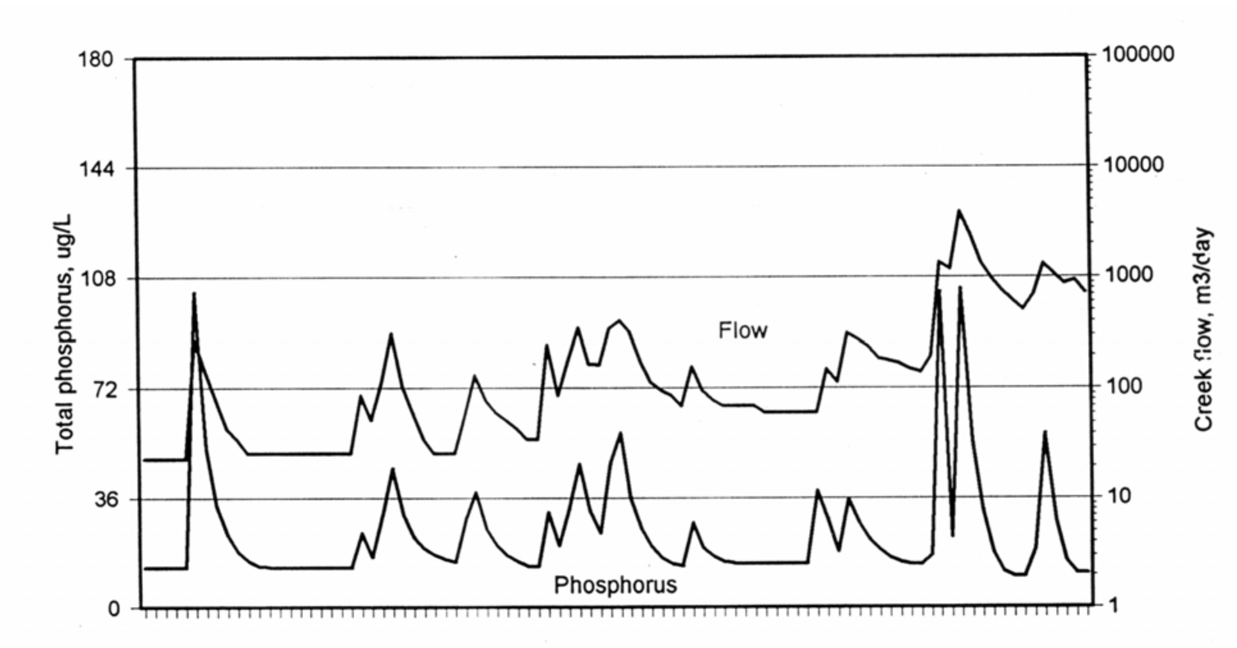
Phosphorus runoff from the upper Cusheon basin, Salt Spring Island, B.C.



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A background report for
The Cusheon Watershed Management Plan
and Steering Committee
Salt Spring Island, B.C.

Phosphorus runoff from the upper Cusheon basin, Salt Spring Island, B.C

- Report written by John B. Sprague, Sprague Associates Ltd., Salt Spring Island, B.C. 2007. October

- Work carried out by: Wiebke Ortlepp, Wilfried Ortlepp, Wayne Hewitt, John B. Sprague. Financial support: Water Council of Salt Spring Island, Islands Trust Local Committee for Salt Spring Island.

- A background report for the Cusheon Watershed Management Steering Committee and Management Plan.

Summary

(1) The purpose of this research was to measure how much phosphorus is carried downstream in upper Blackburn Creek during one year. Almost all of this phosphorus is derived from land runoff. The estimate will help to assess the sources of enrichment for downstream Cusheon Lake.

(2) The total amount carried during one year of study (2004-05) was estimated as 69.5 kg, mostly associated with suspended sediment during surges of high flow in the winter.

(3) A severe storm flow with flooding occurred in mid-January. It was considered to be a 10-year flooding event and therefore the year of study did not represent a typical year. During nine days of fierce flow, 39.6 kg of phosphorus was carried downstream. It seemed likely that most of this phosphorus was firmly bound into silt particles carried by the very muddy runoff water, and would never become available to algae or other organisms in downstream lakes.

(4) For a more likely load in a typical year, the nine days of data were arbitrarily removed and replaced by nine days of data from the second biggest flow event of the year, in December.

(5) The revised yearly load of phosphorus was calculated as 35.2 kg. The estimate might be a little higher than a "typical" year because the revised year was still somewhat wetter than average.

