 days, 67% of the annual P export was transported from a forested stream in New Hampshire (Meyer and Likens 1979).

The transport of P within different size fractions and the relationship with discharge has been studied for two groups of streams flowing over granite: the headwater streams located in deciduous forest at Hubbard Brook (Meyer and Likens 1979) and the grazed moorland streams in Dartmoor, England (Rigler 1979). In the Hubbard Brook and Dartmoor streams, increases in P concentration during floods were larger during ascending than descending stage of the hydrograph, and P increases were greater in summer than in winter. Most of the P increase during flooding was in the particulate fraction; Rigler postulated that these increases could be explained if P accumulated on the streambed during periods of base flow and was resuspended as particulate P during floods. In Hubbard Brook, the relationship between fine particulate P (FPP; 0.45 μm - 1 mm) and discharge varied with season, position of hydrograph, and watershed area. In the moorland streams, total dissolved P (TDP; < 0.45 μm) concentrations increased slightly with an increase in discharge whereas in Hubbard Brook, there was no significant change in TDP when discharge increased. As well, the contribution of coarse particulate P (CPP; > 1 mm) to P loading and the variation in P concentrations between summer and winter have been investigated for only one stream (Meyer and Likens 1979). Very little is known about what to expect in different stream types such as those underlain by glacial till rather than granite bedrock, where groundwater seepage may be important, where seasonal discharge patterns vary from the classical spring and autumn peaks, and where vegetation is not characterized by deciduous trees with a potentially heavy P input at autumn leaffall.

The standard approach for sampling streamwater, the grab sample technique, has never been tested for adequacy in estimating P concentration in streamwater. In other words, horizontal heterogeneity in stream P concentration at one location has not been adequately evaluated. As well, diel patterning may influence P loading. Although Meyer and Likens (1979) reported no diel patterns in TDP concentration, de March (1975) reported diurnal changes in flow, TDP, and FPP concentrations for streams entering Char Lake. If diel patterns exist, sampling regimes should incorporate samples taken at different times in the 24-h cycle.

There are no published data on seasonal variation in P loading and partitioning in streams located on glacial till in watersheds with primarily coniferous trees. This information is necessary both to develop sampling routines to monitor nutrient export from similar streams in boreal forested regions and to develop a broader perspective on seasonal patterns in nutrient loading and P partitioning in streams. Thus, I investigated the following questions in two undisturbed, headwater streams located on glacial till in a boreal mixed-wood biome in central Alberta: (1) the influence of season on P export, (2) the influence of deterministic (e.g. spring runoff) and stochastic (e.g. storm events) changes in the ecosystem on P concentration and partitioning, and (3) the influence of the grab sample technique and possible diel patterns on sampling programs. I also developed models to predict P loading in these forested headwater streams.

C. Materials and Methods

Field Sampling- Field work was conducted from stream ice-off (April 22) to freeze-up (October 25) during 1983. Two streams, Two Creek and Sakwatamau River, were sampled twice daily and more frequently during storm events except for sixteen 2-d periods when samples were being analyzed in the laboratory. Air and water temperatures were measured with a hand thermometer. A Price AA current meter was used to measure velocity and water depth at 1.0 or 0.5 m intervals across the stream width. Water level was recorded wi[illegible] continuous recorders as well as from a depth gauge placed in each stream in April. On each visit, a grab sample of streamwater was collected from the middle of each stream in 1-L Nalgene bottles for P analysis. Occasionally, grab samples of streamwater were collected for analysis of other physical and chemical parameters such as turbidity, colour, and conductivity. To estimate transport of CPP (>1 mm), coarse particulate matter (CPM) was collected from a 1-mm mesh net (35 X 40 cm) placed in each stream such that the entire water column was sampled. To quantify the volume of water passing through the nets, water velocity was measured 1 m in front of each net at the time of sampling. Material was collected daily from the nets from June to October and later analyzed for P content.

To test if one grab sample was adequate to quantify P transported downstream, replicate grab samples were taken monthly from both streams. To test for spatia[illegible] [illegible]erogeneity across the stream width, grab samples were taken at 2-m intervals across the width of the stream and analyzed for total phosphorus (TP) and TDP concentrations. To test f[illegible] diel variation in FPP and TDP concentrations, grab samples of streamwater were collected every 4 h for 24 h. Samples for diel analyses were collected on five dates for Two Creek and four dates for Sakwatamau River throughout the sampling year.

Daily precipitation data were obtained from an Alberta Forest Service fire lookout station located on the northern border of Two Creek watershed. Discharge data for Sakwatamau River were compared to discharge data collected by Environment Canada since 1973 at the mouth of Sakwatamau River (Environment Canada 1973-1983).

Heavy rainstorms flooded the road to Sakwatamau River from July 4-19 and the stream could not be sampled. Consequently, Sakwatamau River loading data were interpolated from a regression of Sakwatamau River P loading data on Two Creek P loading data for the summer months excluding this 16-d period ($r=0.92$). As well, Sakwatamau River data were not used to analyze the influence of July storms on P concentration and partitioning. During the heavy rain storms in July, water depth increased in both streams such that normal sampling procedures were disrupted; flow velocity was calculated by multiplying surface velocity by a factor of 0.8 (Gray 1970). To collect CPM, 1-mm mesh nets were held from the bank in the water for 3 to 5 min.

The two study streams were frozen to the bottom from November to April and consequently, there was no export during this period.

Laboratory Methods- Total P was determined in triplicate (standard error always $< 7\%$ of P value) on 50-mL subsamples filtered through a 1-mm mesh net and analyzed by the potassium persulfate technique (Prepas and Rigler 1982). Water to be analyzed for TDP was filtered through a prerinsed 0.45-*um* Millipore HAWP membrane filter and analyzed as for TP. Fine particulate P was calculated as the difference between TP and TDP. To determine the size of materials within the fine particulate size fraction, FPP was subdivided further (1 mm-80 *um*, 80-64 *um*, 64-10 *um*, 10-5 *um*, 5-0.45 *um*) on eight dates from August to October as well as on three dates in the spring of 1984. Coarse particulate matter was dried for 24 h at 105°C and weighed. Approximately monthly, six 1-g subsamples of dried CPM were analyzed for P content and these data were used to convert daily CPM dry weights to daily CPP values.

Total Kjeldahl nitrogen was analyzed by the sulfuric acid-copper sulfate method of D'Elia et al. (1977) as modified by Prepas and Trew (1983). Sulfate analyses were done on samples filtered through a prewashed Whatman GF/C filter by the gravimetric method with ignition of the residue (American Public Health Association 1975). Chloride samples were pretreated as sulfate samples and analyzed by the mercuric-nitrate method (American Public Health Association 1975). Sodium and potassium were measured with flame photometry methods (American Public Health Association 1975). Calcium and magnesium were analyzed with flame emission on a Jarrel Ash (Model JA82-270) atomic absorption spectrophotometer (American Public Health Association 1975) except no lanthanum was added. Alkalinity was determined by the potentiometric titration method of Environment Canada (1979). A Fisher Accumet Digital pH meter model 520 was used to measure pH and to determine the end points of the alkalinity titration. Colour was measured visually, after samples were centrifuged for 10 min, on a Hazen platinum-cobalt scale with a Hellige aqua tester model 611A. Turbidity was measured with a Hach Turbidimeter model 2100A and conductivity was measured with a conductivity Bridge meter model 31.

Data Manipulation- Average monthly TP, TDP, and FPP concentrations were calculated. These averages were calculated after weighting each set of values by the corresponding time interval between sample collection. Phosphorus loading was calculated by summing the product of P concentration (mg/m^3) and discharge (m^3/s) for all sampling intervals. Export coefficients were calculated by dividing the total mass of P transported by the watershed area. Relationships between TP, FPP, and TDP concentrations and discharge were analyzed on an annual and seasonal basis with regression and correlation analysis. To reduce outliers, these analyses were done after the data were transformed to natural logarithms. When the data were grouped seasonally or on the rising vs. falling stage of the discharge hydrograph, analysis of covariance (ANCOVA) was used to test for equality of the regression lines. Linear regression lines were compared in all cases because (1) not all relationships were described by nonlinear models, (2) nonlinear and linear correlation coefficients were very similar. Analysis of covariance was also used to compare slopes between the various P fractions and discharge. Degree of similarity for TP loading between months was determined by cluster analysis. The regression, ANCOVA, and cluster analyses were performed with BMDP statistical software (Dixon 1981) on the Amdahl computer model 580/5860 at the University of Alberta.

Replicate grab samples were compared with paired *t*-tests (Snedecor and Cochran 1980). Data collected to estimate spatial heterogeneity as well as to test for diel variation were analyzed with the maximum normed residual (MNR) test for outliers. Since multiple comparisons were used when looking at diel variation and spatial heterogeneity, significance was accepted at $P<0.01$. This test is not refined enough to test for small differences; only large differences could be detected.

Data from Two Creek were used for most illustrations except where important differences between the two streams warranted added illustrations. Illustrations for Sakwatamau River data are in Appendix C. Raw data for both Two Creek and Sakwatamau River are listed in Appendix D.

D. Site Description

This study was conducted on two adjacent, undisturbed watersheds (Two Creek and Sakwatamau River) located approximately 230 km northwest of Edmonton, Alberta (Fig. 2.1). At the sampling sites, Two Creek (54°18'N, 116°20'W) is a third-order stream draining 161 km^2 and Sakwatamau River (54°24'N, 116°05'W) is a fourth-order stream draining a 281 km^2 watershed. Two Creek and Sakwatamau River drain into the Athabasca River 8 and 30 km downstream from the sampling sites, respectively.

Watershed vegetation is mixed boreal forest; the dominant tree species are white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), aspen poplar (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*). Shrub species along stream banks include willows (*Salix* spp.), wild rose (*Rosa acicularis*), river alder (*Alnus tenuifolia*), and various berries. Stream faunal communities are represented by invertebrates (primarily Corixidae and Ephemeroptera; Appendix A), mountain whitefish (*Prosopium williamsoni*), and arctic grayling (*Thymallus arcticus*).

Bedrock underlying the streams is sedimentary (shale, sandstone, and mudstone) of the Paskapoo formation (Paleocene) overlain by 3 to 5 m of glacial till (Knapik and Lindsay 1983). Watershed soils are primarily Gleysolic, which is a clay or sandy-clay loam, and organic soils are found along the stream beds (Knapik and Lindsay 1983).

Dominant ions in the streamwater are calcium and bicarbonate; average conductivity was moderate (185 and 174 umhos/cm for Two Creek and Sakwatamau River, respectively). Average turbidity of streamwater was low (2.5 and 2.6 NTU for Two Creek and Sakwatamau River, respectively) although average colour was moderate (69 and 47 mg/L Pt for Two Creek and Sakwatamau River, respectively). Total nitrogen to total P ratios were moderate (22-27). Average pH was high (8.1) for both streams and water temperature ranged between 0° and 20°C.

E. Results

When replicate grab samples collected at the same time and location were compared, there were no significant differences in TP concentrations (16.6±1.2 mg/m^3, n=11, t=1.82, P>0.05) and TDP concentrations (10.2±0.4 mg/m^3, n=11, t=0.75, P>0.4) in both streams. Similarly, when samples collected across the width of either stream at approximately the same time were compared, there were no differences in FPP or TDP concentrations on any of the dates sampled (P>0.05; Fig. 2.2). However, there were significant changes in discharge for Two Creek on May 11, June 2, and August 30 (P<0.01). Therefore, in the two study streams, P was mixed fairly well horizontally such that even when discharge was so low it was not detectable at a location (e.g. 7-m on May 11 at Two Creek; Fig. 2.2), P concentration in the water column was uniform. Thus, the grab sample technique used in this study was adequate to estimate P concentration in streamwater.

On eight of the nine sampling dates, there were no diurnal changes (P>0.01) in discharge, FPP, and TDP concentrations for Two Creek and Sakwatamau River (Fig. 2.3). However, for Sakwatamau River on May 5-6, there was a significant change in discharge (P<0.01) due to increased runoff resulting from rain. These results suggest no diel patterns in P concentrations in Two Creek and Sakwatamau River.

During the sampling year, 623 mm of precipitation fell on the watersheds, most (75%) during June and July. Relatively little precipitation fell during spring (9%) and autumn (10%). This pattern of rainfall was reflected in trends of stream discharge (Fig. 2.4). Heavy storms during June and July caused dramatic increases in discharge accompanied by overland flow. Consequently, during June and July, 82% and 64% of annual discharge was recorded for Two Creek and Sakwatamau River, respectively. This pattern of heavy rainfall during early summer is not unusual for the region; maximum daily discharge at the mouth of Sakwatamau River was during June in 5 of the last 11 years. Only once during the 11-yr period was maximum daily discharge recorded during spring runoff (April 27, 1974). Based on data collected by Environment Canada at the mouth of Sakawatamau River, total annual discharge in 1983 (164 000 dam^3) was slightly below the 11-yr average (179 145 dam^3). However, the maximum instantaneous discharge (the largest discharge recorded at any one time in the sampling year) in 1983 was exceeded three times since 1973. Since overland flow accompanied maximum instantaneous discharge at the study site in 1983, overland flow probably occurred at least four times during the last 11 years. Thus, materials transported during overland flow could have accumulated for several years.

Storm Analysis of P Concentrations- Since such a high percentage of annual rainfall fell during late June and July, discrete storm analysis is difficult and cumulative effects were very important. The first rainstorm (May 6-8) came before all the snow in the watershed had melted and consequently, a sustained increase was recorded in discharge and TP concentration because of increased snowmelt. The next storm event (June 17-21) was accompanied by overland flow. During this storm, TP concentration increased by 851% and 1491% over pre-storm concentrations in Two Creek and Sakwatamau River, respectively; 87% and 93% of the increase was in the FPP fraction. At the same time, CPM transport increased by 1001% in Two Creek and by 529% in Sakwatamau River over pre-storm transport. Peak discharge and TDP concentration were measured the day following peak rainfall. However, peak TP concentration was noted three days after peak discharge and consequently TP concentrations were higher on the falling limb of the storm hydrograph (hysteresis effect predicts higher P concentrations at similar discharges on the rising limb than on the falling limb of the storm hydrograph (Gray 1970)). Storms on June 30 to July 3 and July 15 to 17 resulted in similar trends although increases in FPP (443% and 289% in the two storms, respectively) and TDP (134%, 126%) concentrations were not so dramatic.

Rain fell on most days in July but heavy rain storms on July 25 to 27 and again on July 29 resulted in a 266% increase in TP concentration with 93% of this increase in the FPP fraction in Two Creek. During these storms, CPM transport increased by only 141%; however, the relationship between the storm hydrograph and P concentration showed a different pattern from previous s rms. Total P concentrations peaked the same day as rainfall while stream discharge and TDP concentrations peaked the following day, although changes in TDP concentrations were slight. Consequently, TP concentrations were higher on the rising limb than on the falling limb of the storm hydrograph (hysteresis effect).

Patterns in Phosphorus Dynamics- Average TP, TDP, and FPP concentrations (time-weighted) over the sampling year were very similar in Two Creek and Sakwatamau River (Table 2.1). In both streams, average monthly TP and FPP concentrations were highest in June when discharge was also high. In Sakwatamau River, average monthly TDP concentration was highest in July whereas in Two Creek, TDP was highest in April. In Sakwatamau River, the second highest average monthly TP, TDP, and FPP concentrations were all in April. The reason for relatively low spring FPP concentration in Two Creek compared to Sakwatamau River can be postulated. Ice on the Sakwatamau River streambed melted before April 22 and all ice along the banks was gone by April 24. However, in Two Creek, ice melted from the top to the bottom and ice sitting on the substrate did not melt until May 3. Fine particulate P transport was significantly greater in Sakwatamau River than in Two Creek from April 22 - May 3 (Wilcoxon two-sample rank test, $n=14$, $P<0.01$). This suggests that there was no resuspension of FPP from the streambed in Two Creek during this period whereas there was resuspension from the streambed in Sakwatamau River. In both streams, TP, TDP, and FPP concentrations were lowest in October when discharge was also low.

Most of the P in the FPP size fraction from August to October was bound to materials in the 5-10 *um* size range for both Two Creek (50%) and Sakwatamau River (71%). The next most important fraction in FPP was the 0.45 to 5.0 *um* fraction in Two Creek (33%) and in Sakwatamau River (12%), especially in the autumn. There was relatively little P in the 10-100 *um* size fractions in Two Creek (18%) and Sakwatamau River (17%) from August to October. From April to June, 1984, P was bound to all fractions of FPP; no fraction was dominant (Figs. 6.3 and 6.4).

Discharge and FPP concentration were strongly correlated ($r=0.81$ and $r=0.74$ for Two Creek (Fig. 2.5) and Sakwatamau River(Fig 6.5), respectively). For both streams, a second order polynomial fits the FPP - discharge (Q) data better than the linear model, and when the rate of change of discharge (R) was added as a third independent variable, the nonlinear model fits the FPP data even better ($P<0.05$). In both streams, when the FPP on Q and R relationship was compared between rising and falling stage of the hydrograph, there were no significant differences ($n=207$, $P=0.12$ for Two Creek; $n=165$, $P=0.75$ for Sakwatamau River). In Two Creek, there were no significant seasonal differences in the relationship of FPP on discharge between early vs. late summer storms ($n=65$, $P=0.08$); there were insufficient data to do a similar analysis for Sakwatamau River data. In both Two Creek (Fig. 2.6) and Sakwatamau River (Fig. 6.6), TDP concentration was positively correlated to discharge ($r=0.68$ and $r=0.66$, respectively) although the slope of the regression of TDP on Q was significantly lower than the slope of the regression of FPP on Q ($P<0.01$). For the TDP - Q data, a linear model was the best fit ($P>0.05$). Finally, the relationship between TP concentration and discharge was similar to the relationship between FPP and discharge, although more of the variability in the data set was explained with the TP models than the FPP models in both Two Creek (Eq.1) and Sakwatamau River (Eq. 2).

$$\ln TP = 3.04 + 0.25\ln Q + 0.09(\ln Q)^2 + 0.12R, \qquad (r=0.87,\ n=209) \qquad (1)$$

$$\ln TP = 2.91 + 0.26\ln Q + 0.12(\ln Q)^2 - 0.09R, \qquad (r=0.78,\ n=166) \qquad (2)$$

In Two Creek, contrary to the FPP on Q and R results, there was a significant difference between regressions of TP on Q and R based on early (June 18 - July 13; Eq. 3) vs. late summer storm data (July 14 - August 4; Eq. 4) ($P<0.001$).

$$\ln TP = 2.36 + 0.54\ln Q + 0.12(\ln Q)^2 - 0.33R, \qquad (r=0.94,\ n=33) \qquad (3)$$

$$\ln TP = 3.06 + 0.09\ln Q + 0.14(\ln Q)^2 + 0.25R, \qquad (r=0.90,\ n=33) \qquad (4)$$

The mass of coarse particulate matter transported downstream during storms was large; 48 533 and 5071 kg dry weight was transported from Two Creek and Sakwatamau River, respectively. The relationship between CPM and discharge is linear reflecting the strong increase in total CPM transport during high discharge ($r=0.88$ and $r=0.79$ for Two Creek and Sakwatamau River, respectively; Fig. 2.7). The seasonal pattern of P content of CPM was consistent between streams; CPM transport was largest in June (25 918 and 4365 kg for Two Creek and Sakwatamau River, respectively) and lowest in October (3 kg for both streams).. Phosphorus content of CPM generally increased over summer (from 0.13% to 0.21% of dry weight in Two Creek and from 0.11 to 0.22% of dry weight in Sakwatamau River) and then declined during peak needle and leaffall in autumn (Table 2). This suggests that P content of CPM increases with length of time in the stream. However, 99 and 98% of CPM for Two Creek and Sakwatamau River, respectively, was transported during storms in June and July so CPP loading was highest in summer and lowest in autumn when flows were low (Tables 2.3 and 2.4).

During the sampling period, 13.04 mg/m² and 7.49 mg/m² of P (including TP and CPP) was exported from Two Creek and Sakwatamau River, respectively. Both streams carried 72% of the annual P export in the FPP size fraction. Coarse particulate matter was a relatively insignificant portion of the P load; 3% and 0.3% of total P transport for Two Creek and Sakwatamau River, respectively. In Two Creek, P transport was greatest in June for all three size fraction. In Sakwatamau River, this general pattern also held, although TDP transport was also high in July. For all size fractions in both streams, P loading was lowest during October. In all months except June and July, TDP transport was greater than FPP transport for both streams. To determine which months were most closely related in terms of P export, a cluster analysis was used; TP loading in the months of June, July, and August were most closely related. These were next most similar to May and then September. The first and last months of the study (April and October) were the least related to any other month. This trend held true for both Two Creek and Sakwatamau River (Fig. 6.8). This pattern suggests a seasonal influence in TP loading reflecting large increases in discharge during the summer months.

Phosphorus export was strongly pulsed during storm events; in Two Creek, 42% of TP was exported with 19% of the water in 2% of the time (Fig. 2.8A). Export of FPP was more strongly pulsed than was export of TDP; 75% of FPP was transported within the same time period as 47% of TDP transport (Fig. 2.8B). To determine how important the two major storms were in terms of pulsing, the mass of P transported during storms was calculated. In Two Creek, 83% of the TP loading in June (1097 Kg) was transported during the first storm (June 17-21) and this storm accounted for 55% of TP loading for the entire sampling year. In Two Creek, 50% of the TP loading in July (294 Kg) was transported during the second large storm (July 24-30) and this storm accounted for 14% of TP transport for the sampling year. Consequently, 68% of TP loading was transported during 12 days (6% of the time); 76% of FPP loading was transported during the two storms. Thus, P export, primarily in the FPP fraction, was strongly pulsed during storm events.

F. Discussion

Although de March (1975) reported diel changes in P concentration in arctic streams, I found no diel patterns in P concentration in Two Creek and Sakwatamau River. Meyer and Likens (1979) also observed no diel trends in TDP concentrations. O'Connell and Davies (1977) reported differences in fine particulate detritus density over a 24-h period for mountain headwater streams in Alberta, possibly due to changes in the rate of detrital processing by stream invertebrates. Kaplan and Bott (1982) postulated several reasons for observed diel fluctuation in dissolved organic carbon: diel changes in inputs of allochthonous litter, autochthonous production and processing, or fluctuation in inputs of groundwater. If these processes can also explain diel P patterns, I postulate that other physical processes such as flow were dominant over detrital processing by invertebrates in Two Creek and Sakwatamau River. Diel patterns may be more prevalent in smaller streams where discharge is low and thus not likely to be a dominant influence or in streams that are influenced by other diel patterns such as beaver activity or point-source effluents.