(6) On the basis of a 35.2 kg load, the runoff from upstream areas of land was estimated as 0.106 kg of total phosphorus per hectare in one year. This is close to standard estimates for forested land in eastern Canada, and only 19% higher than a value obtained by modelling the land runoff from the Roberts and Blackburn drainage basins.

(7) During most of the year, particulate phosphorus was the dominant form in the water. Dissolved phosphorus, the most readily available form for algae and other biota, was a small fraction of the total. It appeared to have a base concentration of 8 to 24 ppb, probably derived from groundwater emerging as springs. However, during the very first small freshet after the summer dry period, there was a peak of phosphorus which was almost entirely dissolved, not particulate. That peak might largely represent soluble phosphorus from the ashes of "burn piles" and from decay of vegetable matter during the previous dry season.

(8) Certain constants were adopted or derived for use in background calculations.

(a) Average yearly rain and snowfall in the upper Cusheon watershed was taken as 0.980 metres. This was the average from 29 recent years of record at a location 2.1 km north from the centre of that area of watershed.

(b) The runoff of rain and snowfall from the land is taken as 48% of the precipitation falling during the year, from a tabulation of eleven estimates by other workers (Sprague 2007c).

(c) Evaporation from lake surfaces during one year was taken to be 0.713 metres, from a recent estimate on Salt Spring Island.

(d) The amount of phosphorus in rain and snowfall was estimated as 0.11 kg per hectare in one year, the average of four values during a typical year, in B.C. and coastal Washington state.

(9) The work was done at a culvert where the creek crosses Blackburn Road, upstream of Blackburn Lake. The general approach for collecting data included the following steps.

(a) Phosphorus concentration was measured in samples taken on 130 days during the year. Total phosphorus was always measured; it includes both dissolved and suspended (particulate) forms of the nutrient. Occasional measurements of dissolved phosphorus were also done.

(b) Sampling focused on freshets (times of increased flow because of rainfall). During periods of quiescent and gradually declining flow, sampling decreased to approximately weekly. For the days between samples, estimates of decreasing phosphorus concentrations were made by graphical interpretation.

(c) The amount of water flowing in the creek was estimated on sampling days and additional days, for a total of 146 measurements. This was done by calibrating the culvert. The depth of water in the culvert was converted by standard trigonometry to the cross-section of water in the culvert. Velocity through the culvert, measured at a variety of flows, could be estimated for any given depth. The flow (litres per second) was then calculated as the velocity multiplied by the cross-section, times a factor of 0.8 to allow for drag of the culvert wall.

(d) Multiplying daily flow by the concentration of phosphorus gave an estimate of the *load* of phosphorus, i.e. the amount (weight) of phosphorus carried downstream per day.

(e) The area of the upstream watershed was measured by a mapping expert of Islands Trust, who interpreted contour lines on a detailed electronic map of the watershed. He measured 116.5 hectares of land draining into Roberts Lake and thence to upper Blackburn Creek, and a further 255 hectares which drained directly to Blackburn Creek, upstream of the culvert.

(f) These methods led to an estimate of 0.106 kg of phosphorus per hectare in a typical year.

(10) This report provides the technical details of the work producing these estimates.

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1. INTRODUCTION

The Cusheon Lake Stewardship Committee was formed in the late 1990s to look after the welfare of Cusheon Lake on Salt Spring Island. In 2003 the Cusheon Watershed Management Steering Committee was formed as an offshoot, to develop a management plan for the lake and its watershed. A major stimulus for this activity was concern about algal blooms in Cusheon Lake, with a bloom of cyanobacteria in 1999 which led to a prohibition on use of the water for several weeks.

It was realized that the amount of algal growth was governed by the concentrations of nutrients in the water, and that phosphorus (P) was the key nutrient which limited the severity of algal blooms. Accordingly, if the inputs of phosphorus to the lake could be reduced, the blooms should decrease.

Before the management committee could recommend steps to reduce P, there was an obvious need to know which sources of the nutrient were most important. Preliminary modelling had indicated that the major source of phosphorus was apparently from the land. However, no definitive statement was found in the scientific literature, for the amounts of phosphorus that would be expected to run off the land in coastal regions of southwestern British Columbia.

A modelling exercise had predicted that 0.089 kg of phosphorus ran off each hectare of land in the upper watershed, every year. Land runoff was estimated to provide about 53% of the phosphorus supply to Cusheon Lake (Sprague 2007a), and much of it was carried by Blackburn Creek. (A further 23% came from septic systems near the lake, 22% recycled each year by regeneration from the bottom sediments, with other minor sources. Those predictions came from limited measurements in the Cusheon basin, from excellent research on enriched lakes in Ontario, and from mathematical modelling of the Cusheon chain of lakes.

The purpose of the present study was to measure the phosphorus load carried by Blackburn Creek during one year. This would allow an estimate the how much phosphorus ran off each hectare of land. The estimate would then be used to check whether the predicted runoff of 0.089 kg/ha was realistic.

Companion studies measured flows and phosphorus levels in smaller creeks of the Cusheon basin, and in a series of culverts that drain directly into Cusheon Lake (Sprague 2007d, e).

Funding for chemical analyses was shared by the Water Council of Salt Spring Island, sponsored by the Salt Spring Director for the Capital Regional District, and by the Local Trust Committee of Islands Trust. The work was done by volunteers, as noted on the opening page.

Style and content of this report. This is a background technical report for the Cusheon Watershed Management Plan (CWMPSC 2007). The main findings are reported in the preceding summary. The remainder of the report provides the supporting technical data and analysis. The report first covers the general nature of the watershed and the investigation, then proceeds with details of rainfall, creek flow, and chemical data. Each topic is supported by details in an appendix.

The symbol P is used to signify phosphorus, and it includes all forms of phosphorus which are measured by the chemical test (i.e., *total phosphorus* or its abbreviation TP). A few measurements of *total dissolved phosphorus* were made, and identified in the text as such, as the abbreviation TDP, or in most cases simply as "dissolved P".

2. LOCATION, LAND AREAS, AND SAMPLING RATIONALE

Location and land use

All measurements in this report were obtained in Blackburn Creek at a culvert which ran under Blackburn Road, about 1.2 km westerly along Blackburn Road from the Fulford-Ganges Road. The culvert is 1.4 km upstream of Blackburn Lake as the stream flows. This is the creek that carries water from the upper part of the Cusheon watershed. This study includes about 45% of the land area that drains into Cusheon Lake (Table 1), shown by the two left-hand sub-basins in Figure 1.

Table 1. **Size of the drainage sub-basins in the Cusheon watershed.** Values are in hectares. Areas were estimated with a GIS computer program, by Brett Korteling of Islands Trust (Korteling 2006). The values are "flat" as on a map, and do not allow for slope of the land. Lake areas are those of BC MSRM (2006). Some totals do not add because of rounding.

Basin	Total area	Lake area	Land without lake
Roberts Lake	119.9	3.44	116.5
Culvert, Blackburn Road	247.5		
Remainder to Blackburn Lake	263.3	3.08	260.2
Blackburn Lake total	510.8	3.08	507.7
Cusheon Lake	220.0	26.9	193.1
Total to Cusheon Lake	850.7	33.4	817.3
Cusheon Creek below lake	214.5		214.5
Total Cusheon watershed	1065.2	33.42	1031.9

The top part of the watershed drains into Roberts Lake through two intermittent creeks and surface runoff (upper left sub-basin in Figure 1). Roberts Lake drains into Blackburn Creek, which also receives runoff from a second major part of the basin before it reaches the culvert. In all, 648.9 hectares drains through the culvert, according to definitive estimates by GIS mapping programs (Korteling 2006).