Although Meyer and Likens (1979) reported no relationship between TDP and discharge in the forested Hubbard Brook streams, there was a positive relationship between TDP and discharge in Two Creek and Sakwatamau River. However, my results concur with results obtained in grazed watersheds in Dartmoor, England (Rigler 1979). In the study streams, positive correlations between TDP concentration and discharge could be a result of several factors: 1) higher TDP concentrations at higher discharges during spring caused by resuspension of sediment, that had accumulated during low flows the previous autumn, from a thawing streambed, 2) high TDP concentration due to increased allochthonous inputs with overland flow (at high discharge), or 3) decreasing TDP concentration during declining flows in autumn, perhaps due to increased processing and thus conversion into FPM during low flows. These explanations would suggest a seasonal relationship between TDP and discharge. This last hypothetical process concerning increased processing at low flows is supported by research on P spiralling which suggests that processing within stream biotic compartments is most important at low flows (Newbold et al. 1983). Meyer and Likens (1979) attribute the absence of a relationship between TDP and discharge to very low concentrations of TDP resulting from biotic (e.g. periphyton) and abiotic (e.g. sediments) P sinks. However, the Dartmoor streams have an organic-rich soil horizon which could act as a P sink which would suggest no relationship between TDP and discharge, contrary to the observed positive relationship between TDP and discharge. In Two Creek and Sakwatamau River, periphyton only grew for a 2-wk period in early fall and there were no bryophytes at any time so a biotic sink is an unlikely explanation in these streams. During low flow, stream bacteria may have been an important P sink, however, bacteria were not quantified in this study. A possible explanation for a positive relationship between TDP and discharge in the study streams is increase in groundwater inputs during storm events; groundwater is usually high in TDP. A positive relationship may exist between TDP and discharge for all streams overlying sedimentary rock.

Although both TDP and FPP concentrations increased with increasing discharge in the two study streams, increases in FPP were stronger than increases in TDP ($P<0.01$). These results concur with earlier studies which reported a stronger response of FPP concentration to discharge during summer than winter (Meyer and Likens 1979, Rigler 1979). As well, these two earlier studies did not report seasonal differences except between summer and winter or between rising ~~and~~ falling stage. In contrast, there were no significant differences between P concentrations on the rising vs. falling stage of the discharge hydrograph in Two Creek and Sakwatamau River. In addition, in the central Alberta streams, storms during the early part of the summer did not elicit the hysteresis effect. These two unexpected results suggest that a large P pool was still contributing to P in the flowing water while discharge was decreasing. A large P pool could have accumulated during autumn and winter and remained in the stream during the relatively small spring runoff compared to other areas. As well, P may have accumulated since spring runoff. In the later part of the summer, hysteresis effects were apparent in Two Creek and Sakwatamau River during storms. This late appearance of the hysteresis effect suggests that during the early summer storms, FPM that had accumulated over a considerable time period was washed out of the streambeds whereas increases in later summer were due to P which had accumulated over a much shorter time period, i.e., since the last storm, as was suggested by Rigler (1979). Thus, all these detailed stream studies indicate that FPP transport is dependent on discharge as well as length of time since the last storm. The dependency of FPP transport on discharge is further supported by FPP fractionation; P was transported in all fractions at high flows when coarser sediments were suspended and in smaller fractions during low flows when only finer sediments were transported.

In Two Creek and Sakwatamau River, P content of CPM increased during summer and peaked during autumn. This pattern was also observed on hardwood watersheds at Hubbard Brook (Meyer and Likens 1979). However, there was little seasonal variation in nutrient content of coniferous and deciduous fractions from two streams in Ontario (Dance et al. 1979). Since the watersheds in this study are dominated by coniferous trees, leaffall was slight but large amounts of spruce needles were transported in streamwater. In the study streams, the decline in P content of CPM at peak leaffall could be caused by retention of nutrients by trees when they shed their needles or leaves. Even though Dance et al. (1979) reported lower P content in coniferous matter than deciduous matter, the P content of CPM from Two Creek and Sakwatamau River (0.10% - 0.22%) was higher than for a deciduous forest stream (0.079%) at Hubbard Brook (Gosz et al.. 1972). Geographic variation could explain this discrepancy. Even though the P content of CPM was highest in autumn in the two study streams, P transport of CPM was greatest in summer because of the large mass of CPM transported during storms. While CPP was transported primarily in autumn at Hubbard Brook, this autumn peak can be explained by leaffall from the deciduous watershed and increased flows in autumn. The two different trends suggest that CPP export is dependent upon type of watershed vegetation and regional pattern of discharge.

Export coefficients from Two Creek and Sakwatamau River were 13.0 mg/m^2 and 7.5 mg/m^2, respectively. Export coefficients in this study are similar to coefficients developed for forested watersheds overlying sedimentary bedrock in southern Ontario (11.7 mg/m^2; Dillon and Kirchner 1975). While Dillon and Kirchner's (1975) coefficient is relatively high, partly because of large inputs in autumn from deciduous trees, their estimate is probably an underestimate because of inadequate sampling frequency. As expected, export from the two undisturbed study streams was less than export from grazed watersheds in Dartmoor (19.9 mg/m^2; Rigler 1979) and Ireland (25.1 mg/m^2; Stevens and Smith 1978). Since Dillon and Kirchner's (1975) study reported less P export from igneous than sedimentary watersheds, it is not surprising that P export from the Hubbard Brook stream (7.3 mg/m^2; Meyer and Likens 1979) was less than from Two Creek and Sakwatamau River. One major difference between this study and the Hubbard Brook study was that CPP accounted for 19% of export from the watershed in Hubbard Brook whereas CPP accounted for 3% and 0.3% of the export from Two Creek and Sakwatamau River, respectively. One major factor that could explain this difference is autumn leaffall from deciduous trees in Hubbard Brook. In contrast, Two Creek and Sakwatamau River watersheds are forested primarily by spruce trees and there is no autumn leaffall. This study supports the general hypothesis that P export is predictable from bedrock geology and land use in the watershed.

However, there is no apparent reason why the Two Creek export coefficient is 69% higher than the Sakwatamau River export coefficient. Average monthly P concentrations were similar for the two streams and P mass exported by the two streams were also very similar; Sakwatamau River exported 3% more P than Two Creek based on absolute mass. The relatively large watershed size results in a low export coefficient for Sakwatamau River as compared to Two Creek. This discrepancy suggests that the actual size of the Sakwatamau River watershed may be smaller than that calculated from surficial topography. As well, groundwater may alter P concentrations or the direction of subsurface flow. These data suggest that export coefficients based on watershed size may not be appropriate for streams on glacial till over sedimentary bedrock.

In the study streams, P transport was strongly pulsed during the first part of the summer and storm events were the dominant factor influencing P transport. Other studies report strong P pulsing, although sources and timing of the pulses vary. For example, in Bear Brook, a forested stream in New Hampshire, 67% of the annual exports were transported during 10 days, primarily during spring and autumn (Meyer and Likens 1979). In two contour-farmed watersheds, 50% of P exports were transported during snowmelt runoff in March (Alberts et al. 1978). In a rural stream in New York, 75% of the P was exported during highest flows in 10% of the time (Johnson et al. 1976). A large portion of stream P inputs can be exported within the first few days of spring runoff for Char Lake (de March 1975) and few hours for the Saqvaqjuak region (H.E. Welch, Freshwater Institute, pers.comm.) in the Canadian Arctic. Low winter snowpack in central Alberta compared to southern Ontario, Quebec, and the New England states as well as a long period of snowmelt (e.g. a chinook followed by a snowstorm in April 1983) could account for the negligible importance of spring runoff compared to other studies. Regional differences in patterns of storm events could account for some differences in timing of P transport. For example, in New Hampshire, major storms are more likely to occur in spring and autumn (Meyer and Likens 1979) whereas in central Alberta, major storms are more likely to occur in early summer. Thus, the timing of P pulsing may be predictable on a regional scale based on climatic regimes and this information can be used to plan monitoring programs for sampling fluvial P. For example, this study indicates that a major portion of the P loading takes place during storm events and that sampling frequency should be on the order of every few hours during heavy storms in central Alberta. As well, in this region, daily sampling is adequate during the low spring runoff and bi-monthly sampling during low flow in the fall. However, the efficiency of this suggested sampling regime is strongly dependent on climatic patterns and year-to-year variation may be significant (Meyer and Likens 1979). When TP loading coefficients were recalculated based on a weekly sampling frequency, the coefficients for Two Creek ranged between an underestimate of 54% to an overestimate of 10% (mean underestimate of 15%), depending on which day of the week sampling was done. Coefficients based on weekly sampling for Sakwatamau River were all underestimates ranging between 10 and 49% (mean 34%). This underestimation indicates the inadequacy of weekly sampling regimes. As well, the discrepancy between the coefficients for the two streams based on weekly samples indicates the unpredicatability of weekly sampling regimes.

The degree and causes of pulsing have important implications for the biotic community within the stream. If pulsing is caused by large increases in discharge, as in this study, P cycling distance would be long at high discharges since distance travelled in one cycle is the product of cycling time and downstream velocity (Newbold et al. 1983). Although P uptake rate does increase at higher flows because of turbulent contact of the water column with the substrate, this increase would likely be overshadowed in the two study streams by the rapid downstream transport of FPM and CPM at high flows and the large increase in water depth. Estimations of biologically available P for streams in Quebec indicated low availability of the suspended particulate fraction (Peters 1981) which is the largest fraction transported during high storm flow in Two Creek and Sakwatamau River (see Chapter 5). During low flows in all streams, P cycling length would be shorter and a P atom would be retained longer in the stream within both biotic and abiotic compartments. Thus, while estimating mass of P transported downstream is undoubtedly important to downstream water bodies, mass transported does not indicate availability of P to the stream community itself. Rather, P uptake and cycling (assuming some degree of relatedness to availability) is dependent upon a number of factors including flow rates, standing stock of particulate matter, and standing stock of exchangeable P.

This study concurs with earlier predictions that abiotic factors, such as watershed land use, bedrock geology, and climatic regimes, all influence P export patterns. However, this study suggests that P export coefficients based on watershed area may not be an appropriate export expression for forested streams overlying sedimentary bedrock. Alberta streams would be ideal for many studies including: (1) a P budget for headwater streams on coniferous watersheds where the CPP inputs and outputs are low relative to deciduous watersheds and where groundwater may be a significant input to the system, (2) availability of P during high vs. low flows, (3) possible retention or accumulation of P in stream sediments, and (4) the influence of watershed size on P export in streams overlying glacial till.

G. References

American Public Health Association. 1975. Standard Methods for the examination of water and wastewater, 14th edition. APHA, AWWA, WPCF, New York.

Alberts, E.E., G.E. Schuman, and Burwell. 1978. Seasonal runoff losses of nitrogen and phosphorus from Missouri Valley Loess watersheds. Journal of Environmental Quality 7:203-208.

Dance, K.W., H.B.N. Hynes, and N.K. Kaushik. 1979. Seasonal drift of solid matter in two adjacent streams. Archiv fur Hydrobiologia **87**:139-151.

D'Elia, C.F., P.A. Steudler, and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnology and Oceanography **22**:760-764.

de March, L. 1975. Nutrient budgets for a high arctic lake (Char Lake, N.W.T.). Verhandlungen Internationale Vereinigung fur Theorretische und Angewandte Limnologie **19**:496-503.

Dillon, P.J., and W.B. Kirchner. 1975. The effects of geology and land use on the export of phosphorus from watersheds. Water Research **9**:135-148.

Dixon, W.J. 1981. BMDP statistical softwate. Univeristy of California Press, Berkeley.

Environment Canada. 1973-1983. Surface water data: Alberta. Inland Water Directorate, Water Resources Branch, Calgary.

Environment Canada. 1979. Analytical Methods Manual, IWD, Water Quality Branch, Ottawa.

Gosz, J.R., G.E. Likens, and F.H. Bormann. 1972. Nutrient content of litter fall on the Hubbard Brook Experimental Forest, New Hampshire. Ecology **53**:769-784.

Gray, D.M., editor. 1970. Handbook on the principles of hydrology. Water Information Center, Inc., New York.

Johnson, A.H., D.R. Bouldin, E.A. Goyette, and A.M. Hedges. 1976. Phosphorus loss by stream transport from a rural watershed: quantities, processes, and sources. Journal of Environmental Quality **5**:148-157.

Kaplan, L.A., and T.L. Bott. 1982. Diel fluctuations of DOC generated by algae in a piedmont stream. Limnology and Oceanography **27**:1091-1100.

Knapik, L.J., and J.D. Lindsay. 1983. Reconnaisance Soil Survey of the Iosegun Lake area, Alberta. Alberta Research Council, Natural Resources Division. 93p.

Meyer, J.L., and G.E. Likens. 1979. Transport and transformation of phosphorus in a forest stream ecosystem. Ecology **60**:1255-1269.

Newbold, J.D., J.W. Elwood, R.V. O'Neill, and A.L. Sheldon. 1983. Phosphorus dynamics in a woodland stream ecosystem: a study of nutrient spiralling. Ecology **64**:1249-1265.

O'Connell, M., and R.W. Davies. 1977. The relationship between invertebrate drift and detritus in a mountainous region of the Oldman River, Alberta. American Zoologist **17**:868.

Peters, R.H. 1981. Phosphorus availability in Lake Memphremagog and its tributaries. Limnology and Oceanography **26**:1150-1161.

Prepas, E.E., and F.H. Rigler. 1982. Improvements in quantifying the phosphorus concentration in lake water. Canadian Journal of Fisheries and Aquatic Sciences **39**:822-829

Prepas, E.E., and D.O. Trew. 1983. Evaluation of the phosphorus-chlorophyll relationship for lakes off the Precambrian Shield in western Canada. Canadian Journal of Fisheries and Aquatic Sciences **40**:27-35.

Rast, W., and G.F. Lee. 1978. Summary analysis of the North American (U.S. portion) OECD Eutrophication Project: nutrient loading-lake response relationships and trophic state indices. U.S.EPA-600/3-78-008. 455p.

Rigler, F.H. 1979. The export of phosphorus from Dartmoor catchments: a model to explain variations of phosphorus concentrations in stream water. Journal of the Marine Biology Association of the U.K. **59**:659-687.

Snedecor, G.W., and W.G. Cochran. 1980. Statistical methods. 7th ed. Iowa State Univ., IA. 507pp.

Stevens, R.J. and R.V. Smith. 1978. A comparison of discrete and intensive sampling for measuring the loads of nitrogen and phosphorus in the River Main, County Antrim. Water

Research **12**:823-830.

Table 2.1. Time-weighted average total phosphorus (TP), fine particulate phosphorus (FPP), and total dissolved phosphorus (TDP) concentrations (mg/m^3) for Two Creek and Sakwatamau River.

	TWO CREEK			SAKWATAMAU RIVER		
Month	TP	TDP	FPP	TP	TDP	FPP
April	28.4	17.5	10.9	37.0	21.7	15.2
May	22.0	11.6	10.3	22.7	12.7	10.1
June	43.3	11.6	32.2	48.3	11.0	38.2
July	35.0	14.7	20.3	32.2	23.3	13.1
August	20.5	11.2	9.4	18.0	10.7	7.4
September	15.8	9.3	6.6	14.6	9.7	5.0
October	13.5	8.6	4.9	13.6	9.2	4.4
Average	25.5	11.7	14.0	25.8	13.1	13.1

Table 2.2. Percent phosphorus (P) content of coarse particulate matter (CPM) for Two Creek and Sakwatamau River for 5 dates in 1983.

DATE	TWO CREEK	SAKWATAMAU RIVER
June 17	0.13	0.11
August 1	0.14	0.16
September 6	0.16	0.16
September 22	0.21	0.22
October 10	0.10	0.12

Table 2.3. Mass of total phosphorus (TP), total dissolved phosphorus (TDP), fine particulate phosphorus (FPP), and coarse particulate phosphorus (CPP) in kg transported past Two Creek study site during each month of the study and over the whole study period expressed in total mass and mass per unit area of watershed (Export Coefficient mg/m²). Note that TP does not include CPP.

Month	TP	TDP	FPP	CPP
April	11.1	6.7	4.4	
May	59.5	29.8	29.7	
June	1326.0	249.5	1076.5	33.69
July	584.4	201.2	383.2	30.43
August	37.5	19.5	18.0	0.09
September	11.3	6.6	4.7	0:01
October	5.4	3.4	2.0	0.00
Total Transport	2035.2	516.7	1518.5	64.23
Export Coefficient	12.64	3.21	9.43	0.40

Table 2.4. Mass of total phosphorus (TP), total dissolved phosphorus (TDP), fine particulate phosphorus (FPP), and coarse particulate phosphorus (CPP) in kg transported past Sakwatamau River study site during each month of the study and over the whole study period expressed in total mass and mass per unit area of watershed (Export Coefficient mg/m^2). Note that TP does not include CPP.

Month	TP	TDP	FPP	CPP
April	53.1	29.9	23.2	
May	86.7	44.7	42.0	
June	1265.8	181.2	1084.6	4.80
July	556.8	191.2	365.6	0.83
August	76.4	42.4	33.9	0.13
September	37.7	25.2	12.6	0.02
October	22.8	15.4	7.4	0.00
Total Transport	2099.3	530.0	1569.3	5.78
Export Coefficient	7.47	1.87	5.58	0.02

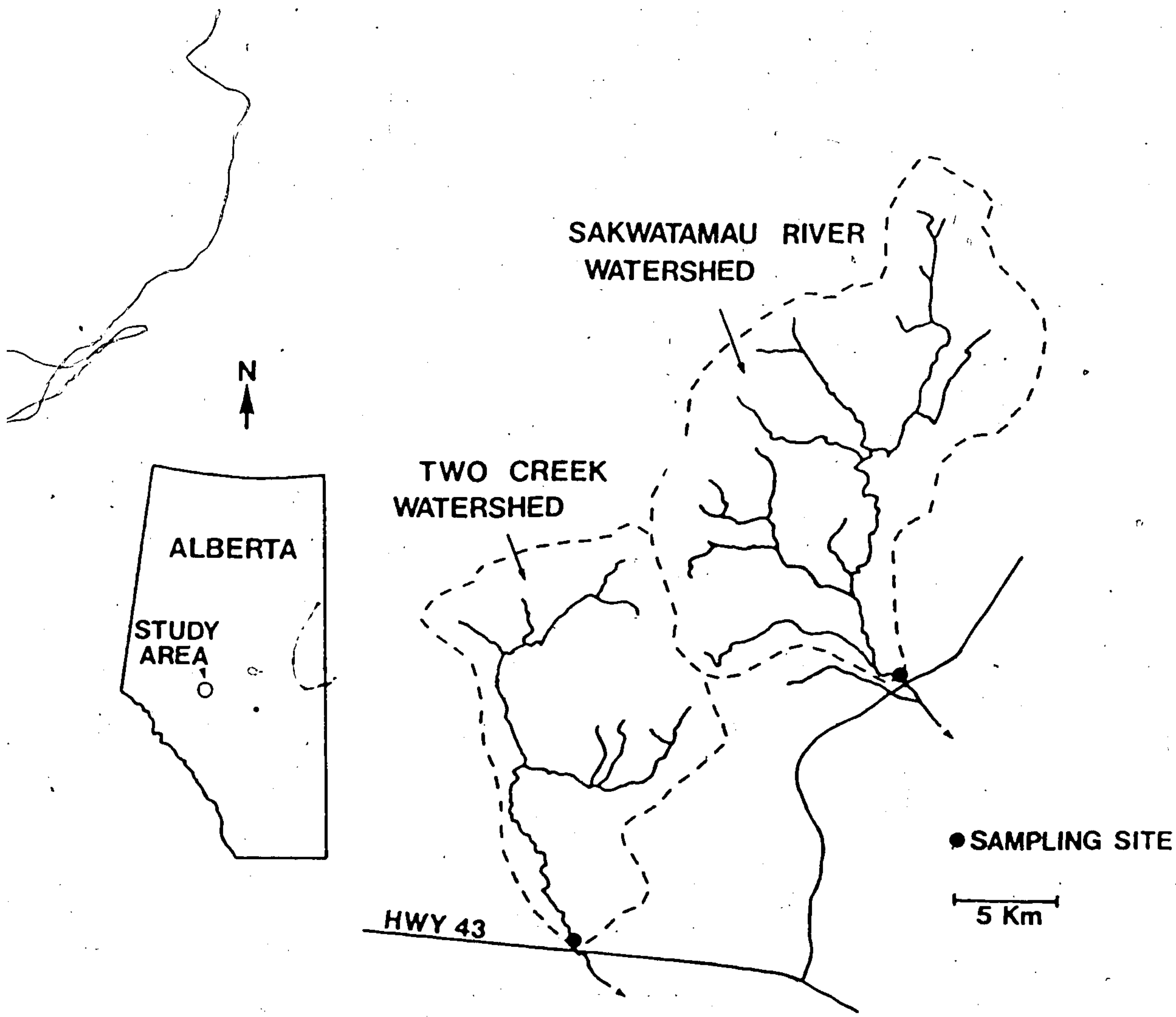

Fig. 2.1. Map of study area.

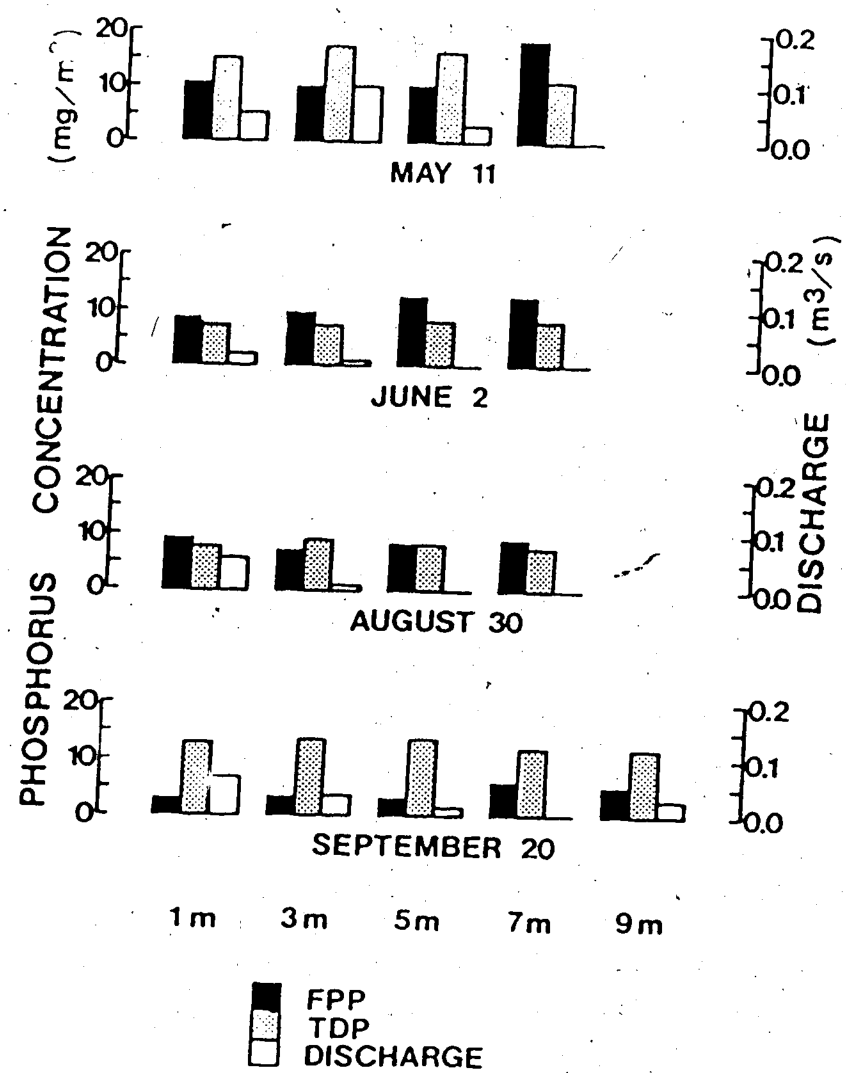

Fig. 2.2. Discharge, fine particulate phosphorus (FPP), and total dissolved phosphorus (TDP) concentrations at 2-m intervals across the width of Two Creek.

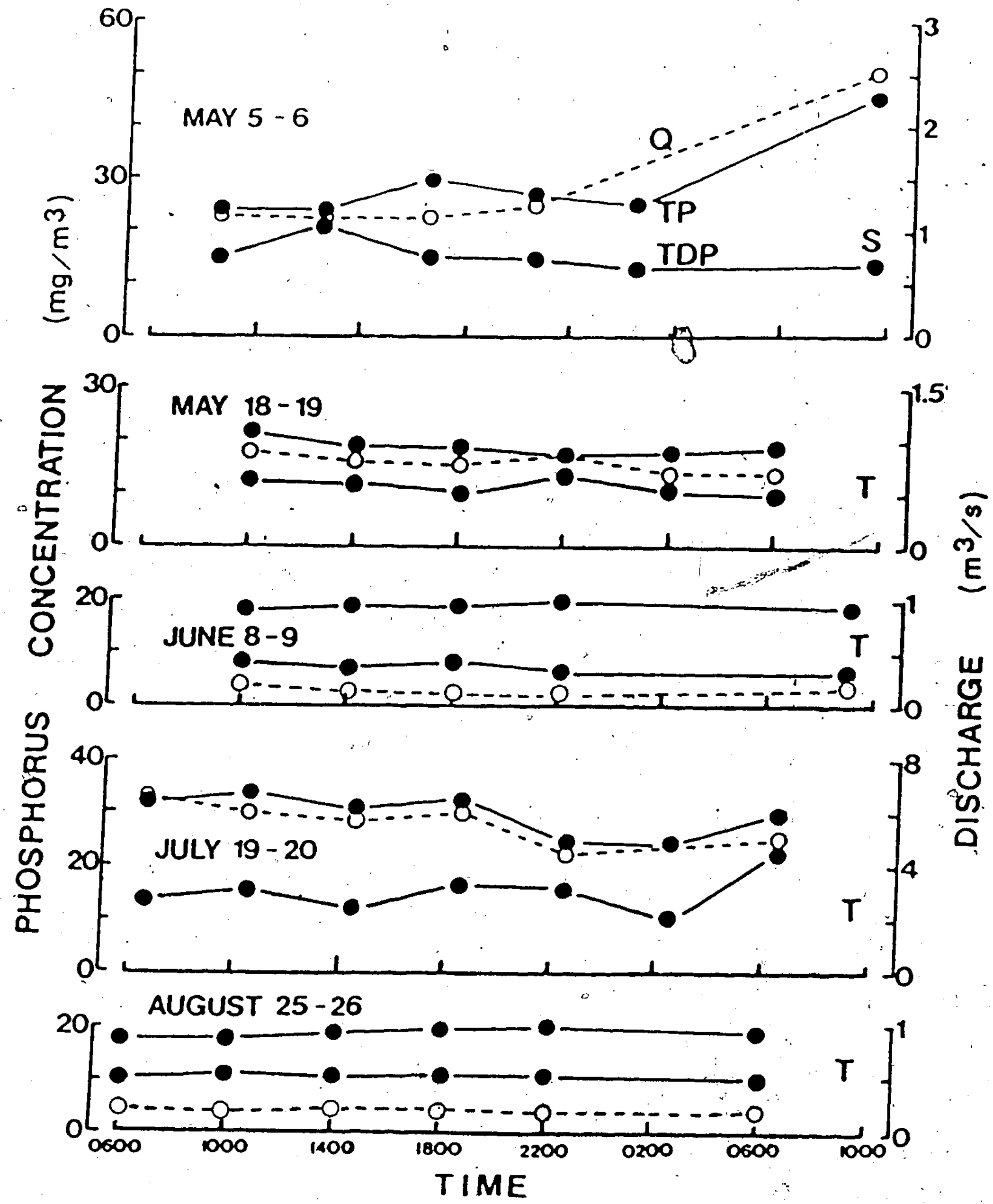

Fig. 2.3. Diel patterns in discharge (Q), total phosphorus (TP), and total dissolved phosphorus (TDP) concentrations for Two Creek (T) and Sakwatamau River (S). Note that discharge scale changes..

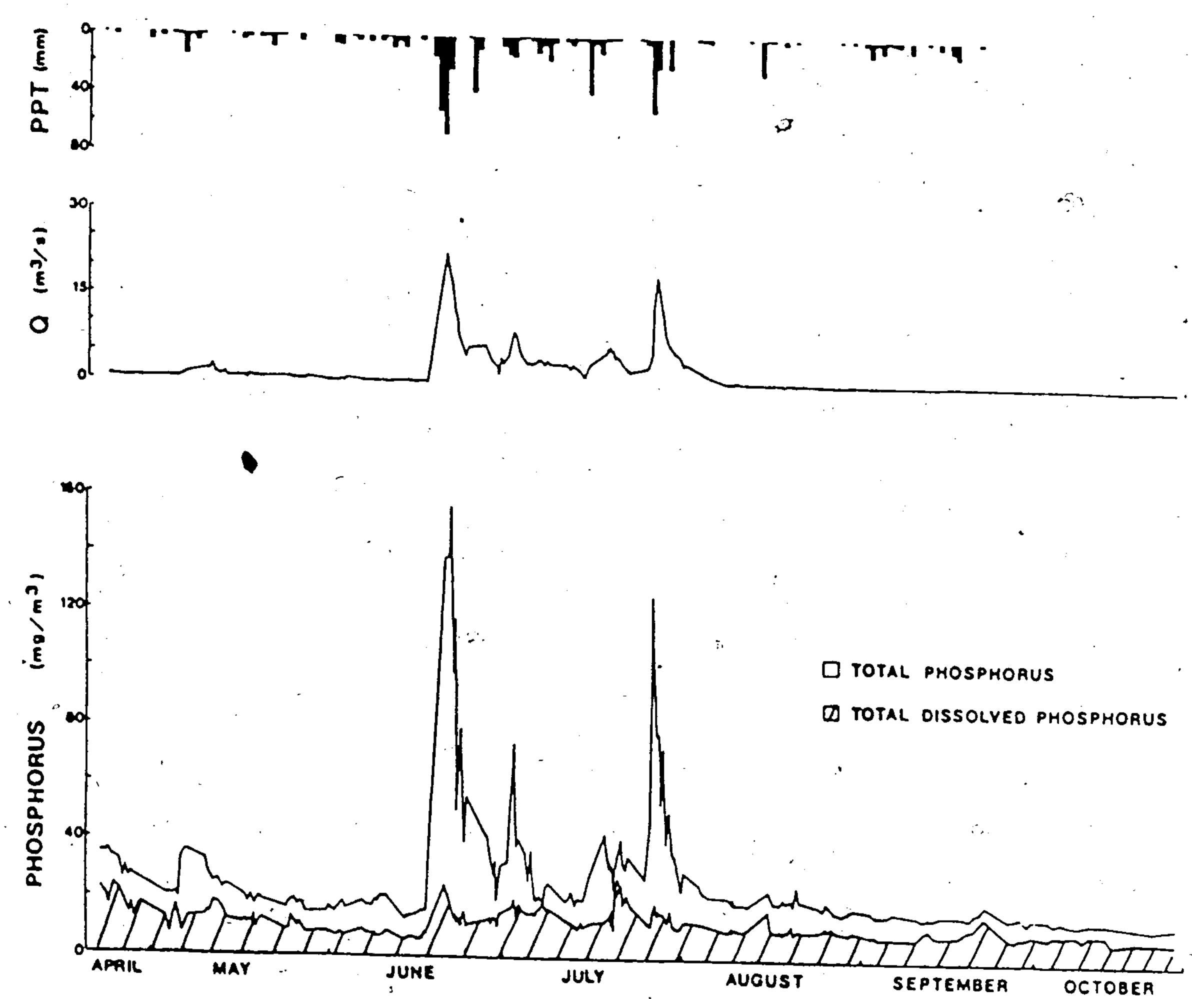

Fig. 2.4. Variation in precipitation (PPT), discharge(Q), total phosphorus (TP), and total dissolved phosphorus (TDP) concentrations from April to October, 1983, for Two Creek.

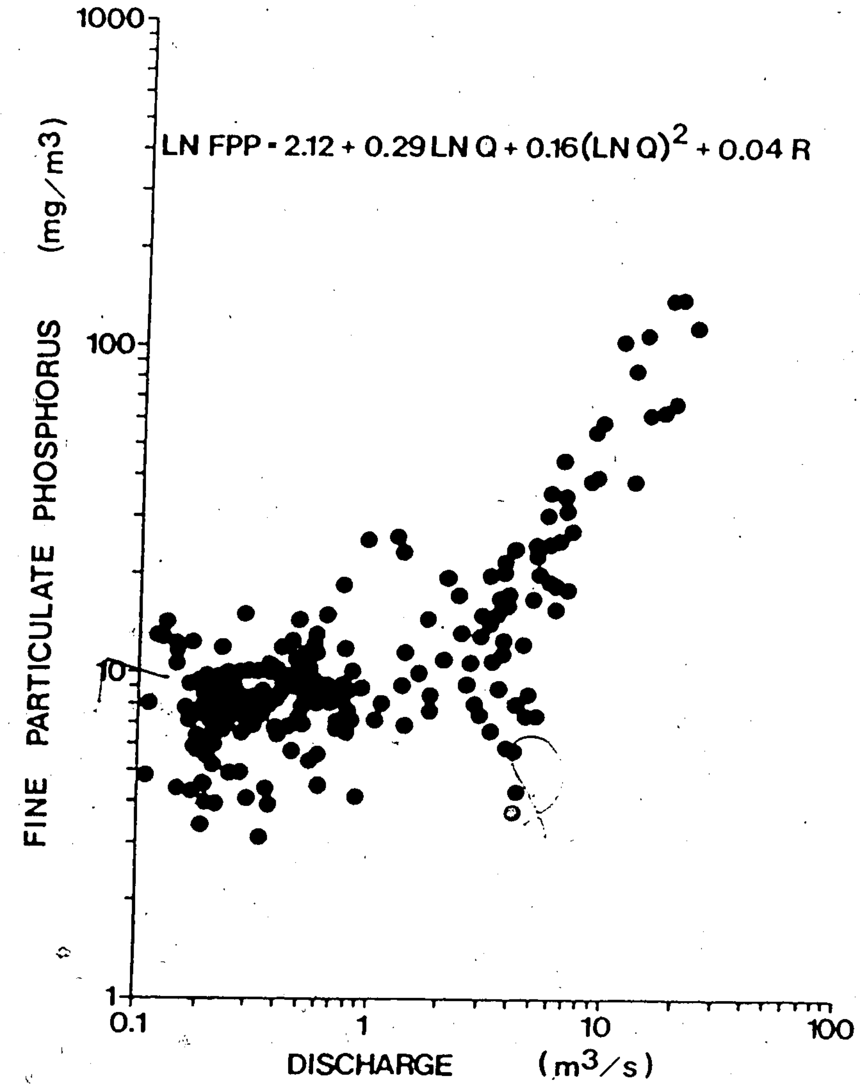

Fig. 2.5. Relationship between fine particulate phorphorus (FPP) concentration and discharge (Q) in Two Creek (n=218). R is rate of change of discharge.

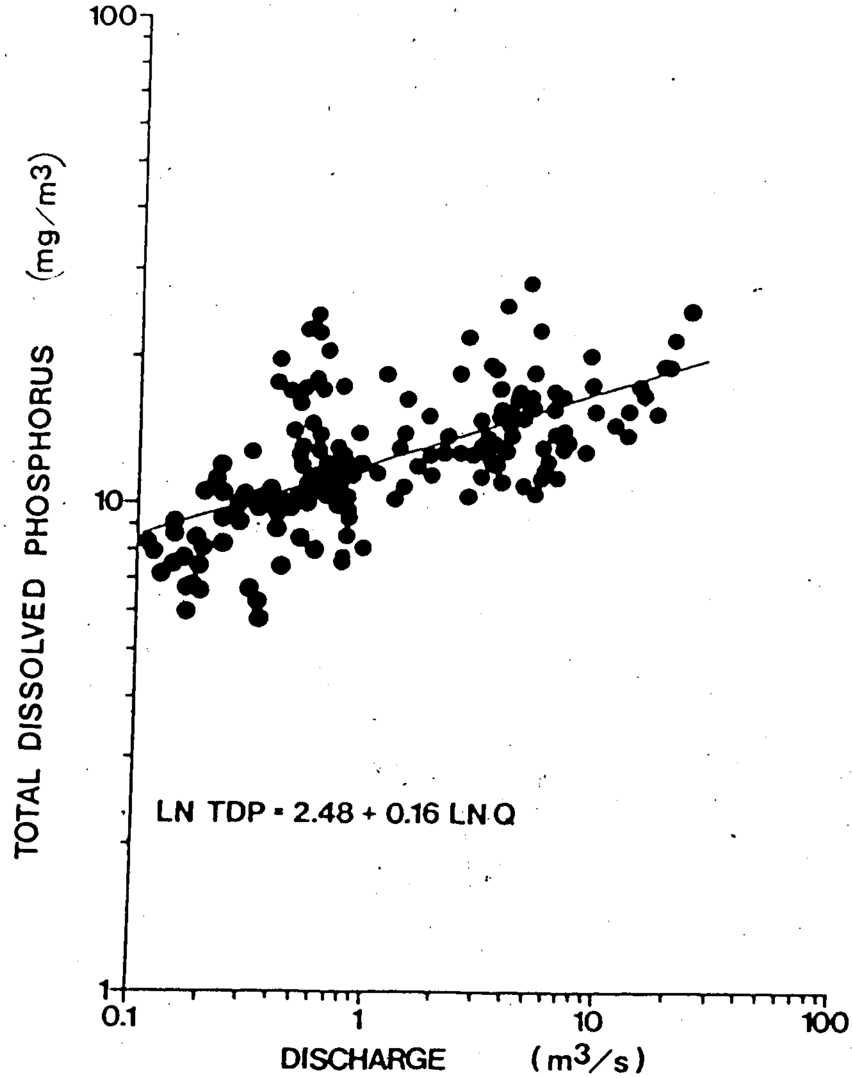

Fig. 2.6. Relationship between total dissolved phosphorus (TDP) concentration and discharge (Q) in Two Creek.

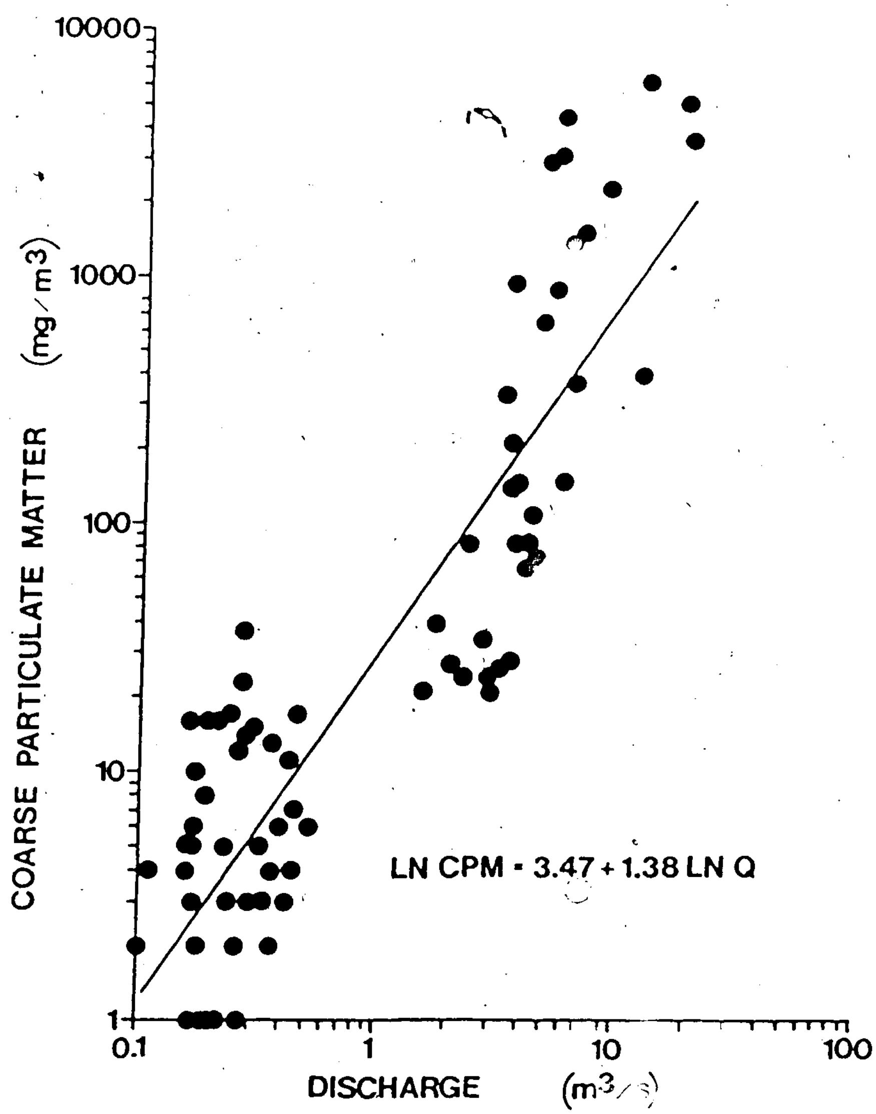

Fig. 2.7. Relationship between coarse particulate matter (CPM) transport and discharge (Q) in Two Creek.

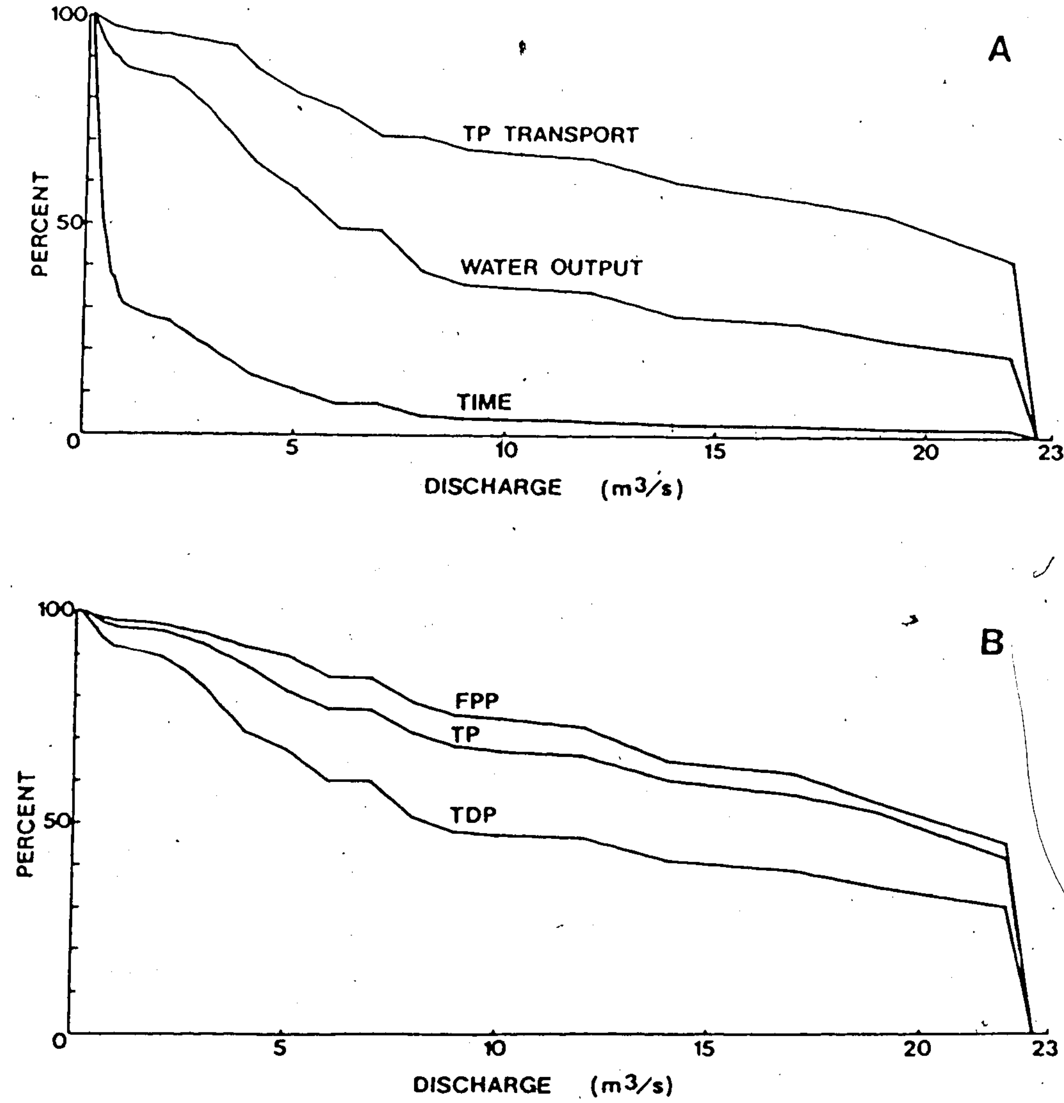

Fig. 2.8. Flow duration curves for Two Creek indicating: A. the % total time, % water output, and % total phosphorus (TP) transport measured at or above the specified discharge, and B. the % TP, % fine particulate phosphorus (FPP), and % total dissolved phosphorus (TDP) transport measured at or above the specified discharge in Two Creek.