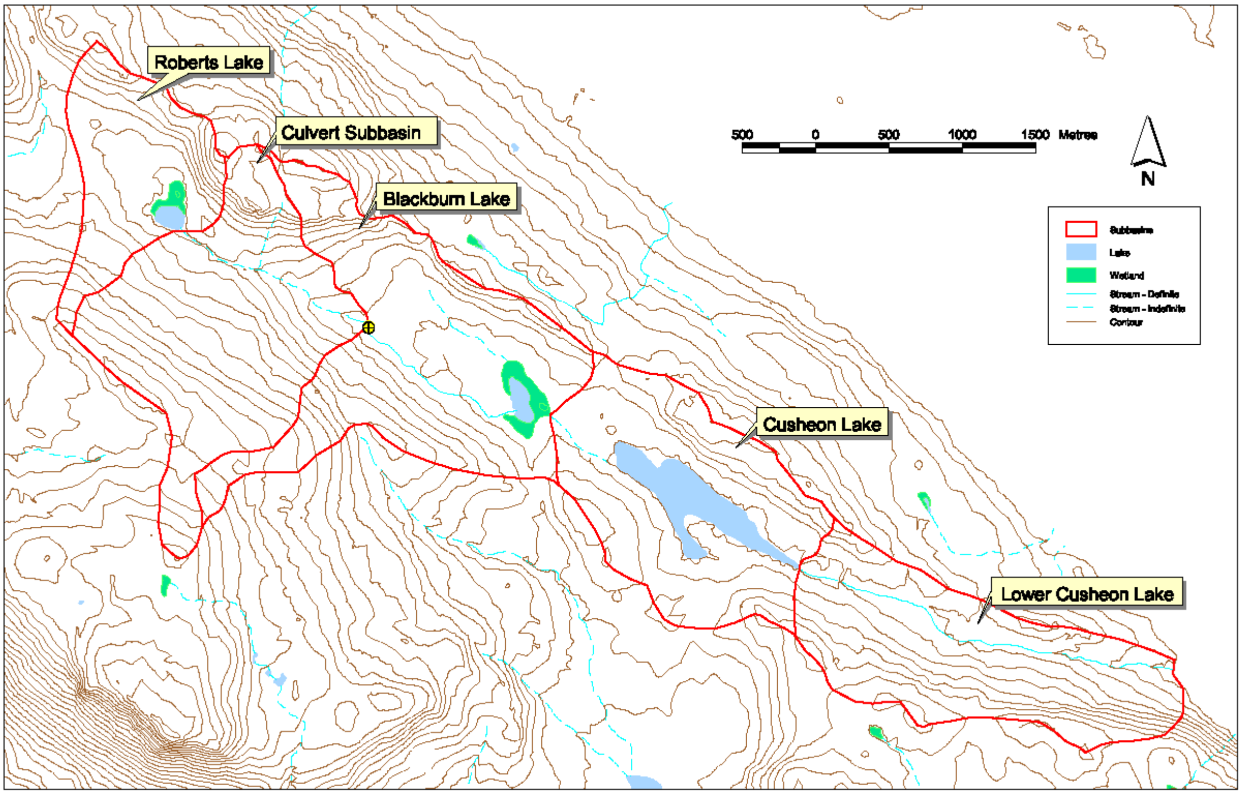

Figure 1. **Sub-basins in the Cusheon Lake watershed.** The two upper sub-basins (left side of the map) are the ones that flow through the culvert on Blackburn Road. The culvert is marked by a small white circle and cross. The label "Lower Cusheon Lake" on the right side refers to Cusheon Creek which drains Cusheon Lake. Prepared by Korteling (2006).

The upper Cusheon basin (upstream of the culvert) is less developed than downstream areas. Rural residences occupy less than 1% of the upper basin (estimated from a map of land use created by Islands Trust from an aerial photograph; Figure 2 of CWMPSC 2006). For the entire Cusheon watershed, rural residential area is higher, at 14% (Table 1 of CWMPSC 2006). The upper basin has somewhat more agricultural land (about 12%), and more young forest (about 70%), than the entire watershed (9% and 62%). Mature/ old growth forest (8%) and wetland (1%) are similar to the overall watershed (8.2% and 2%).

About 7% of the upper watershed was clear-cut four years before this study. The hillside was in the upper Blackburn Lake basin. The cut area had grown a strong ground cover of low bushes and other vegetation by the time of the survey. A small creek which drained the hillside had runoff water that was clear with low-to-normal concentrations of phosphorus (Sprague 2007e). In other words, this clear-cut area had healed sufficiently that it did not have excessive erosion or contribution of nutrient.

Timing of the study and sampling

The one-year period of study ran from August 1, 2004 until July 31, 2005. This includes the autumn-to-spring wet period when creeks flow on the Gulf Islands. During the summer, there is little or no flow in most of the creeks on Salt Spring Island. That applies in the Cusheon drainage basin, where smaller creeks dry up, and Blackburn Creek either dries or declines to a trickle (section 4). A twelve-month period starting August 1 was also used by Nordin et al. (1983) as a “water-year”.

It was expected that August would be a dry month with no flow at the culvert, but there was significant rainfall on August 6 so sampling started then. Two other rainfalls occurred later in the month, so sampling continued in August and ended after the following July. By then, flow through the culvert had again dropped to an insignificant trickle.

Although regular daily sampling would have been desirable, we did not have the funding for that and it would have been a strain on the available time of volunteers. Therefore we attempted to sample the most important times when phosphorus was likely to be elevated, during and after freshets in the creek (surges of flow).