III. General Discussion

In this study, epistemological difficulties involved in relating patterns with processes (Hart 1983) are apparent. For example, I have demonstrated that there are seasonal patterns in phosphorus (P) transport, a potential limiting energy source for stream biotic communities. While I can speculate on how this influences functional feeding group dynamics, the predictions would involve too many assumptions to be useful. These assumptions include: (1) P is in limiting supply to at least the dominant species or functional groups, (2) that P is limiting at all times, and (3) it is possible to isolate the influence of P from other physical factors such as seasonal temperature change. An enormous effort would be required to support these assumptions. Thus, the link between stream community processes and P dynamics is largely speculative. Stream community ecology remains a young science although the prevailing view is that abiotic variables (such as discharge) override biotic variables (such as invertebrate detritus processing) in determining stream community organization (Barnes and Minshall 1983).

The use of radioactive tracers has been important in discerning the role of P within biotic and abiotic compartments within streams (Newbold et al. 1983). The cycling (spiralling) of P includes three processes: (1) downstream transport, (2) turnover length within the water column, and (3) consumer turnover length. However, work needs to be done on metabolic P requirements of stream organisms in relation to P availability and natural variation in metabolic requirements. Also, the interactions of P in flowing water with the sediments and groundwater has largely been ignored in stream P studies.

However, the detection of patterns is a necessary step in the modelling of stream ecosystems. This study represents the first detailed study of P dynamics on coniferous watersheds; all previous work has been done on hardwood watersheds (e.g. Meyer and Likens 1979, Newbold et al. 1983) or on disturbed watersheds (e.g. Rigler 1979). Major differences in this study compared with previous work include the larger proportion of P being transported as dissolved P rather than fine particulate P at low flows (e.g. 63% of total P transport in October was in the dissolved fraction) and the relatively limited importance of coarse particulate P transport (3% of total P transport). Whether these differences can be attributed to differences in watershed vegetation is unknown. As well, regional climatic variation can alter timing of storms, leaffall, and other factors that have a strong influence on P export dynamics (Johnson et al. 1976, Meyer and Likens 1979). The models (Eq.1 and Eq. 2 whereby Q is discharge and R is rate of change of discharge) I constructed for two streams draining coniferous watersheds

Two Creek:

$$\ln TP = 3.04 + 0.25\ln Q + 0.09(\ln Q)^2 + 0.12R \qquad (n=209,\ r=0.87) \qquad (1)$$

Sakwatamau River:

$$\ln TP = 2.91 + 0.26\ln Q + 0.12(\ln Q)^2 - 0.09R \qquad (n=166,\ r=0.78) \qquad (2)$$

can be refined by testing data obtained from other coniferous watersheds that differ in climatic patterns.

The detection of patterns is also important on a regional scale for use in management programs. For example, this study indicates that major P loading occurs during storm events which suggests that sampling frequency should be on the order of every few hours during heavy summer storms in central Alberta. As well, daily sampling would be adequate during spring runoff and bi-monthly sampling would be adequate during low flows in the fall. However, the efficiency of this suggested sampling regime is strongly dependent on climatic patterns and year-to-year variation may be significant (Meyer and Likens 1979).

Current stream ecosystem models are descriptions of local patterns and ignore ecosytem stability (Webster et al. 1983). Stability can be defined in terms of resistance (ability of ecosystem to exhibit minimal response to disturbance) and resilience (rapidity with which an ecosystem responds once it has been displaced by a disturbance) (Webster et al. 1983). Eventually, stream ecosystem models should be developed to predict biotic response to stochastic disturbances within the ecosystem based on the magnitude and duration of the disturbance. The rapid return to pre-storm P export patterns exhibited by Two Creek and Sakwatamau River following major storms would suggest a resilient ecosystem. Even though there was overland flow and physical alteration of the stream channels (uprooted trees and streambank erosion; i.e. strong disturbance), these events only represent a short-term disturbance (2 weeks). Two Creek and Sakwatamau River may not be so resilient to long-term disturbances. Resistance was low in the watersheds since stream discharge responded strongly to rain events. However, evaluation of resistance and resilience is subjective at this point for stream ecosystems.

I conclude that this study represents an important advance in the modeling of stream P dynamics. It is the first model based on detailed data from watersheds with the following characteristics: (1) coniferous trees, (2) 3-5 m of glacial till overlying sedimentary bedrock, and (3) climatic regime with strong summer storms. The direct effect of each characteristic is unknown although the combined effect is important. Phosphorus transport was pulsed during summer storms; 68% of total P export was transported during 12 days for Two Creek. While other studies on both forested and agricultural watersheds report stronger pulsing (e.g. Johnson et al. 1976), most studies report pulsing primarily during spring and autumn (e.g. Meyer and Likens 1979). The P pulsing during early summer storms suggests a depletion of P pools during storm events and an accumulation of P on [illegible] sediments in autumn. The potential for retention of P during autumn and winter in Two Creek and Sakwatamau River sediments suggests an energy source for organisms over-wintering under the ice and in the sediments. Whether P retention occurs and whether P retained is available to biotic compartments remain to be tested.

A. References

Barnes, J.R., and G.W. Minshall. 1983. Stream ecology: an historical and current perspective. Pages 1-6 *in* J.R. Barnes and G.W. Minshall, editors. Stream ecology. Application and testing of general ecological theory. Plenum Press, New York, New York, USA.

Hart, D.D. 1983. The importance of competitive interactions within stream populations and communities, Pages 99-136 *in* J.R. Barnes and G.W. Minshall, editors. Stream ecology. Application and testing of general ecological theory. Plenum Press, New York, New York, USA.

Johnson, A.H., D.R. Boulden, E.A. Goyette, and A.M. Hedges. 1976. Phosphorus loss by stream transport from a rural watershed: quantities, processes, and sources. Journal of Environmental Quality 5:148-157.

Meyer, J.L., and G.E. Likens. 1979. Transport and transformations of phosphorus in a forest stream ecosystem. Ecology **60**:1255-1269.

Newbold, J.D., J.W. Elwood, R.V. O'Neill, and A.L. Sheldon. 1983. Phosphorus dynamics in a woodland stream ecosystem: a study of nutrient spiralling. Ecology **64**:1249-1265.

Rigler, F.H. 1979. The export of phosphorus from Dartmoor catchments: a model to explain variations of phosphorus concentrations in stream water. Journal of the Marine Biology Association of U.K. **59**:659-587.

Webster, J.R., M.E. Gurtz, J.J. Hains, J.L. Meyer, W.T. Swank, J.B. Waide, and J.B. Wallace. Stability of stream eocystems, Pages 355-396 *in* J.R. Barnes and G.W. Minshall, editors. Stream ecology. Application and testing of general ecological theory. Plenum Press, New York, New York, USA.

IV. APPENDIX A: Taxonomic list of invertebrates collected from Two Creek and Sakwatamau River using dipnets.

ORDER	FAMILY	GENERA
Ephemeroptera	Heptageniidae	*Heptagenia*
		Cinygmula
	Ephemerellidae	*Ephemerella*
	Siphionuridae	*Ameletus*
	Leptophlebiidae	
Plecoptera	Taeniopterygidae	*Doddsia*
	Nemouridae	*Zapada*
	Chloroperlidae	*Utaperla*
	Perlodidae	*Isoperla*
	Perlidae	*Claasenia*
		Acroneuria
	Pteronarcyidae	*Pteronarcys*
	Capniidae	
Trichoptera	Hydropsychidae	*Arcopsyche*
	Brachycentridae	*Brachycentrus*
	Limnephilidae	*Limnephilus*
		Hydatopylax
	Rhyacophilidae	*Rhyacophila*
	Lepidostomatidae	*Lepidostoma*
		Theliopsyche
Diptera	Tabanidae	*Tabanus*
	Chironomidae	
Hemiptera	Corixidae	
Coleoptera		

V. APPENDIX B: Longitudinal transport of phosphorus

The study of material transport past one stream site yields valuable information about temporal changes in transport and the influence of physical characteristics in the watershed on transport dynamics. However, the measurement of changes in concentrations and relative importance of vari[illegible]s materials are transported downstream, can yield information on processes occur[illegible]stream. Vannote et al. (1980) elaborated on these ideas and developed a mod[illegible]ver continuum concept, to describe the structure and function of communities along [illegible]ver system. Minshall (1978) reported a switch in dependence from allochthonous to autochthonous sources of energy in higher-order woodland streams by measuring photosynthesis and respiration rates as well as inputs and exports of organic matter which supports the river continuum model. A major implication is that downstream communities capitalize on upstream processing inefficiencies and that both upstream inefficiencies and downstream adjustments are predictable. General predictions of the river continuum model were congruent with results obtained from analyses of longitudinal and seasonal shifts in functional group abundance with concurrent changes in food availability in Oregon streams (Hawkins and Sedell 1981) and in an Albertan river system (Culp and Davies 1982).

The measurement of food availability includes the measurement of materials being transported within different size fractions. Food availability is then usually related to the density of animals at each site most likely to use that size fraction as a food source (i.e. functional group); for example, shredders vs. coarse particulate organic matter. Thus, for each site along a river, the relationship between potential food resource and invertebrate density is known and can be tested against predictions from the continuum hypothesis. The biggest problem with this methodology is the lack of knowledge about cause and effect. For example, is a shift in abundance of a functional group a response to a shift in the size fraction of materials being transported, or is the distribution of animals a result of changing substrate types? Is the shift in size of materials being transported a reflection of different processing rates caused by a change in the abundance of a functional group? Macroinvertebrates are an important component in the longitudinal linkage because their influence on the quantity and timing of fine particulate matter transport (Webster 1983). The obvious approach to overcome this problem is well-controlled field experiments that alter either food availability or abundance of a functional group and measure the response within other ecosystem components. The focus would be more on process than pattern.

On August 4 and October 4 1983, I measured phosphorus (P) partitioning at 9 sites (plus 3 seeps which are springs or small streams draining into the main channel) along a 3390 m section of Two Creek to see if it was possible to detect changes in the partitioning of P en route downstream (Fig. 5.1). Phosphorus was separated into two size fractions: total dissolved phosphorus (TDP, <0.45um) and fine particulate phosphorus (FPP, 0.45um - 1mm). The P energy pathway was chosen to test for changes in food availability for two reasons: (1) measurement of benthic biomass and transport of material is not necessarily an adequate estimate of food availability because food quality varies, and (2) P can limit rates of detritus decomposition and aufwuchs production (Elwood et al. 1981) and thus may control rates of energy transformations.

The two sampling dates are representative of different seasons. On August 4, flow was on the falling limb of the summer storm hydrograph (2.0 m^3/s) and coarse particulate matter (CPM) transport was also declining (27.1 mg/m^3 at site 1). Air and water temperatures were 10°C and 13°C, respectively. Flows were much lower on October 4 (0.2 m^3/s) and it had been two weeks since the last rain storm. Stream transport of autumn litterfall (primarily spruce needles) was high; concentration of CPM transported past site 1 was 16.5 mg/m^3 compared with 3.0 mg/m^3 of CPM transported past site 1 on September 22. Air and water temperatures were 3°C and 4°C, respectively.

On both dates, there were no significant changes in FPP or TDP concentrations as streamwater was transported downstream (Table 5.1). However, both FPP and TDP concentrations were lower in October than August (n=12, t=14.1, $P<0.05$; $n=12$, t=13.0,

$P<0.05$, respectively) probably due to lower flows and lack of suspension of fine particulate materials. As well, in August, there was no significant difference between FPP and TDP concentrations ($n=12$, $t=2.0$, $P>0.05$) but in October, TDP was significantly higher than FPP concentrations ($n=12$, $t=10.0$, $P<0.05$).

The variability in P concentration between seeps was a surprising pattern that emerged, perhaps reflecting different origins of the seeps (e.g. groundwater vs. bog) and distance travelled before entering Two Creek. An overall trend, however, is relatively low FPP concentration and relatively high TDP concentration in seepwater. The low FPP concentration in seeps had no apparent effect (i.e. no dilution effect) on streamwater due to the low volume of water entering the streams via seeps or due to a conversion of dissolved to fine particulate material as reported by Meyer and Likens (1979).

These results suggest seasonal but no longitudinal trends in Two Creek based on measurement of materials in transport due to: (1) significant differences in both TDP and FPP concentration between August and October, and (2) no downstream change in either TDP or FPP concentration in August or in October. Thus, I predict no change in frequency and abundance of functional feeding groups of invertebrates along Two Creek. However, I predict a seasonal shift from collector-filterers in August (Cummins 1974) to a community comprised of bacteria and other decomposers in October. These predictions ignore the availability of benthic food. However, these results suggest that invertebrates do not have a large role in transport dynamics.

The first predictions that functional groups would not change in a longitudinal gradient appear congruent with trends observed in low-order streams in the southern Appalachian region where macroinvertebrates accelerated the turnover of particulate matter so that by the end of the summer there was almost no particulate material left in the stream (Webster 1983). However, I postulate that in Two Creek the greater amount of particulate material transported during summer as compared with autumn was due primarily to higher flows and not invertebrate processing. I suggest that in Two Creek, P transport and processing were more similar to patterns observed at Hubbard Brook (New Hampshire) where macroinvertebrates do not appear to have a significant role, and large amounts of detritus accumulated and were susceptible to transport during major storms (Fisher and Likens 1973, Meyer and Likens 1979). The basis for this suggestion is the strong pulsing of fine particulate material during storm events in Two Creek (Chapter 2) which is different from Hurricane Branch where strong pulsing of particulate matter was absent (Webster 1983).

Thus, I suggest that abiotic rather than biotic factors have a dominant influence on the partitioning of P transport. To either support or refute these predictions, the following work needs to be done: (1) quantifying the volume as well as the P concentration of water entering the main stream channel via seeps, (2) quantifying abundance of invertebrates and categorizing them according to functional feeding group, (3) measuring standing stock of detrital material during all seasons, (4) quantifying rates of invertebrate detrital processing during all seasons, and (5) addition and removal experiments of both invertebrates and detrital material.

A. References.

Culp, J.M., and R.W. Davies. 1982. Analysis of longitudinal zonation and the river continuum concept in the Oldman-South Saskatchewan River system. Canadian Journal of Fisheries and Aquatic Sciences **39**:1258-1266.

Cummins, K.W. 1974. Stucture and function of stream ecosystems. Bioscience **24**:631-641.

Elwood, J.W., J.D. Newbold, A.F. Trimble, and R.W. Stark. 1981. The limiting role of phosphorus in a woodland stream ecosystem: effects of P enrichment on leaf decomposition and primary producers. Ecology **62**:146-158.

Fisher, S.G., and G.E. Likens. 1973. Energy flow in Bear Brook, New Hampshire: an intergrative approach to stream ecosystem metabolism. Ecological Monographs **43**:421-439.

Hawkins, C.P., and J.R. Sedell. 1981. Longitudinal and seasonal changes in functional organization of macroinvertebrate communities in four Oregon streams. Ecology **62**:387-397.

Meyer, J.L., and G.E. Likens. 1979. Transport and transformations of phosphorus in a forest stream ecosystem. Ecology **60**:1255-1269.

Minshall, G.W. 1978. Autotrophy in stream ecosystems. Bioscience **28**:767-771.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushinig. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences **37**:130-137.

Webster, J.R. 1983. The role of benthic macroinvertebrates in detritus dynamics of streams: a computer simulation. Ecological Monographs **53**:383-404.

Table 5.1. Fine particulate phosphorus (FPP) and total dissolved phosphorus (TDP) concentrations (mg/m^3) of streamwater at twelve different sites along Two Creek: site 1 is the main study site.

SITE		AUGUST 4		OCTOBER 4	
		FPP	TDP	FPP	TDP
1		10.9	12.6	3.9	9.8
2		13.9	11.7	3.9	10.1
3	seep	2.5	19.5	7.8	10.1
4		12.4	11.9	4.7	9.4
5		11.4	12.6	6.6	8.8
6		11.3	12.2	5.9	8.9
7	seep	1.8	8.7	0.6	7.8
8		10.9	12.3	5.7	8.3
9		11.5	12.2	5.8	8.0
10	seep	4.5	10.0	3.2	6.7
11		11.3	12.3	5.2	8.2
12		10.8	12.6	4.3	8.9

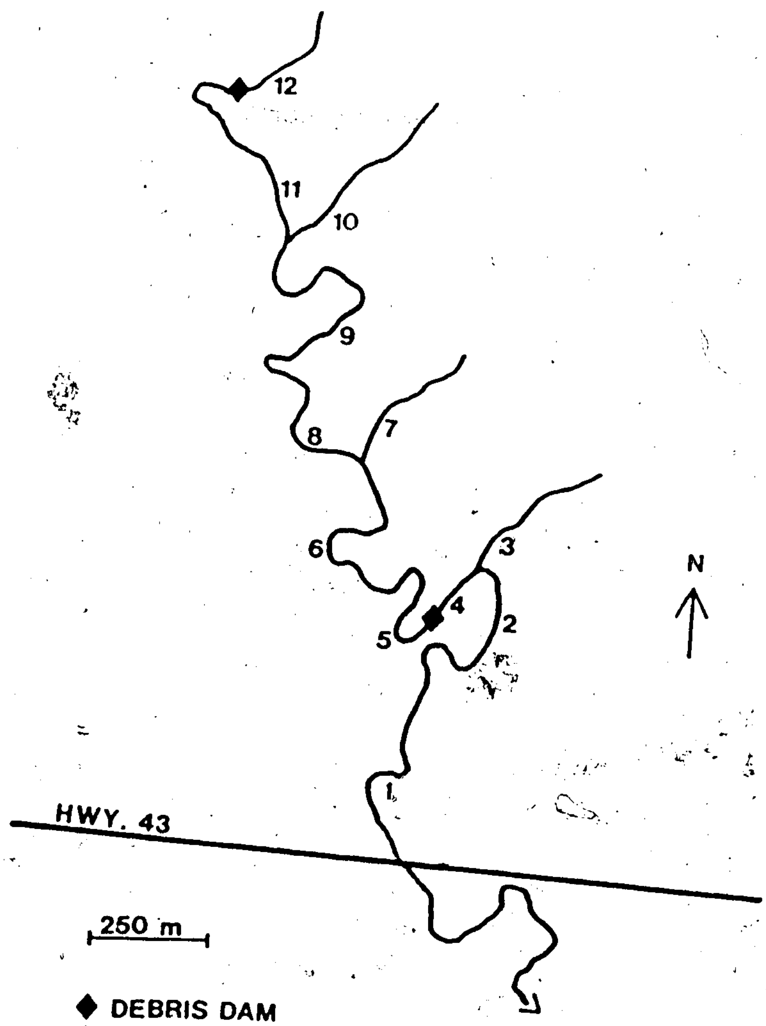

Fig. 5.1. Two Creek study site with numbers indicating sampling sites.

VI. APPENDIX C: Figures of Sakwatamau River and Two Creek data not included in Chapter II and cluster analysis dendrogram for total phosphorus loading in Two Creek.

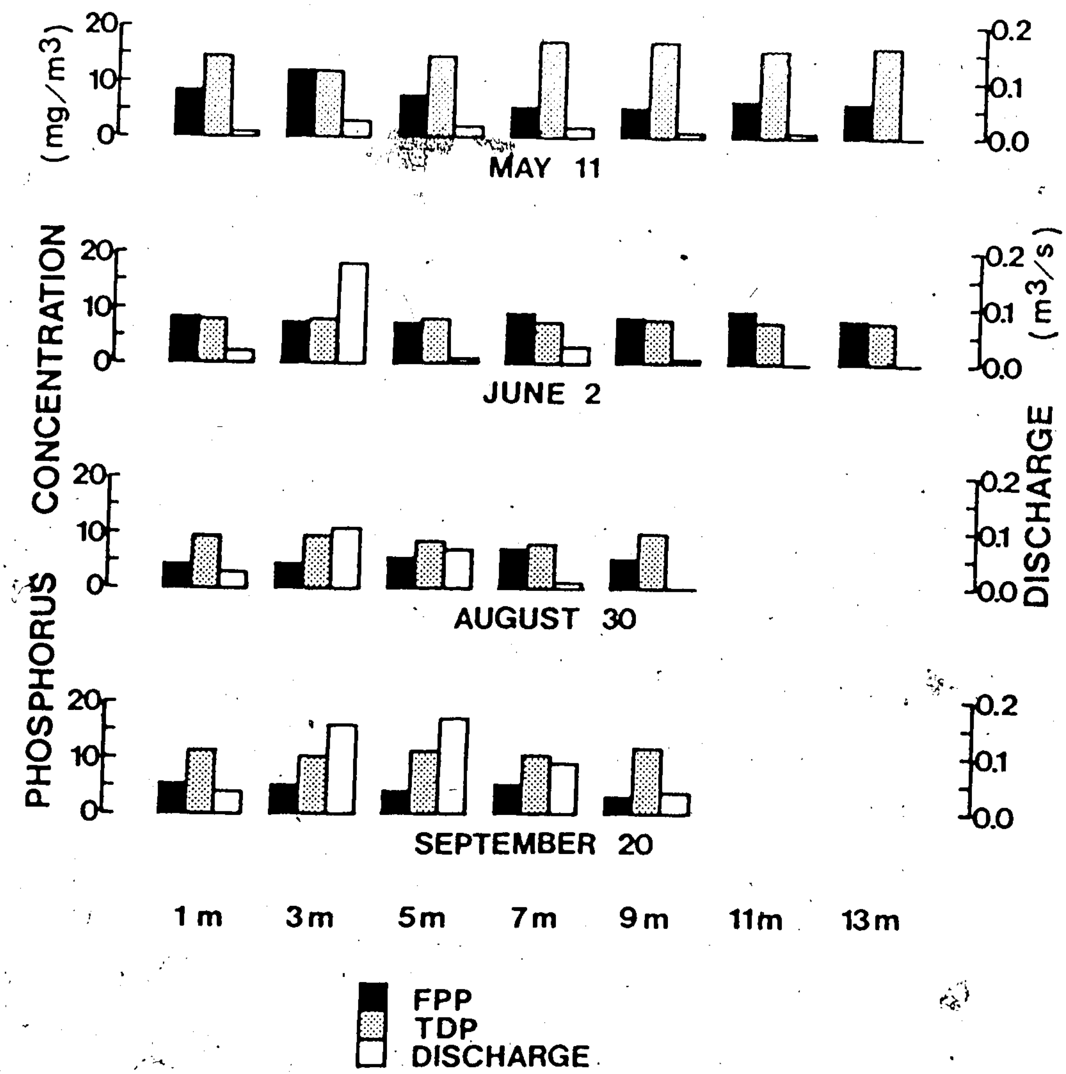

Fig. 6.1. Discharge, fine particulate phosphorus (FPP), and total dissolved phosphorus (TDP) concentrations at 2-m intervals across the width of Sakwatamau River.

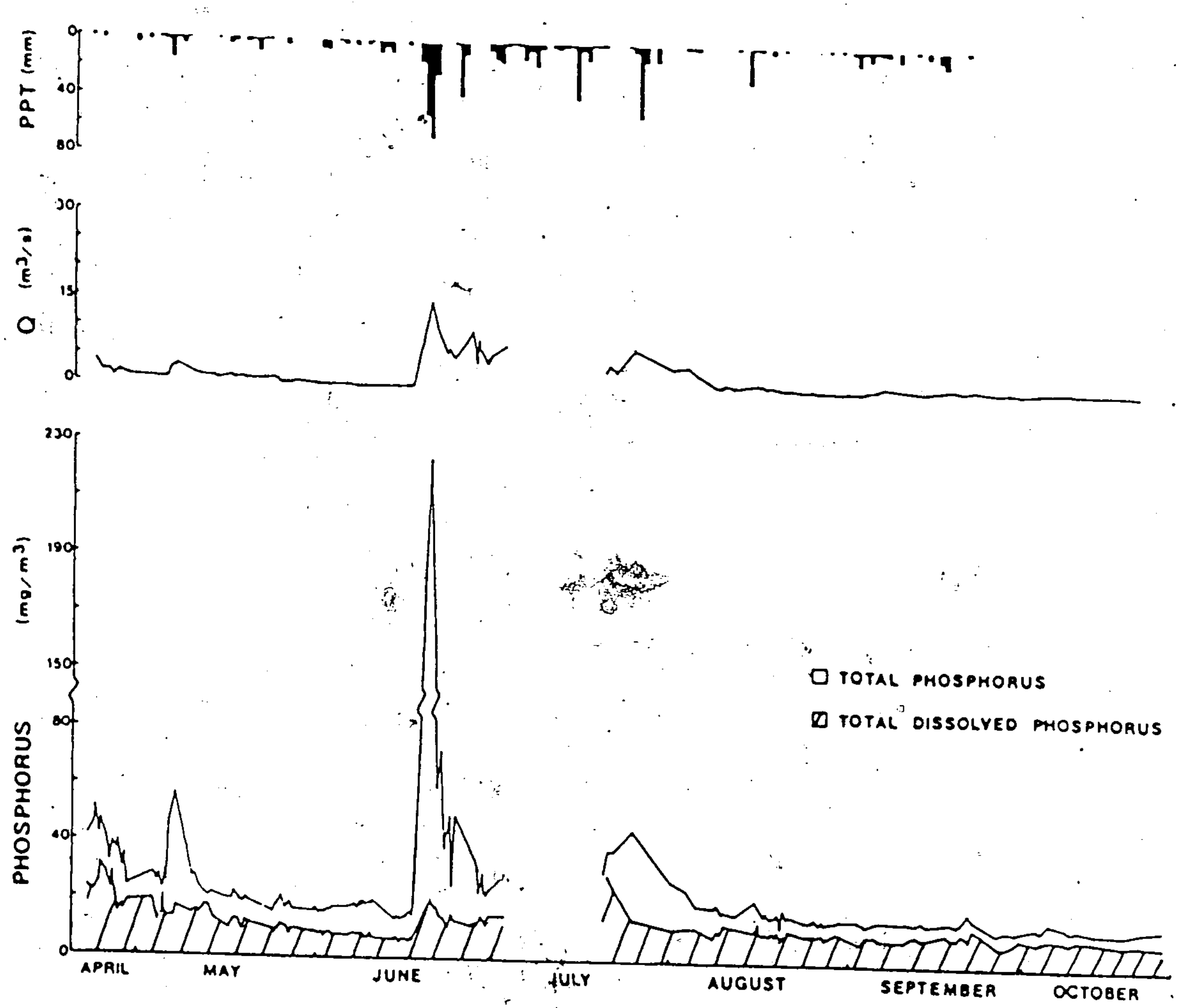

Fig. 6.2. Variation in precipitation (PPT), discharge (Q), total phosphorus (TP), and total dissolved phosphorus (TDP) concentrations from April to October, 1983, for Sakwatamau River.

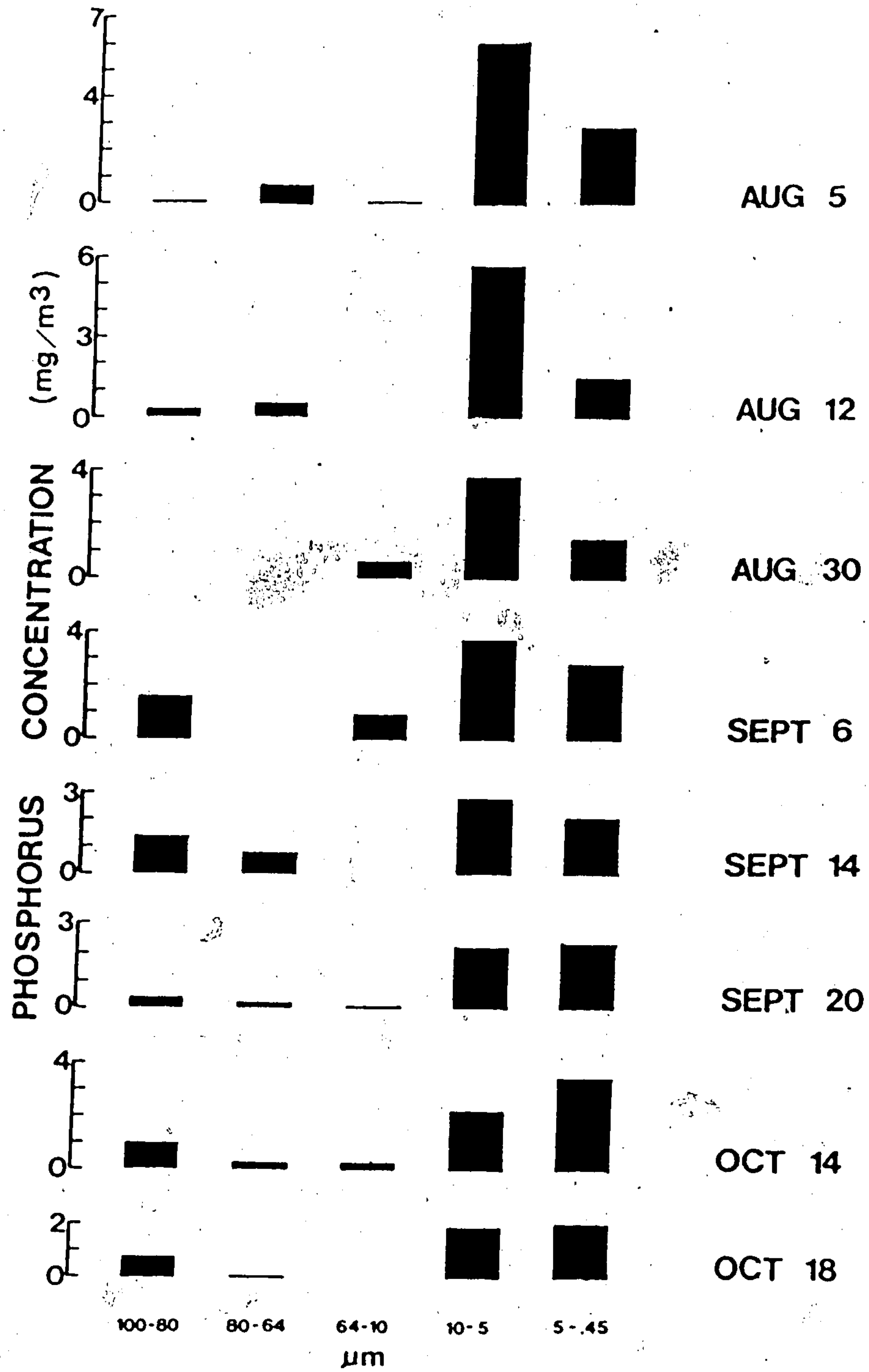

Fig. 6.3. Fractionation of the fine particulate phosphorus size fraction for Two Creek.

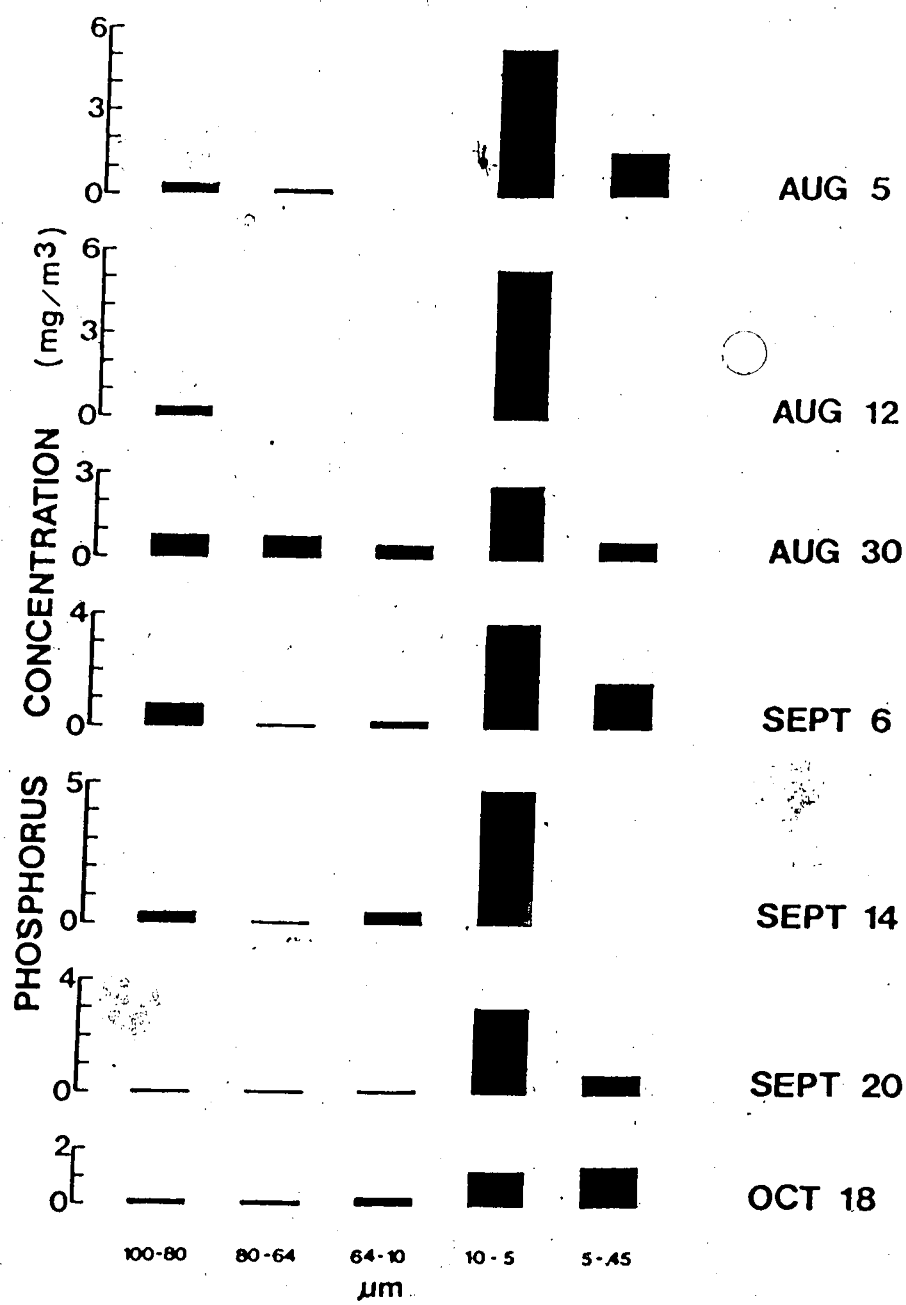

Fig. 6.4. Fractionation of the fine particulate phosphorus size fraction for Sakwatamau River.

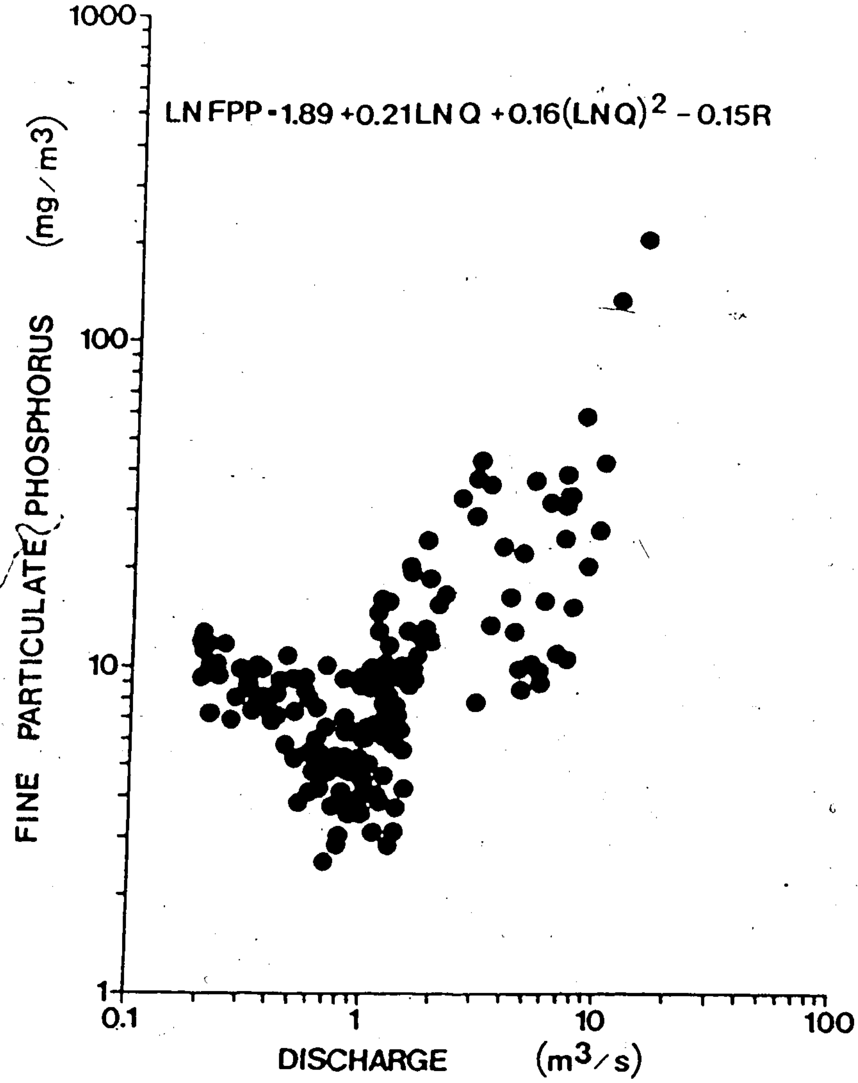

Fig. 6.5. Relationship between fine particulate phosphorus (FPP) concentration and discharge (Q) for Sakwatamau River (n=170). R is rate of change of discharge.

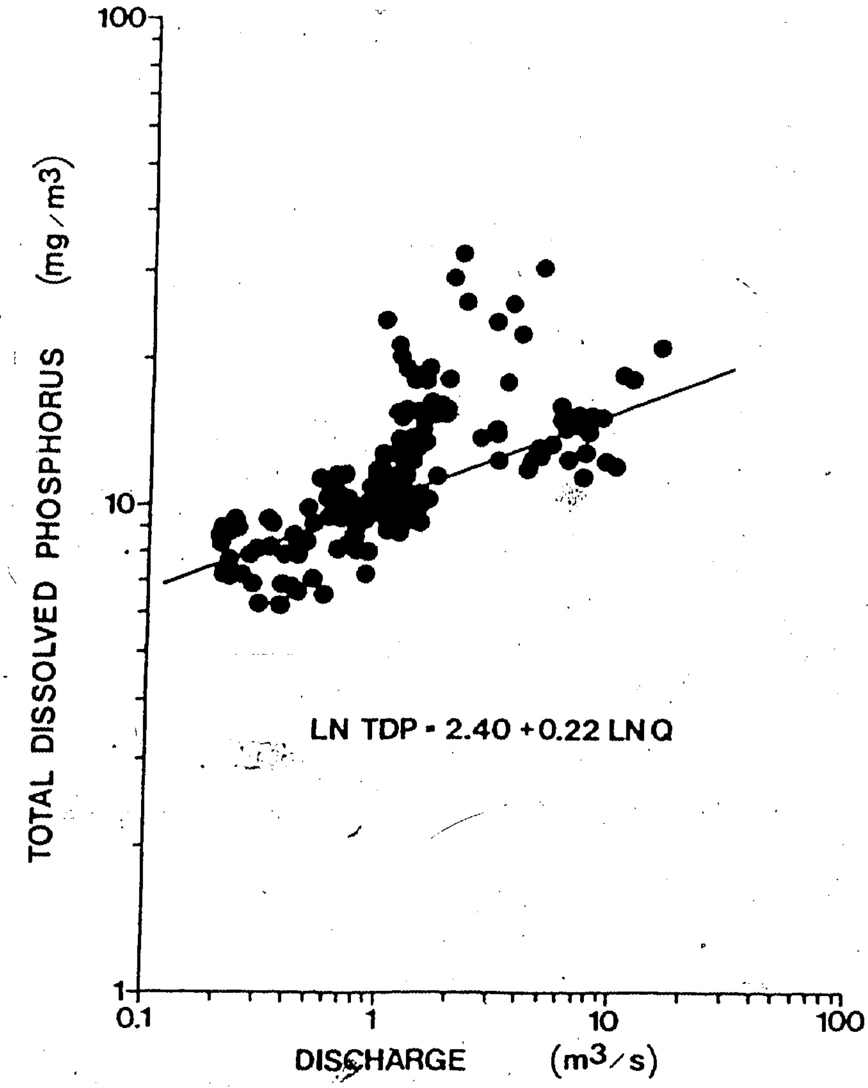

Fig. 6.6. Relationship between total dissolved phosphorus (TDP) concentration and discharge (Q) for Sakwatamau River.

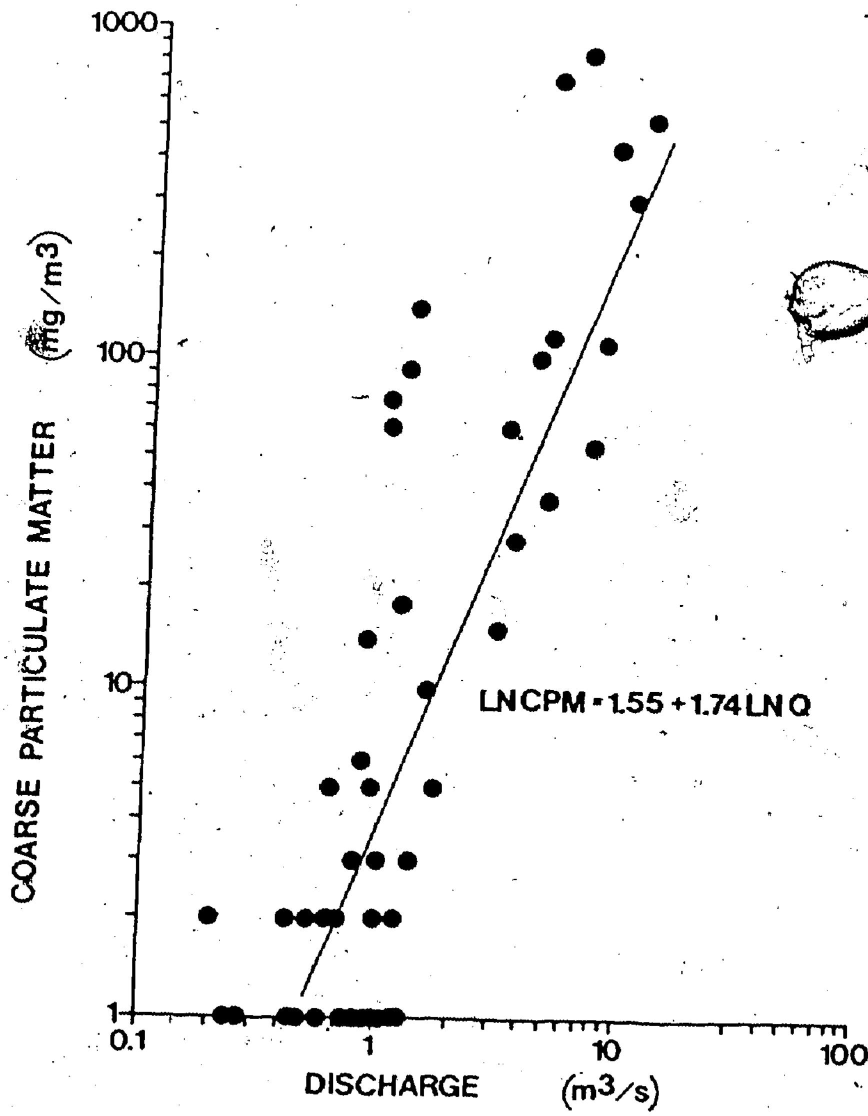

Fig. 6.7. Relationship between coarse particulate matter (CPM) and discharge (Q) for Sakwatamau River.

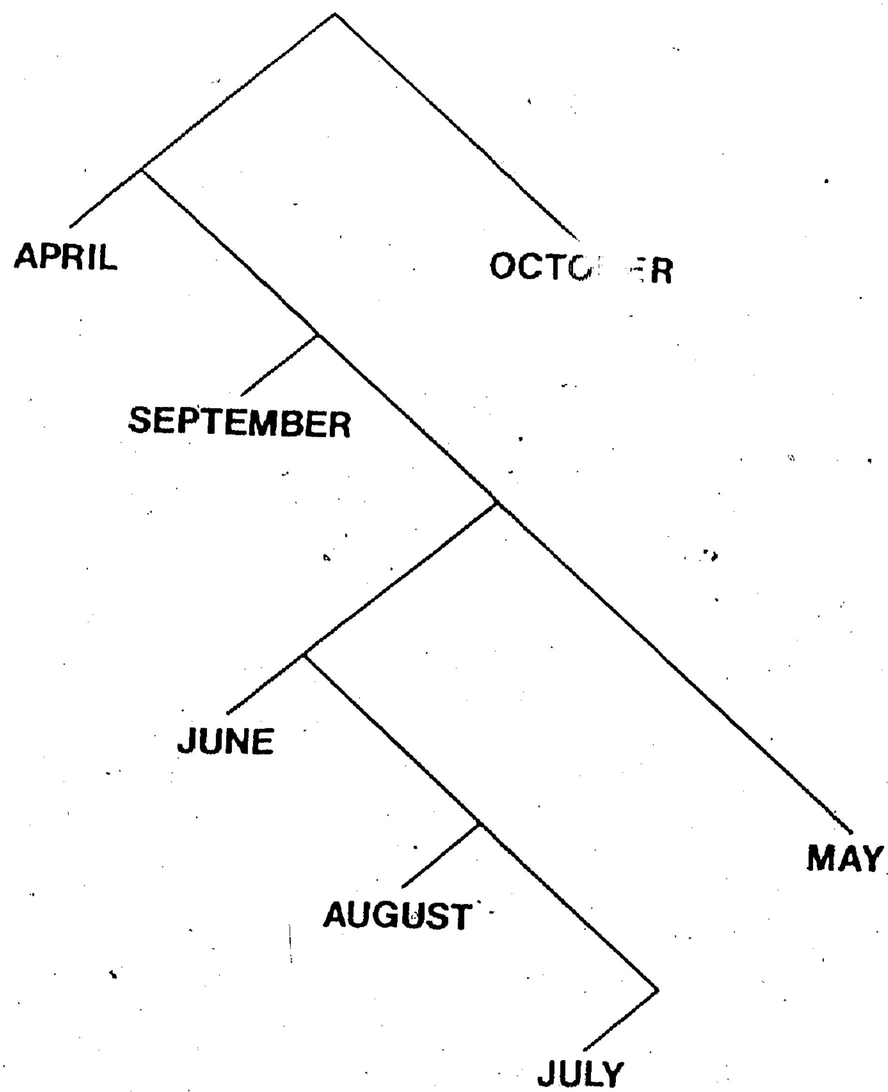

Fig. 6.8. Cluster analysis dendrogram indicating degree of similarity in total phosphorus loading between months for Two Creek.

VII. APPENDIX D: Physical and chemical data collected from Two Creek and Sakwatamau River during 1983

Table 7.1. Precipitation data collected from April-September, 1983, at Eagle Looko[illegible]tion (Alberta Forest Service firetower) located on the northern edge of Two Creek watersh[illegible]

Month	Daily Maximum (mm)	Average Daily (mm/day)	Total (mm)
April	5.0	0.25	7.6
May	14.7	1.58	49.1
June	67.3	8.55	256.1
July	38.9	6.84	212.1
August	25.4	1.23	38.1
September	11.0	1.98	59.5
Total			622.9

Table 7.2. Summary of 1983 discharge data for Two Creek and Sakwatamau River; X is average discharge (m^3/s) for the sampling period and T is total discharge (dam^3) for the sampling period.

	TWO CREEK			SAKWATAMAU RIVER		
	Mean Monthly Discharge (m^3/s)	Total Discharge (dam^3)	% of Total	Mean Monthly Discharge (m^3/s)	Total Discharge (dam^3)	% of Total
April	0.525	386	1.2 %	1.829	1349	3.8 %
May	0.901	2413	7.7 %	1.256	3364	9.5 %
June	4.901	12704	40.3 %	4.419	11454	32.5 %
July	4.951	13261	42.1 %	4.160	11142	31.6 %
August	0.612	1639	5.2 %	1.410	3777	10.7 %
September	0.276	715	2.6 %		2535	7.2 %
October	0.185	392	1.2 %		1628	4.6 %
	x=1.95	T=31510		x=2.19	T=35249	

Table 7.3. Two Creek and Sakwatamau River pH data collected during 1983.

Date	Sakwatamau River	Two Creek
May 14	8.0	8.0
May 27	8.3	8.3
July 31	7.6	7.6
September 6	8.4	8.4
September 22	8.0	8.2
October 1	8.2	8.1
October 14		8.3
Mean (SD)	8.1 (.29)	8.1 (.26)

Table 7.4. Average nitrate and nitrite nitrogen (mg/m^3), average Kjeldahl nitrogen (mg/m^3), and average total nitrogen (TN; mg/m^3 concentrations as well as total nitrogen to total phosphorus ratios (TN:TP) for Sakwatamau River and Two Creek during 1983.

Date	Stream	Nitrate + Nitrite	Kjeldahl	TN	TN:TP
May 27	Sakwatamau River	[illegible]	458.2	460.1	24
	Two Creek	1.3	495.3	[illegible]	[illegible]
August 1	Sakwatamau River	2.4	603.4	605.8	22
	Two Creek	3.2	766.1	769.3	26

Table 7.5 Cation (sodium, potassium, calcium, and magnesium) and anion (total alkalinity as $CaCO_3$, bicarbonate, chloride, and sulfate) concentrations in mg/L from samples collected from Sakwatamau River and Two Creek on August 3, 1983.

Ion	Sakwatamau River	Two Creek
Sodium	6.4	5.7
Potassium	0.2	0.2
Calcium	34.1	32.1
Magnesium	8.9	8.1
$CaCO_3$	74.3	65.6
Bicarbonate	90.6	80.0
Chloride	0.10	0.09
Sulfate	0.7	0.6

Table 7.6. Maximum instantaneous discharge (Q; m^3/s), mean daily discharge (m^3/s), and total annual discharge (dam^3) for an eleven year period (1973-1983) collected by Environment Canada at the mouth of Sakwatamau River near Whitecourt, Alberta.

Year	Maximum Q		Mean Daily Q	Total Q
1973	65.4	June 17	8.1	174000
1974	80.1	April 30	9.6	205000
1975	101.0	June 28	6.8	144000
1976	58.3	August 18	9.6	204000
1977	101.0	May 30	1.4	231000
1978	87.8	June 15	7.2	155000
1979			14.2	301000
1980	34.5	May 28	7.1	151000
1981	50.1	June 1	4.7	98600
1982	51.6	August 4	6.8	143000
1983	92.6	June 26	7.4	164000
Mean			7.6	179145

Table 7.7. Sakwatamau River physical and chemical data. Twenty-one variables were measured and are defined as follows:

1- Month
2- Day
3- Time (h)
4- Precipitation (mm)
5- Cummulative Time (h)
6- Total Phosphorus Concentration (mg/m³)
7- Total Dissolved Phosphorus Concentration (mg/m³)
8- Fine Particulate Phosphorus Concentration (mg/m³)
9- Concentration of Coarse Particulate Matter Transport (mg/m³)
10- Instantaneous Total Phosphorus Loading (mg/s)
11- Instantaneous Total Dissolved Phosphorus Loading (mg/s)
12- Instantaneous Fine Particulate Phosphorus Loading (mg/s)
13- Cross-sectional Area of Stream (m²)
14- Average Velocity (m/s)
15- Discharge (m³/s)
16- Depth Guage (m)
17- Air Temperature (°C)
18- Water Temperature (°C)
19- Water Colour (mg/L Pt.)
20- Turbidity (NTU)
21- Conductivity (µmhos/cm)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
04	22	1100	0.6	0.0	42.0	24.2	17.6													
04	23	0930	0.0	22.5	45.3	22.0	23.3		170.3	82.7	87.6	4.78	0.40	3.760						
04	23	1730	0.0	30.5	52.1	23.3	28.8		151.1	67.6	83.5	5.19	0.49	2.900						
04	24	1000	2.0	47.0	42.2	25.6	16.6		92.0	55.8	36.2	4.33	0.48	2.180						
04	24	1530	0.0	52.5	47.7	32.3	15.4		98.3	66.5	31.7	4.52	0.45	2.060						
04	25	1630	0.0	77.5	40.8	28.8	12.0		77.5	54.7	22.8	3.75	0.44	1.900						
04	26	1030	0.0	95.5	32.7	23.5	9.2		31.7	22.8	8.9	2.91	0.36	0.970						
04	26	1630	0.0	101.5	39.0	18.8	20.2		60.4	29.1	31.3	3.14	0.48	1.550						
04	27	1130	0.0	120.5	36.5	17.8	18.7		68.3	33.3	35.0	3.79	0.46	1.870						
04	27	1630	0.0	125.5	39.7	15.5	24.2		72.3	28.2	44.0	3.34	0.49	1.820						
04	28	1130	0.0	144.5	30.5	17.7	12.8		45.4	26.4	19.1	7.49	0.18	1.490						
04	28	1630	0.0	149.5	35.4	16.1	19.3		55.6	25.3	30.3	7.43	0.18	1.570						
04	29	0900	0.0	166.0	34.5	18.8	15.7		42.4	23.1	19.3	7.21	0.15	1.230		15	3	23	3.1	150

Table 7 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
05	03	1700	7.5	270.0	28.7	19.8	8.9		32.8	22.6	10.2	6.66	0.15	1.143						
05	04	1030	0.6	287.5	26.1	13.4	12.7		29.9	15.4	14.6	6.74	0.15	1.146						
05	04	1630	0.1	293.5	28.6	12.5	16.1		33.3	14.6	18.8	6.73	0.15	1.165						
05	05	0830	0.0	309.5	23.8	14.8	9.0		27.5	17.1	10.4	6.84	0.15	1.157						
05	05	1230	0.0	313.5	24.0	20.9	3.1		26.9	23.4	3.5	6.76	0.14	1.121						
05	05	1630	0.0	317.5	29.7	15.2	14.5		33.4	17.1	16.3	6.73	0.14	1.125						
05	05	2030	1.2	321.5	27.1	15.5	11.6		33.8	19.3	14.5	6.89	0.15	1.247						
05	06	0030	0.0	325.5	26.1	13.1	13.0													
05	06	0930	4.3	334.5	46.7	13.5	33.2		118.1	34.1	83.9	7.97	0.29	2.528						
05	06	1830	0.4	343.5	51.0	13.8	37.2		153.0	41.4	111.6	8.42	0.33	3.000						
05	07	0700	1.2	356.0	56.8	14.1	42.7		170.2	42.2	127.9	8.34	0.33	2.996						
05	07	1230	0.0	361.5	53.4	17.6	35.8		176.6	58.2	118.4	8.37	0.34	3.307				50	11.0	115
05	10	1000	0.0	431.0	28.2	15.1	13.1		51.0	27.3	23.7	8.02	0.21	1.810	0.76	10	4			
05	10	1700	4.8	438.0	28.3	15.9	12.4		48.7	27.3	21.3	7.73	0.20	1.720	0.70	16	9			
05	11	1000	0.0	455.0	25.8	15.9	9.9		41.5	25.6	15.9	7.69	0.22	1.610	0.70	12	5			
05	11	1600	0.0	461.0	24.1	15.0	9.1		38.6	24.0	14.6	7.55	0.19	1.600	0.69					
05	12	1430	0.0	483.5	22.0	18.3	3.7		30.6	25.4	5.1	7.38	0.15	1.390	0.70					
05	13	1030	0.0	503.5	20.8	17.7	3.1		28.3	24.1	4.2	7.22	0.16	1.360	0.69					
05	13	1900	0.0	512.0	22.4	15.3	7.1		31.4	21.4	9.9	7.09	0.18	1.400	0.69					
05	14	0630	0.6	523.5	21.9	12.8	9.1		24.7	14.5	10.3	6.97	0.15	1.130	0.68			40	2.6	160
05	16	1700	4.1	582.0	19.9	9.9	10.0		28.7	14.3	14.4	7.05	0.18	1.440	0.68					
05	17	0830	0.0	597.5	20.2	12.1	8.1		25.9	15.5	10.4	7.14	0.15	1.280	0.68	4	5			
05	17	1430	2.2	603.5	23.0	12.9	10.1		28.1	15.7	12.3	7.15	0.15	1.220	0.68	16	9			
05	18	1100	0.0	624.0	20.6	13.0	7.6		28.2	17.8	10.4	7.32	0.16	1.370	0.69	10	8			
05	18	1700	0.0	630.0	19.4	10.3	9.1		27.0	14.3	12.6	6.72	0.17	1.390	0.68	10	11			
05	19	0700	0.0	644.0	19.3	9.5	9.8		21.2	10.5	10.8	7.31	0.13	1.100	0.68	5	8			
05	19	1600	2.1	653.0	20.8	12.8	8.0		25.6	15.7	9.8	7.27	0.15	1.230	0.68	16	11			
05	20	0530	1.3	666.5	19.5	12.0	7.5		23.6	14.5	9.1	7.34	0.15	1.210	0.68	6	8	40	2.2	135
05	24	1100	9.7	768.0	16.0	9.4	6.6		21.3	12.5	8.8	7.32	0.16	1.332	0.66	19	10			
05	24	1830	0.0	775.5	18.2	8.9	9.3		21.6	10.5	11.0	7.11	0.13	1.185	0.71	14	15			
05	25	1030	0.0	791.5	19.5	10.2	9.3		10.9	5.7	5.2	7.01	0.06	0.558	0.72	18	11			
05	25	1730	0.0	798.5	21.4	11.4	10.0		14.6	7.8	6.8	7.10	0.08	0.682	0.73	17	14			
05	26	1100	0.0	816.0	17.2	11.3	5.9		10.8	7.1	3.7	7.12	0.07	0.626	0.70	7	10			
05	26	2000	4.2	825.0	18.5	10.4	8.1		10.6	6.0	4.6	7.06	0.07	0.574	0.71	11	13			
05	27	0830	0.0	837.5	19.1	8.3	10.8		9.0	3.9	5.1	7.01	0.05	0.470	0.71	8	8	40	1.6	200
05	27	1700	0.0	846.0	16.9	10.0	6.9		14.0	8.3	5.7	6.90	0.09	0.830	0.66	21	15			
05	31	1000	0.0	935.0	16.3	9.0	7.3		8.2	4.5	3.7	6.70	0.05	0.501	0.69	10	13			
05	31	1730	0.0	942.5	17.6	9.2	8.4		5.6	2.9	2.7	6.56	0.04	0.319	0.69	23	17			
06	01	1000	0.2	959.0	15.4	8.6	6.8		6.2	3.5	[illegible]	6.60	0.05	0.402	0.69	9	12			
06	01	2130	5.8	970.5	16.3	9.0	7.3		5.4	3.0	2.4	6.61	[illegible]	0.330	0.69	7	13			

Table 7 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
06	02	0730	6.6	980.5	16.1	7.8	8.3		6.7	3.3	3.5	6.62	0.05	0.417	0.69	4	7			
06	02	1500	0.5	988.0	16.7	8.1	8.6		5.3	2.6	2.7	6.22	0.04	0.316	0.69	14	14			
06	03	0830	0.0	1005.5	16.9	8.0	8.9		7.3	3.5	3.9	6.53	0.05	0.434	0.69	2	10			
06	03	1500	0.0	1012.0	17.6	7.8	9.8		6.5	2.9	3.6	6.44	0.05	0.372	0.69	11	13	30	1.3	200
06	06	1630	3.5	1085.5	17.9	8.1	9.8		5.7	2.6	3.1	6.43	0.04	0.321	0.69	18	16			
06	07	1130	0.0	1104.5	18.9	8.8	10.1		4.0	1.9	[illegible]	6.38	0.03	0.214	0.67	14	13			
06	07	2200	3.7	1115.0	17.4	8.2	9.2		3.4	1.6	[illegible]	6.33	0.03	0.198	0.67	0	17			
06	08	1100	0.0	1128.0	20.1	8.9	11.2	2.5	4.1	1.8	[illegible]	6.35	0.03	0.202	0.68	19	15			
06	08	1500	0.0	1132.0	18.2	8.9	9.3		4.3	2.1	2.2	6.36	0.03	0.239	0.68	20	19			
06	08	1900	0.0	1136.0	17.8	8.0	9.8		5.1	2.3	2.8	6.28	0.04	0.287	0.68	21	19			
06	08	2300	0.0	1140.0	20.3	8.4	11.9		4.0	1.7	2.3	6.28	0.03	0.197	0.68	19	6			
06	09	1000	0.0	1151.0	18.8	7.1	11.7	1.8	4.6	1.7	2.9	6.27	0.03	0.246	0.67					
06	09	2200	3.4	1163.0	19.3	7.6	11.7		4.1	1.6	2.5	6.28	0.03	0.214	0.67	18	17			
06	10	0830	0.0	1173.5	19.4	9.2	10.2	0.6	4.5	2.1	2.3	6.31	0.03	0.230	0.67	10	12			
06	10	1500	0.3	1180.0	19.8	7.1	12.7		4.0	1.4	2.6	6.29	0.03	0.202	0.66	23	17 30	1.5	230	
06	13	2130	20.7	1258.5	14.4	6.8	7.6		5.3	2.5	2.8	6.74	0.04	0.365	0.70	10	16			
06	14	1030	0.0	1271.5	13.7	6.6	7.1	2.3	5.8	2.8	3.0	6.67	0.05	0.421	0.70	15	13			
06	14	1800	0.0	1279.0	14.7	7.8	6.9		4.0	2.1	1.9	6.65	0.03	0.270	0.69	17	18			
06	15	1030	0.0	1295.5	14.1	6.1	8.0	0.9	5.0	2.2	2.9	6.64	0.04	0.357	0.69	14	14			
06	15	1930	0.0	1304.5	14.2	7.0	7.2		3.1	1.5	1.6	6.60	0.03	0.218	0.69	18	17			
06	16	1100	0.0	1320.0	14.8	6.8	8.0	1.0	4.0	1.9	2.2	6.59	0.04	0.273	0.69	13	16			
06	16	1900	2.4	1328.0	15.8	6.2	9.6		4.6	1.8	2.8	6.71	0.04	0.292	0.70	21	20			
06	17	0700	0.0	1340.0	16.2	7.0	9.2	1.0	7.9	3.4	4.5	7.03	0.06	0.489	0.72	9	14			
06	17	1400	0.0	1347.0	15.1	6.5	8.6		8.4	3.6	4.8	7.06	0.06	0.558	0.72	20	16	30	1.7	220
06	20	1630	123.1	1421.5	225.1	20.7	204.4		3362.8	309.2	3053.5		1.82	14.939		15	6			
06	21	1000	22.8	1439.0	151.1	17.7	133.4	528.7	1734.8	203.2	1531.6		1.40	11.481		10	7			
06	21	1630	0.5	1445.5	60.1	18.1	42.0		616.9	185.8	431.1		1.25	10.264		12	7			
06	22	1000	0.0	1463.0	73.0	14.8	58.2	431.1	609.0	123.5	485.6		1.01	8.343		12	6			
06	22	1700	0.0	1470.0	46.9	13.9	33.0		346.2	102.6	243.6		0.89	7.382		16	8			
06	22	2200	0.0	1475.0	38.8	14.2	24.6		276.5	101.2	175.3		0.86	7.126		11	8			
06	23	0930	0.0	1486.5	43.7	12.1	31.6	841.0	266.6	73.8	192.8		0.73	6.101		12	7			
06	23	1700	0.0	1494.0	50.0	11.2	38.8		353.1	79.1	274.0		0.85	7.062		15	9			
06	24	0800	0.1	1509.0	25.4	15.6	9.8		142.0	87.2	54.8		0.67	5.589		11	7			
06	24	1500	0.0	1516.0	50.3	13.0	37.3		261.8	67.7	194.1		0.62	5.205		14	8	110	4.4	100
06	27	1600	46.9	1589.0	37.7	11.8	25.9	298.7	370.1	115.8	254.2		1.19	9.816		16	9			
06	28	1000	0.0	1607.0	34.9	12.8	22.1	694.3	161.5	59.2	102.3		0.55	4.628		13	9			
06	28	1600	0.0	1613.0	32.2	12.0	20.2		283.1	105.5	177.6		1.06	8.791		22	12			
06	28	2230	0.0	1619.5	23.1	12.6	10.5		166.1	90.6	75.5		0.87	7.190		11	11			
06	29	0900	0.0	1630.0	25.9	15.0	10.9		171.3	99.2	72.1		0.80	6.614		17	9			
06	29	1500	0.0	1636.0	30.0	14.2	15.8		175.4	83.0	92.4		0.70	5.845		23	13			

Table 7 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
06	29	2230	0.0	1643.5	23.4	13.2	10.2		119.4	67.3	52.0		0.65	5.101		17	13			
06	30	0830	11.0	1653.5	22.3	12.4	9.9	115.3	103.2	57.4	45.8		0.55	4.628		13	9			
06	30	1430	4.0	1659.5	23.8	14.9	8.9		133.0	83.3	49.7		0.67	5.589		14	11			
07	03	1230	27.7	1729.5	30.1	15.0	15.1	110.1	231.8	115.5	116.3		0.93	7.702		21	11			
07	20	1530	1.0	2140.5	30.9			61.7	97.5				0.37	3.156		19	14			
07	21	0930	0.0	2158.5	38.6	30.1	8.5	37.6	181.2	141.3	39.9	7.26	0.58	4.694		14	12			
07	22	1300	0.0	2186.0	38.8	25.5	13.3	28.4	132.0	86.7	45.2	6.31	0.49	3.401		21	14			
07	25	1430	4.8	2259.5	45.7	14.5	31.2	54.8	324.8	103.1	221.7	8.04	0.82	7.107		21	14	70	2.2	130
08	01	0730	0.0	2420.5	27.9	11.6	16.3	99.3	114.8	47.7	67.1		0.49	4.116		14	13			
08	03	2000	1.4	2481.0	25.0	12.2	12.8		107.7	52.6	55.1		0.54	4.308		16	18	95	3.8	80
08	05	1300	4.1	2522.0	19.8	12.1	7.7	15.6	59.5	36.4	23.2	7.58	0.27	3.007		21	16			
08	08	1600	0.0	2597.0	19.2	9.9	9.3	18.6	22.8	11.7	11.0	6.70	0.12	1.186	0.71	24	19	70	2.4	140
08	09	0700	0.0	2612.0	20.3	11.2	9.1		22.8	12.6	10.2	6.47	0.12	1.125	0.71	9	15			
08	09	1100	0.0	2616.0	19.8	10.8	9.0		22.3	12.1	10.1	6.61	0.12	1.124	0.69	17	16			
08	09	1500	0.0	2620.0	18.8	10.3	8.5		20.3	11.1	9.2	6.49	0.11	1.082	0.69	24	20			
08	09	1900	0.0	2624.0	19.0	10.4	8.6	2.1	18.7	10.2	8.5	6.51	0.11	0.984	0.69	20	20			
08	09	2300	0.0	2628.0	17.2	10.9	6.3		19.1	12.1	7.0	6.47	0.12	1.113	0.68	15	20			
08	10	0300	0.0	2632.0	17.4	11.3	6.1		21.8	14.2	7.6	6.42	0.14	1.253	0.68	11	17			
08	10	0700	0.0	2636.0	17.5	13.3	4.2		26.3	20.0	6.3	6.40	0.19	1.501	0.68	10	15			
08	12	1200	1.1	2689.0	16.8	12.4	4.4	74.3	16.7	12.3	4.4	5.98	0.14	0.995	0.64	18	17	60	1.8	-195
08	15	1830	25.8	2767.5	22.1	11.3	10.8	5.2	37.0	18.9	18.1	6.63	0.20	1.675	0.74	14	16			
08	16	1100	0.0	2784.0	19.7	14.2	5.5		29.1	21.0	8.1	6.29	0.18	1.477	0.71	12	14			
08	16	1800	0.8	2791.0	18.8	10.2	8.6	10.7	29.1	15.8	13.3	6.20	0.20	1.549	0.71	16	15			
08	17	1000	0.0	2807.0	16.6	10.0	6.6		18.3	11.0	7.3	5.99	0.14	1.105	0.69	18	13			
08	17	1800	0.0	2815.0	17.4	10.4	7.0	1.2	22.2	13.3	8.9	6.02	0.18	1.275	0.67	16	17			
08	18	1030	0.0	2831.5	15.8	9.8	6.0		19.8	12.3	7.5	6.00	0.17	1.252	0.67	8	11			
08	18	1730	3.1	2838.5	15.9	11.3	4.6	141.9	19.7	14.0	5.7	6.02	0.17	1.242	0.67	8	7			
08	19	1130	0.0	2856.5	16.0	9.5	6.5		16.9	10.0	6.9	5.90	0.15	1.055	0.66	15	12			
08	19	1930	0.0	2864.5	17.4	11.4	6.0	61.0	17.5	11.5	6.0	5.85	0.14	1.008	0.66	12	13			
08	20	0800	0.0	2877.0	12.7	8.7	4.0	91.3	14.8	10.1	4.7	5.79	0.13	1.165	0.66	12	11			
08	20	1730	0.6	2886.5	19.1	9.9	[illegible]		15.7	8.1	7.6	5.70	0.13	0.823	0.66	16	14			
08	21	0830	0.0	2901.5	16.0	9.7			15.1	9.2	5.9	5.69	0.14	0.944	0.66	10	9			
08	21	1530	0.0	2908.5	16.5	11.6	[illegible]	5.8	15.0	10.6	4.5	5.59	0.13	0.910	0.66	17	14			
08	24	1400	0.0	2979.0	14.8	9.9	4.9		10.4	6.9	3.4	4.63	0.13	0.700	0.60	19	11			
08	25	0700	0.0	2996.0	14.8	10.1	4.7		10.0	6.8	3.2	4.67	0.12	0.677	0.60	6	11			
08	25	1100	0.0	3000.0	14.9	9.5	5.4		9.9	6.3	3.6	4.54	0.12	0.666	[illegible]	13	13			
08	25	1500	0.0	3004.0	15.0	9.5	5.5	2.5	9.3	5.9	3.4	4.52	0.12	0.621	0.60	20	15			
08	25	1900	0.0	3008.0	15.0	10.3	4.7		9.1	6.3	2.9	4.58	0.11	0.608	0.59	17	17			
08	25	2300	0.0	3012.0	15.8	10.1	5.7		9.6	6.2	3.5	4.50	0.11	0.610	0.59	11	15			
08	26	0700	0.0	3020.0	15.6	9.7	5.9		9.6	6.0	3.6	4.46	0.11	0.618	0.59	7	12			

Table 7 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
08	26	1730	0.0	3030.5	14.2	10.1	4.1	1.3	8.5	6.0	2.5	4.43	0.11	0.598	0.59	14	17			
08	27	1130	0.0	3048.5	15.4	10.5	4.9	5.3	9.7	6.6	3.1	4.35	0.11	0.628	0.59	14	13			
08	27	1830	0.6	[illegible]	14.3	9.1	5.2		7.3	4.6	2.6	4.35	0.10	0.507	0.59	14	17			
08	28	1200	0.0	3073.0	14.8	9.4	5.4	0.9	8.6	5.5	3.1	4.31	0.11	0.582	0.59	13	14	30	1.8	235
08	29	1700	0.0	3102.0	15.0	11.2	3.8	2.8	7.8	5.9	2.0	4.31	0.10	0.523	0.58	17	17			
08	30	1230	0.6	3121.5	15.4	9.7	5.7	1.3	7.2	4.5	2.7	4.27	0.09	0.466	0.57	14	16			
09	02	1600	12.7	3197.0	15.5	8.0	7.5		9.7	5.0	4.7	4.60	0.12	0.625	0.59	14	16			
09	03	1000	1.2	3215.0	14.7	8.2	6.5	2.6	10.1	5.6	4.5	4.53	0.13	0.687	0.61	11	14			
09	03	1700	0.7	3222.0	13.9	9.8	4.1		11.3	[illegible]	[illegible]	4.82	0.15	0.811	0.62	12	16			
09	05	1330	1.5	3266.5	15.3	10.3	5.0	1.1	15.8	[illegible]	5.2	5.12	0.18	1.033	0.65	9	10			
09	06	1300	2.6	3290.0	15.5	9.1	6.4	0.8	22.1	[illegible]	9.1	5.55	0.23	1.424	0.69	5	8	30	2.1	195
09	10	1600	9.7	3389.0	15.2	8.7	6.5		16.2	[illegible]	6.9	5.33	0.18	1.065	0.66	10	10			
09	11	1530	0.0	3412.5	15.3	10.1	5.2	1.6	14.9	9.8	5.1	4.75	0.17	0.974	0.65	10	9			
09	12	1330	0.8	3434.5	14.5	10.8	3.7	1.2	12.7	9.5	3.2	5.16	0.15	0.877	0.64	9	8			
09	13	1430	0.0	3459.5	15.7	9.4	6.3	1.2	13.0	7.8	5.2	5.09	0.15	0.831	0.64	11	9			
09	14	1000	4.2	3479.0	14.6	9.8	4.8	0.8	12.7	8.6	4.2	5.04	0.16	0.873	0.64	8	8	35	1.8	225
09	17	1730	18.0	3558.5	16.2	11.6	4.6		20.0	14.3	[illegible]	5.79	0.19	1.235	0.69	3	6			
09	18	1430	0.0	3579.5	15.6	9.9	5.7	3.3	21.1	13.4	[illegible]	5.82	0.21	1.353	0.69	2	5			
09	19	1600	0.0	3605.0	14.6	10.8	3.8	2.0	17.5	12.9	[illegible]	5.54	0.19	1.198	0.68	6	6			
09	20	1200	0.0	3625.0	15.4	11.4	5.0	1.3	16.2	12.0	5.3	5.41	0.18	1.054	0.67	2	4			
09	21	1500	1.2	3652.0	18.7	14.9	3.8	1.0	22.2	17.7	4.5	5.50	0.19	1.185	0.68	11	8			
09	22	1000	0.0	3671.0	16.4	13.6	2.8	1.7	21.3	17.7	3.6	5.47	0.21	1.298	0.69	3	5	40	1.6	210
09	26	1400	0.0	3771.0	11.8	8.0	3.8		9.1	6.2	2.9	5.12	0.12	0.773	0.65	14	9			
09	27	1530	0.0	3796.5	12.4	7.1	5.3	6.8	10.3	5.9	4.4	5.09	0.14	0.833	0.64	0	5			
09	28	1130	0.0	3816.5	12.8	7.9	4.9	14.6	10.9	6.7	4.2	5.07	0.14	0.850	0.64	-2	2			
09	29	1700	0.0	3846.0	12.3	9.0	3.0	3.7	9.7	7.1	2.4	4.92	0.13	0.791	0.63	3	4			
09	30	1200	0.0	3865.0	12.7	10.2	2.5	2.4	8.8	7.0	1.7	4.79	0.12	0.691	0.62	-1	1	40	1.4	205
10	03	1300	0.0	3938.0	14.3	9.0	5.3		11.0	6.9	4.1	4.95	0.13	0.767	0.63	7	6			
10	04	0930	0.0	3958.5	12.9	9.4	3.5	3.5	12.7	9.2	3.4	4.76	0.12	0.984	0.63	3	4			
10	05	1300	0.0	3986.0	16.1	10.2	5.9	1.3	15.8	10.0	5.8	5.25	0.15	0.984	0.66	3	4			
10	08	1300	0.0	4058.0	14.3	9.5	4.8		14.5	9.6	4.9	5.29	0.16	1.012	0.66	5	3			
10	09	1030	0.0	4079.5	13.3	9.3	4.0	3.0	13.3	9.3	4.0	5.27	0.16	0.998	0.65	0	2			
10	10	1300	0.0	4106.0	13.7	10.2	3.5	0.9	11.9	8.9	3.0	5.21	0.14	0.870	0.64	-2	1			
10	13	1300	0.0	4178.0	12.6	9.8	2.8		9.8	7.6	2.2	5.05	0.13	0.778	0.64	8	5			
10	18	1300	0.0	4298.0	12.3	8.6	3.7	1.1	9.1	6.4	2.7	4.90	0.13	0.742	0.63	3	1	30	1.5	175
10	21	1300	0.0	4370.0	13.4	9.2	4.2	0.2	8.7	5.9	2.7	4.81	0.11	0.646	0.61	2	0			
10	25	1300	0.0	4466.0	14.5	8.5	6.0									3	0	40	2.0	200

Table 7.8. Two Creek physical and chemical data. Twenty-one variables were measured and are defined as follows:

1- Month
2- Day
3- Time (h)
4- Precipitation (mm)
5- Cummulative Time (h)
6- Total Phosphorus Concentration (mg/m³)
7- Total Dissolved Phosphorus Concentration (mg/m³)
8- Fine Particulate Phosphorus Concentration (mg/m³)
9- Concentration of Coarse Particulate Matter Transport (mg/m³)
10- Instantaneous Total Phosphorus Loading (mg/s)
11- Instantaneous Total Dissolved Phosphorus Loading (mg/s)
12- Instantaneous Fine Particulate Phosphorus Loading (mg/s)
13- Cross-sectional Area of Stream (m²)
14- Average Velocity (m/s)
15- Discharge (m³/s)
16- Depth Guage (m)
17- Air Temperature (°C)
18- Water Temperature (°C)
19- Water Colour (mg/L Pt.)
20- Turbidity (NTU)
21- Conductivity (µmhos/cm)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
04	22	1200	0.6	0.0	35.0	22.9	12.1													
04	23	1100	0.0	23.0	35.3	20.4	14.9		21.9	12.6	9.2	3.16	0.14	0.620						
04	23	1830	0.0	30.5	35.9	17.3	18.6		26.2	12.6	13.6	3.71	0.16	0.730						
04	24	1100	2.0	47.0	33.6	22.2	11.4		19.2	12.7	6.5	2.86	0.15	0.570						
04	24	1630	0.0	52.5	33.5	24.2	9.3		18.8	13.6	5.2	2.75	0.15	0.560						
04	25	1730	0.0	77.5	32.2	22.5	9.7		16.4	11.5	4.9	2.06	0.15	0.510						
04	26	0930	0.0	93.5	26.1	19.6	6.5		10.2	7.6	2.5	2.62	0.09	0.390						
04	26	1730	0.0	101.5	30.3	18.0	12.3		17.0	10.1	6.9	2.88	0.14	0.560						
04	27	1030	0.0	118.5	26.5	14.0	12.5		11.9	6.3	5.6	2.62	0.12	0.450						
04	27	1730	0.0	125.5	28.1	17.2	10.9		14.1	8.6	5.4	2.23	0.14	0.500						
04	28	0930	0.0	141.5	27.1	12.6	14.5		13.0	6.0	7.0	2.35	0.14	0.480						
04	28	1730	0.0	149.5	26.8	15.9	10.9		12.9	7.6	5.2	2.06	0.15	0.480						
04	29	0900	0.0	165.0	25.8	17.5	8.3		9.8	6.6	3.2	2.07	0.10	0.380				20	2.9	200

Table 8 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
05	03	0600	7.3	268.0	21.0	12.7	8.3		12.3	7.4	4.9	4.79	0.11	0.585						
05	04	0930	0.6	285.5	21.0	8.0	13.0		11.9	4.5	7.3	5.01	0.09	0.565						
05	04	1730	0.1	293.5	20.8	13.0	7.8		10.2	6.4	3.8	4.75	0.09	0.491						
05	05	0930	0.0	309.5	21.6	17.1	4.5		12.8	10.2	2.7	4.65	0.11	0.594						
05	05	1530	1.2	315.5	19.9	14.6	5.3		10.8	7.9	2.9	4.59	0.20	0.541						
05	06	1030	14.3	334.5	33.4	8.1	25.3		30.6	7.4	23.1	5.21	0.14	0.915						
05	06	2130	0.4	345.5	36.1	10.2	25.9		44.4	12.6	31.9	5.73	0.18	1.231						
05	07	1100	1.2	359.0	36.1	12.9	23.2		46.9	16.8	30.2	5.88	0.19	1.300				35	7.0	120
05	10	1130	0.0	431.5	33.2	13.7	19.5		68.4	28.2	40.2	6.05	0.27	2.060	0.80	14	2			
05	10	1800	4.8	438.0	29.4	15.0	14.4		50.3	25.6	24.6	5.50	0.24	1.710	0.70	16	4			
05	11	0900	0.0	453.0	27.7	14.8	12.9		79.8	42.6	37.2	6.29	0.38	2.880	0.79	7	1			
05	11	1700	0.0	461.0	25.3	13.8	11.5		34.2	18.6	15.5	5.32	0.19	1.350	0.68					
05	12	1530	0.0	483.5	26.3	18.3	8.0		28.9	20.1	8.8	5.00	0.16	1.100	0.65					
05	13	1130	0.0	503.5	23.1	16.2	6.9		32.1	22.5	9.6	4.92	0.15	1.390	0.63					
05	13	2030	0.0	512.5	24.3					14.8		4.93	0.08	0.610	0.63					
05	14	0700	0.6	523.0	24.3	12.5	11.8		18.2	9.4	8.8	4.92	0.09	0.750	0.63			60	2.7	155
05	16	1800	4.1	582.0	21.5	11.5	10.0		17.4	9.3	8.1	4.74	0.12	0.810	0.60					
05	17	0930	0.0	597.5	20.7	12.1	8.6		14.1	8.2	5.8	4.71	0.09	0.680	0.60		6			
05	17	1400	2.2	602.0	18.6	11.5	7.1		19.2	11.8	7.3	4.75	0.15	1.030	0.60	13	8			
05	18	1000	0.0	622.0	20.9	12.0	8.9		18.4	10.6	7.8	4.86	0.13	0.880	0.62	12	7			
05	18	1400	0.0	626.0	19.1	12.0	7.1		15.5	9.7	5.8	4.84	0.11	0.810	0.60	11	9			
05	18	1800	0.0	630.0	19.0	10.3	8.7		14.6	7.9	6.7	4.92	0.11	0.770	0.62		11			
05	18	2200	0.0	634.0	17.9	13.8	4.1		15.4	11.9	3.5	4.91	0.13	0.860	0.62	8	10			
05	19	0200	0.0	638.0	18.1	11.0	7.1		12.9	7.8	5.0	4.93	0.10	0.710	0.61					
05	19	0600	0.0	642.0	18.7	9.9	8.8		13.3	7.0	6.2	4.92	0.10	0.710	0.61	6	8			
05	19	1530	2.1	651.5	20.5	12.0	8.5		15.2	8.9	6.3	4.90	0.11	0.740	0.62	15	10			
05	20	0600	1.3	666.0	19.6	12.9	6.7		13.9	9.2	4.8	4.83	0.09	0.710	0.61	6	7	55	1.5	135
05	24	1200	9.7	768.0	16.9	9.3	7.6		13.3	7.3	6.0	5.03	0.13	0.788	0.65	19	11			
05	24	1930	0.0	775.5	18.4	9.6	8.8		14.6	7.6	7.0	5.01	0.13	0.793	0.64	16	13			
05	25	0930	0.0	789.5	19.3	13.7	5.6		11.3	8.1	3.3	4.82	0.10	0.588	0.64	17	11			
05	25	1700	0.0	797.0	20.1	11.8	8.3		12.4	7.3	5.1	4.95	0.10	0.619	0.64	19	14			
05	26	1000	0.0	814.0	17.6	10.4	7.2		8.4	5.0	3.4	4.79	0.08	0.479	0.62	7	10			
05	26	1900	4.2	823.0	18.8	11.9	6.9		9.3	5.9	3.4	4.85	0.08	0.496	0.64	16	12			
05	27	0730	0.0	835.5	18.4	10.0	8.4		9.4	5.1	4.3	4.81	0.08	0.511	0.63	5	9	60	1.3	205
05	27	1830	0.0	846.5	15.2	8.6	6.6		11.8	6.7	5.1	5.19	0.13	0.775	0.63	23	14			
05	31	1100	0.0	935.0	15.6	8.9	6.7		6.0	3.4	2.6	4.52	0.06	0.385	0.59	14	14			
05	31	1830	0.0	942.5	17.6	8.3	9.3		4.0	1.9	2.1	4.40	0.04	0.228	0.59	23	17			
06	01	1000	0.2	958.0	16.2	8.2	8.0		3.8	1.9	1.9	4.48	0.04	0.235	0.59	9	13			
06	01	2000	5.8	968.0	15.5	7.7	7.8		2.5	1.2	1.2	4.43	0.03	0.159	0.59	9	15			
06	02	0630	6.6	978.5	16.7	7.4	9.3		3.1	1.4	1.7	4.37	0.03	0.184	0.59	3	10			

Table 8 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
06	02	1400	0.5	986.0	17.8	8.4	9.4		8.6	4.1	4.6	4.67	0.09	0.485	0.62	12	12			
06	03	0800	0.9	1004.0	19.3	7.4	11.9		7.9	3.0	4.9	4.55	0.08	0.410	0.60	[illegible]	11			
06	03	1400	0.0	1010.0	16.7	7.7	9.0		12.5	5.8	6.7	5.01	0.13	0.749	0.65	14	12	45	1.2	209
06	06	1500	3.5	1083.0	19.3	9.4	9.9		4.7	2.3	2.4	4.37	0.04	0.242	0.59	12	15			
06	07	1000	0.0	1102.0	17.8	8.2	9.6		4.0	1.9	2.2	4.44	0.04	0.226	0.60	12	11			
06	07	2100	3.7	1113.0	17.7	8.1	9.6		3.3	1.5	1.8	4.49	0.04	0.187	0.60	11	16			
06	08	1000	0.0	1126.0	17.8	8.1	9.7	8.1	3.5	1.6	1.9	4.52	0.04	0.196	0.59	14	14			
06	08	1400	0.0	1130.0	19.3	7.5	11.8		2.8	1.1	1.7	4.51	0.03	0.144	0.59	23	16			
06	08	1800	0.0	1134.0	19.2	8.6	10.6		2.7	1.2	1.5	4.49	0.03	0.143	0.59	17	17			
06	08	2200	0.0	1138.0	19.9	7.2	12.7		2.5	0.9	1.6	4.47	0.02	0.127	0.59	11	17			
06	09	0900	0.0	1149.0	19.1	6.8	12.3	6.4	3.2	1.2	2.1	4.44	0.03	0.170	0.58	17	20			
06	09	1500	3.4	1155.0	21.3	7.1	14.2		2.8	0.9	1.8	4.46	0.02	0.130	[illegible]	0	17			
06	10	0730	0.0	1171.5	20.7	7.9	12.8	4.6	2.4	0.9	1.5	4.41	0.02	0.118	0.59	10	14			
06	10	1400	0.3	1178.0	21.3	9.1	12.2		3.1	1.3	1.8	4.37	0.03	0.144	0.58	19	16	40	1.2	230
06	13	2030	20.7	1256.5	13.2	5.8	7.4		4.4	1.9	2.5	4.62	0.06	0.332	0.61	12	14			
06	14	0930	0.0	1269.5	13.7	6.3	7.4	5.4	4.4	2.0	2.4	4.61	0.06	0.324	0.61	17	13			
06	14	1700	0.0	1277.0	14.2	6.7	7.5		4.3	2.0	2.3	4.66	0.06	0.302	0.60	17	16			
06	15	0930	0.0	1293.5	14.4	6.7	7.7	4.8	2.3	1.1	1.3	4.56	0.03	0.163	0.60	14	14			
06	15	1830	0.0	1302.5	14.5	6.6	7.9		2.7	1.2	1.5	4.36	0.03	0.188	0.60	16	17			
06	16	0930	0.0	1317.5	15.2	6.0	9.2	5.1	2.5	1.0	1.5	4.33	0.03	0.164	0.59	13	15			
06	16	2000	2.4	1328.0	16.2	6.7	9.5		2.9	1.2	1.7	4.36	0.03	0.181	0.59	19	18			
06	17	0800	0.0	1340.0	15.9	8.5	7.4	3.5	2.8	1.5	1.3	4.36	0.03	0.178	0.60	10	15			
06	17	1500	0.0	1347.0	16.3	8.3	8.0		1.8	0.9	0.9	4.35	0.02	0.110	0.60	21	17	50	1.2	220
06	20	1800	123.1	1422.0	138.7	24.7	114.0		3141.0	559.4	2581.6	27.17	0.48	22.646	2.95	12	7			
06	21	0930	22.8	1437.5	139.1	21.6	137.5	3502.7	2699.1	419.1	2668.1	24.62	0.46	19.404	2.50	10	6			
06	21	1530	0.5	1443.5	156.5	19.0	137.5		2800.7	340.0	2460.7	23.88	0.43	17.896	2.20	13	6			
06	22	0900	0.0	1461.0	98.4	13.7	84.7	390.7	1222.4	170.2	1052.2	17.00	0.43	12.423	1.84	12	6			
06	22	1600	0.0	1468.0	117.3	14.4	102.9		1287.5	158.1	1129.4	14.50	0.46	10.976	1.75	18	7			
06	22	2130	0.0	1473.5	51.3	12.7	38.6		422.6	[illegible]	317.9	12.22	0.41	8.237	1.52	15	7			
06	23	0830	0.0	1484.5	66.0	13.2	52.8	3178.9					0.41							
06	23	1630	0.0	1492.5	79.1	11.6	67.5						0.40			16	9			
06	24	0700	0.1	1507.0	40.0	15.6	24.4	2846.5	194.5	75.9	118.7	8.28	0.38	4.863	1.26	11	8			
06	24	1430	0.0	1514.5	55.9	11.3	44.6		350.7	70.9	279.8	7.89	0.53	6.274	1.23	13	8	140	7.5	80
06	27	1500	46.9	1587.0	43.7	12.8	30.9	368.3	287.7	84.3	203.4	9.95	0.42	6.583	1.39	16	12			
06	28	0900	0.0	1605.0	41.7	14.3	27.4	693.4					0.39			15	13			
06	28	1430	0.0	1610.5	37.5	13.7	23.8		147.8	54.0	93.8	7.19	0.37	3.942	1.24	15	10			
06	28	2200	0.0	1618.0	34.0	12.3	21.7						0.38			12	11			
06	29	1000	0.0	1630.0	28.8	14.4	14.4	318.0					0.35			19	9			

Table 8 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
06	29	1600	0.0	1636.0	33.2	13.5	19.7		104.1	42.3	61.8	7.87	0.26	[illegible]	1.14	26	14			
06	29	2130	0.0	1641.5	19.9	11.4	8.5		35.3	20.2	15.1	7.87	0.14	[illegible]		17	12			
06	30	0900	11.0	1653.0	27.1	14.9	12.2	107.8	119.8	65.8	53.9	7.87	0.37	4.419	1.10	13	11			
06	30	1530	4.0	1659.5	31.8	15.2	16.6		111.5	53.3	58.2	7.17	0.33	3.505	1.08	15	12			
07	01	1600	12.1	1684.0	33.1	16.4	16.7	652.7	156.9	77.7	79.2	7.89	0.39	4.740	1.23	13	10			
07	02	1100	14.0	1703.0	57.0	17.4	39.6	2228.2	499.7	152.5	347.1	12.22	0.44	8.766	1.67	13	9			
07	02	1930	0.2	1711.5	74.0	20.0	54.0		627.8	169.7	458.1	11.87	0.44	8.484	1.57	13	10			
07	03	1100	0.0	1727.0	38.8	13.8	25.0	1341.8	237.5	84.5	153.0	9.95	0.38	6.120	1.47	17	10			
07	03	1700	1.4	1733.0	41.0	18.5	22.5		202.5	91.4	111.1	8.61	0.37	4.938	1.40	20	12	80		
07	04	1700	0.0	1757.0	35.9	15.5	20.4	928.4	128.2	55.4	72.9	7.19	0.33	3.572	1.29	16	14			
07	05	1000	0.0	1774.0	26.4	15.1	11.3	139.9	94.3	54.0	40.4	8.20	0.29	3.573	1.17	18	11			
07	05	2200	1.4	1786.0	36.9	15.2	21.7		131.8	54.3	77.5	8.20	0.29	3.573	1.17	15	12			
07	06	1000	0.0	1798.0	20.0	14.8	5.8	144.9	76.2	56.4	22.1	8.20	0.30	3.811	1.17	13	11			
07	06	1630	0.0	1804.5	20.7	15.0	5.7		84.9	61.5	23.4	8.20	0.32	4.100	1.17	18	13			
07	06	2230	11.6	1810.5	20.1	16.4	3.7		82.0	66.9	15.1	7.87	0.34	4.078	1.14	13	12			
07	07	0930	0.0	1821.5	21.3	17.0	4.3	83.2	89.7	71.6	18.1	7.87	0.35	4.210	1.12	14	11			
07	07	2100	5.7	1833.0	18.9	18.9	0.0		61.8	61.8		8.20	0.25	3.270	1.17	17	14			
07	08	0630	11.0	1842.5	24.6	16.6	8.0	65.8	101.9	68.8	33.1	7.87	0.34	4.142	1.10	14	12			
07	08	1430	4.8	1850.5	26.0	17.1	8.9		90.0	59.2	30.8	7.87	0.28	3.460	1.13	12	12	100	2.7	95
07	11	1730	6.0	1925.5	19.9	13.3	6.6	26.0	64.2	42.9	21.3	7.17	0.42	3.226	1.08	21	9			
07	12	0730	4.0	1939.5	20.6	12.6	8.0	34.0	56.5	34.5	21.9	6.77	0.38	2.741	1.05	11	11			
07	12	1530	1.1	1947.5	22.9	12.1	10.8		74.5	39.4	35.1	7.01	0.43	3.253	1.05	16	14			
07	13	1000	0.0	1966.0	18.6	11.3	7.3	24.5	53.9	32.7	21.1	6.87	0.39	2.897	1.03	17	12			
07	13	2000	2.2	1976.0	20.8	10.3	10.5		53.7	26.6	22.1	6.46	0.35	2.580	1.01	17	9			
07	14	1000	0.0	1990.0	20.1	12.5	7.6	39.5	35.4	22.0	13.4	5.93	0.27	1.760	1.00	14	12			
07	14	1630	1.5	1996.5	19.9	10.8	9.1		26.8	14.5	12.3	6.85	0.16	1.347	0.94	12	15			
07	15	1600	38.9	2020.0	27.0	12.0	15.0	329.6	90.2	40.1	50.1	7.17	0.31	3.342	1.08	12	11	110	4.7	90
07	18	1630	16.6	2092.5	43.3	13.0	30.3	880.5	234.9	70.5	164.4	10.30	0.32	5.426	1.45	12	10			
07	19	0630	0.0	2106.5	31.8	13.9	17.9		211.2	92.3	118.9	10.00	0.42	6.643	1.41	7	9			
07	19	1030	0.0	2110.5	33.8	15.5	18.3	146.6	202.1	92.7	109.4	9.70	0.39	5.980	1.38	20	16			
07	19	1430	0.0	2114.5	30.9	12.2	18.7		176.2	69.6	106.6	9.70	0.36	5.701	1.36	25	12			
07	19	1830	0.0	2118.5	32.5	16.9	15.6		194.3	101.0	93.3	9.30	0.41	5.979	1.33	24	12			
07	19	2230	1.0	2122.5	24.5	16.0	8.5		114.6	74.8	39.8	9.00	0.33	4.678	1.30	12	12			
07	20	0230	0.0	2126.5	24.4	10.3	14.1								1.27	8	11			
07	20	0630	0.0	2130.5	29.9	22.6	7.3		152.3	115.1	37.2	8.60	0.38	5.093	1.24	9	11			
07	20	1700	0.0	2141.0	35.6	28.3	7.3	73.4	162.6	129.3	33.3	8.33	0.48	4.568	1.21	22	14			
07	21	1100	0.0	2159.0	41.2	25.3	15.9	28.4	148.8	91.4	57.4	7.63	0.44	3.611	1.12	14	12			
07	21	1800	0.0	2166.0	33.3	19.2	14.1		104.6	60.3	44.3	7.47	0.38	3.141	1.11	21	14			

Table 8 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
07	22	0800	0.0	2180.0	31.1	21.9	9.2		78.2	55.0	23.1	6.78	0.34	2.513	1.05	9	11			
07	22	1400	0.0	2186.0	35.6	18.4	17.2	24.6	82.1	42.4	39.7	6.58	0.32	2.306	0.98	24	14	110	2.3	110
07	25	1530	4.8	2259.5	27.8	13.1	14.7	21.7	83.1	39.2	43.9	6.98	0.40	2.989	1.07	20	16			
07	26	1300	21.2	2281.0	47.1	11.7	35.4	3065.4	259.4	64.4	194.9	9.30	0.37	5.507	1.33	8	12			
07	26	2030	29.2	2288.5	125.4	17.2	108.2		1744.2	239.2	1505.0	20.00	0.40	13.909	2.03	9	12			
07	27	0800	0.0	2300.0	85.0	19.0	66.0	4950.7	1578.8	352.9	1225.9	24.00	0.45	18.574	2.39	8	9			
07	27	1400	0.0	2306.0	77.7	15.2	62.5		1294.6	253.2	1041.3	23.00	0.42	16.661	2.19	14	10			
07	27	2000	11.4	2312.0	78.0	16.6	61.4		1136.6	241.9	894.7	20.00	0.42	14.572	2.04	16	10			
07	28	0900	0.0	2325.0	53.9	15.4	38.5	6073.8	679.8	194.2	485.6	17.50	0.42	12.613	1.80	14	9			
07	28	1630	0.0	2332.5	73.1	15.4	57.7		664.3	139.9	524.3	13.00	0.42	9.087	1.69	22	11			
07	29	0730	0.0	2347.5	40.3	13.2	27.1	1476.5	279.4	91.5	187.9	9.80	0.45	6.934	1.44	8	10			
07	29	1730	11.2	2357.5	51.0	16.6	34.4		329.9	107.4	222.5	9.80	0.42	6.468	1.44	16	10			
07	30	0930	0.0	2373.5	36.4	12.0	24.4	4383.5	206.3	68.0	138.3	9.40	0.38	5.668	1.34	14	10			
07	30	1630	0.0	2380.5	35.4	11.2	24.2		187.9	59.4	128.5	8.90	0.38	5.308	1.29	27	15			
07	31	0830	0.0	239[illegible].5	30.3	10.4	19.9		153.3	52.6	100.7	8.90	0.36	5.059	1.29	13	12			
07	31	1930	0.0	240[illegible].5	23.4	11.0	12.4	211.9	83.4	39.2	44.2	7.00	0.34	3.562	1.09	28	16			
08	01	0630	0.0	2418.5	30.0	12.8	17.2	83.3	112.1	47.8	64.3	7.90	0.31	3.738	1.14	15	14	140	4.0	70
08	03	2100	1.4	2481.0	25.8	12.6	13.2	83.5	61.0	29.8	31.2	5.88	0.37	2.365	0.99	13	18			
08	04	0800	1.8	2492.0	23.5	12.6	10.9	27.1	47.6	25.5	22.1	5.83	0.32	2.024	0.96	10	13			
08	05	1200	2.3	2520.0	21.8	11.9	9.9	21.1	34.1	18.6	15.5	5.16	0.28	1.564	0.93	21	15	140	2.4	125
08	08	1700	0.0	2597.0	21.3	10.0	11.3	6.6	11.2	5.3	6.0	4.05	0.11	0.528	0.80	25	19			
08	09	0630	0.0	2610.5	20.6	10.2	10.4		10.9	5.4	5.5	3.99	0.12	0.529	0.76	6	16			
08	09	1030	0.0	2614.5	20.0	11.4	8.6		11.5	6.6	5.0	3.82	0.13	0.576	0.78	17	16			
08	09	1430	0.0	2618.5	19.5	10.3	9.2	17.1	9.0	4.8	4.3	3.89	0.10	0.463	0.78	25	18			
08	09	1830	0.0	2622.5	21.3	10.9	10.4		11.2	5.8	5.5	3.86	0.13	0.528	0.75	25	19			
08	09	2230	0.0	2626.5	18.7	10.7	8.0		10.8	6.2	4.6	3.81	0.14	0.575	0.75	15	20			
08	10	0230	0.0	2630.5	19.0	10.9	8.1		12.8	7.3	5.4	3.80	0.16	0.672	0.76	11	16			
08	10	0630	0.0	2634.5	19.5	10.4	9.1		12.4	6.6	5.8	3.64	0.16	0.636	0.74	9	16			
08	10	1700	0.0	2645.0	18.9	10.2	8.7	5.8	6.4	3.4	2.9	3.62	0.09	0.337	0.74		-			
08	11	1530	0.0	2667.5	19.3	10.0	9.3	3.8	8.2	4.3	4.0	3.36	0.12	0.425	0.73	22	19			
08	12	1030	1.1	2686.5	18.7	10.7	8.0	13.0	6.8	3.9	2.9	3.31	0.11	0.366	0.72	12	16	100	1.8	195
08	15	1900	25.8	2767.0	23.8	17.0	6.8	11.4	10.4	7.4	3.0	3.63	0.12	0.436	0.75	15	14			
08	16	1000	0.0	2782.0	21.4	10.5	10.9		10.0	4.9	5.1	3.35	0.13	0.466	0.74	12				
08	16	1700	0.8	2789.0	19.4	9.9	9.5	4.7	8.7	4.4	4.2	3.44	0.12	0.446	0.73	15	16			
08	17	1100	0.0	2807.0	19.7	9.6	10.1		7.7	3.8	4.0	3.33	0.12	0.392	0.72	19	13			
08	17	1900	0.0	2815.0	18.9	10.3	8.6	6.7	7.5	4.1	3.4	3.30	0.11	0.398	0.70	14	16			
08	18	1000	0.0	2830.0	21.1	9.2	11.9		4.8	2.1	2.7	3.29	0.07	0.228	0.71	10	10			
08	18	1800	3.1	2838.0	20.1	10.1	10.0	4.3	7.2	3.6	3.6	3.10	0.12	0.360	0.71	8	9			

Table 8 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
08	19	1100	0.0	2855.0	19.9	9.8	10.1		6.5	3.2	3.3	3.10	0.11	0.327	0.71	15	11			
08	19	2000	0.0	2864.0	21.0	12.7	8.3	15.3	6.3	3.8	2.5	3.12	0.10	0.300	0.70	11	13			
08	20	0700	0.0	2875.0	19.1	9.1	10.0		5.2	2.5	2.7	3.08	0.09	0.272	0.69	12	10			
08	20	1830	0.6	2886.5	25.4	10.3	15.1	14.3	7.2	2.9	4.3	2.98	0.09	0.282	0.69	15	14			
08	21	0730	0.0	2899.5	20.5	10.4	10.1		5.9	3.0	2.9	2.91	0.07	0.286	0.68	7	10			
08	21	1500	0.0	2907.0	20.2	9.8	10.4	2.7	7.5	3.6	3.8	2.98	0.11	0.369	0.68	20	12			
08	24	1230	0.0	2976.5	18.4	10.0	8.4		5.0	2.7	2.3	2.53	0.10	0.270	0.65	24	15			
08	25	0600	0.0	2994.0	17.4	10.5	6.9		4.1	2.5	1.6	2.50	0.08	0.235	0.65	5	13			
08	25	1000	0.0	2998.0	17.7	11.1	6.6		3.8	2.4	1.4	2.16	0.08	0.216	0.65	11	13			
08	25	1400	0.0	3002.0	18.8	10.6	8.2	1.9	4.3	2.4	1.9	2.44	0.08	0.227	0.65	17	15			
08	25	1800	0.0	3006.0	19.6	12.0	7.6		4.4	2.7	1.7	2.40	0.08	0.227	0.65	17	16			
08	25	2200	0.0	3010.0	20.0	10.8	9.2		4.2	2.3	1.9	2.50	0.08	0.210	0.65	10	15			
08	26	0600	0.0	3018.0	19.0	10.5	8.5		3.6	2.0	1.6	2.43	0.07	0.190	0.64	4	12			
08	26	1700	0.0	3029.0	17.7	11.7	6.0	1.6	3.7	2.5	1.3	2.42	0.08	0.211	0.64	15	16			
08	27	1030	0.0	3046.5	16.6	10.5	6.1	2.3	3.0	1.9	1.1	2.40	0.07	0.182	0.63	12	13			
08	27	1730	0.6	3053.5	16.5	10.1	6.4		3.0	1.8	1.1	2.35	0.07	0.179	0.64	17	17			
08	28	1100	0.0	3071.0	15.8	9.9	5.9	1.2	2.7	1.7	1.0	2.32	0.07	0.174	0.64	14	14	55	1.5	280
08	29	1600	0.0	3100.0	16.4	9.1	7.3	0.7	2.7	1.5	1.2	2.09	0.07	0.162	0.63	24	17			
08	30	1130	0.6	3119.5	17.7	10.0	7.7	0.6	2.8	1.6	1.2	2.08	0.07	0.159	0.63	14	15			
09	02	1500	12.7	3195.0	17.1	8.7	8.4		3.4	1.7	1.6	2.26	0.08	0.196	0.65	17	16			
09	03	0900	1.2	3213.0	15.5	8.8	6.7	5.0	3.6	2.0	1.5	2.35	0.09	0.231	0.65	12	14			
09	03	1600	0.7	3220.0	15.7	8.0	7.7		3.9	2.0	1.9	2.47	0.09	0.250	0.65	13	15			
09	05	1230	1.5	3264.5	15.9	8.1	7.8	2.1	4.2	2.1	2.1	2.91	0.08	0.265	0.67	9	10			
09	06	1200	2.6	3288.0	16.8	7.8	9.0	3.6	4.2	1.9	2.2	2.81	0.08	0.249	0.68	8	8	30	1.4	260
09	10	1500	9.7	3387.0	15.5	7.8	7.7		4.0	2.0	2.0	2.75	0.08	0.258	0.67	13	9			
09	11	1200	0.0	3408.0	14.8	9.9	4.9	1.7	4.1	2.7	1.4	2.81	0.09	0.276	0.65	9	8			
09	12	1100	0.8	3431.0	15.3	11.3	4.0	1.1	3.0	2.2	0.8	2.54	0.07	0.196	0.66	7	8			
09	13	1330	0.0	3457.5	15.1	9.0	6.1	1.2	3.0	1.8	1.2	2.60	0.07	0.201	0.65	10	9			
09	14	0900	4.2	3477.0	15.7	8.6	7.1	1.9	3.2	1.7	1.4	2.58	0.07	0.202	[illegible]		9	45	1.3	280
09	17	1700	18.0	3557.0	16.2	9.0	7.2		5.1	2.8	2.3	3.04	0.10	0.315	0.70	3	[illegible]			
09	18	1330	0.0	3577.5	16.0	10.3	5.7	7.9	7.2	4.6	2.6	3.23	0.13	0.450	0.73	1	[illegible]			
09	19	1430	0.0	3602.5	15.2	11.3	3.9	4.8	5.5	4.1	1.4	3.08	0.11	0.365	0.71	[illegible]	4			
09	20	1030	0.0	3622.5	16.8	11.4	4.4	3.0	5.8	4.0	1.5	2.96	0.10	0.348	0.70	[illegible]	3			
09	21	1400	1.2	3650.0	17.6	14.5	3.1	3.4	5.9	4.9	1.0	3.02	0.11	0.336	0.70	14	[illegible]			
09	22	0900	0.0	3669.0	19.9	15.8	4.1	3.0	5.8	4.6	1.2	2.74	0.12	0.293	0.70	0	[illegible]	50	1.6	245
09	26	1230	0.0	3768.5	15.3	8.4	6.9		4.6	2.5	2.1	2.79	0.10	0.300	[illegible]	[illegible]	8			
09	27	1430	0.0	3794.5	15.4	7.9	7.5	23.2	4.2	2.1	2.0	2.72	0.09	0.272	0.68	0	5			
09	28	1030	0.0	3814.5	16.2	8.7	7.5	37.7	4.5	2.4	2.1	2.66	0.10	0.278	0.67	-3	2			
09	29	1600	0.0	3844.0	13.9	9.0	4.9	17.7	3.5	2.2	1.2	2.61	0.09	0.249	0.67	-6	3			
09	30	1100	0.0	3863.0	15.4	9.8	5.6	16.5	3.0	1.9	1.1	2.55	0.07	0.193	0.66	-3	0	60	1.4	245

Table 8 continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
10	03	1200	0.0	3936.0	15.3	8.8	6.5		4.2	2.4	1.8	2.64	0.10	0.276	0.65	3				
10	04	1030	0.0	3958.5	13.7	9.8	3.9	16.5	3.0	2.1	0.8	2.64	0.07	0.216	0.66	3	4			
10	05	1200	0.0	3984.0	14.5	9.6	4.9	12.9	3.9	2.6	1.3	2.58	0.10	0.268	0.66	3	4			
10	08	1200	0.0	4056.0	13.3	9.9	3.4		2.5	1.9	0.6	2.53	0.07	0.187	0.66	2	3			
10	09	1000	0.0	4078.0	13.7	8.5	5.2	16.0	2.8	1.8	1.1	2.60	0.07	0.207	0.66	-1	2			
10	10	1200	0.0	4104.0	14.3	10.0	4.3	10.6	2.4	1.7	0.7	2.56	0.06	0.170	0.66	-2	1			
10	13	1200	0.0	4176.0	14.2	9.7	4.5		2.7	1.8	0.9	2.53	0.06	0.190	0.66	9	4			
10	14	1200	0.0	4200.0	14.1	6.9	7.2	16.3	2.3	1.1	1.2	2.60	0.06	0.166	0.66	3	3	45	1.5	210
10	18	1100	0.0	4295.0	12.8	8.0	4.8	2.5	1.4	0.9	0.5	2.44	0.04	0.109	0.65	1	1	40	1.5	230
10	21	1200	0.0	4368.0	12.1	7.8	4.3	5.6	2.1	1.4	0.7	2.53	0.06	0.176	0.65	3	0			
10	25	1200	0.0	4464.0	13.2	7.4	5.8		2.4	1.3	1.1	2.48	0.06	0.181	0.64	2	0	40	1.9	270