We attempted to obtain a water sample on every day when there was appreciable precipitation, with an expected rise in flow of the creek. If precipitation continued, daily sampling continued. We also attempted to continue daily sampling during the decrease in flow after the bigger freshets. As flow became more quiescent and steady, we reduced the frequency of sampling, but usually maintained weekly samples during the wet season. Figure 2 shows an example of the days on which flow measurement and sampling were carried out during December 2004. Sampling days in December responded to the frequent periods of precipitation and consequent surges of flow in the creek.

Water samples were collected on 130 days and estimates of flow were made on 146 days. It appears that we were reasonably successful in sampling the periods of heavy flow and high levels of phosphorus (see sections 4 and 5 on flows and P levels, as well as Figure 2 and Appendix 1).

3. RAIN AND SNOWFALL, EVAPORATION, AND RESULTING CREEK FLOWS

Precipitation was measured daily during the year. The main purpose was to help interpret the changes in creek flow, particularly for the periods between actual measurements of flow. For example, if no appreciable rainfall was recorded during a certain week, the creek flow would be expected to gradually decrease during that quiescent week. To tie in this single year of measurement with previous averages and extremes, historic monthly and yearly totals of precipitation were obtained for other sites. Appendix 2 gives the details of methods, reasons for choice of locations, and discussion of historic records.

Methods for daily values of precipitation during 2004-05

Daily measurements were made in an open area at 474 Old Scott Road, the residence of one of the volunteers (J.B.S.). This location is 5.1 km northeast of the centre of the basin that drains to the culvert. Measurements were made at approximately 8 a.m. each day, and the value was used as the data-point for that day (shown in Appendix 1). Thus the value for a given day includes precipitation that fell for the preceding 24 hours. That seems to be a suitable time of day, since there is probably a lag of some hours as runoff builds up during a rainfall event, then flows downstream to the culvert where we measured the flow later in the morning or in early afternoon.

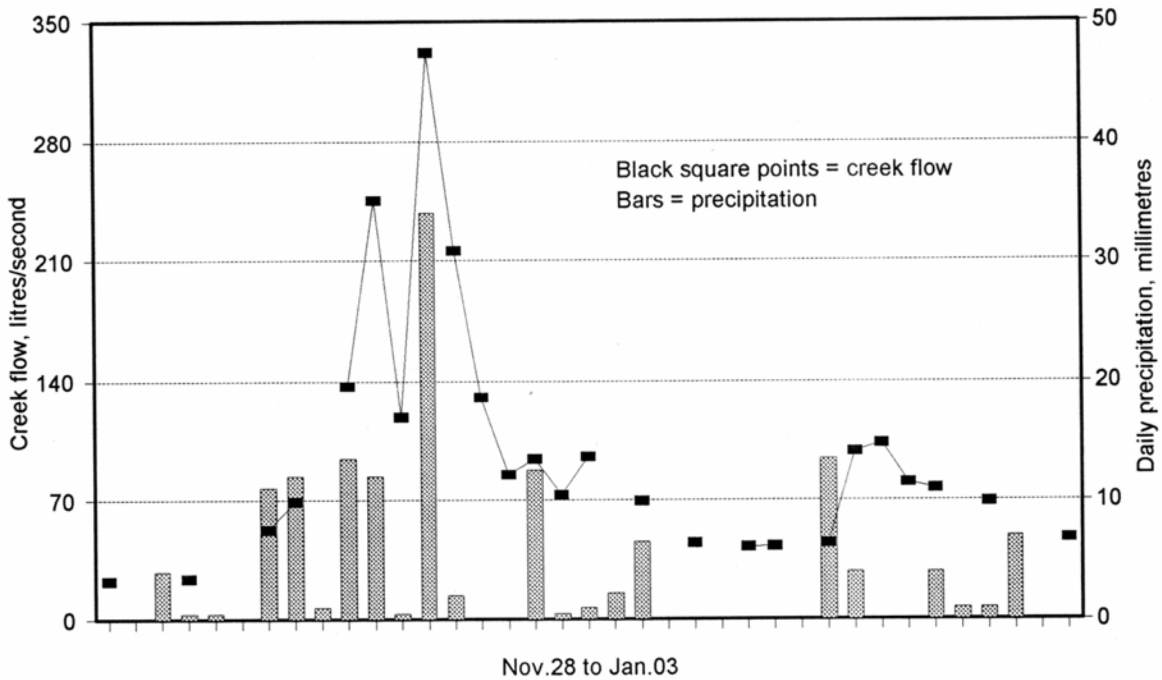

Figure 2. **Precipitation and creek flow during December 2004.** This is an example of data available for graphically estimating flows on days when it was not measured. There were frequent measurements of flow in December, responding to repeated rainfalls and resulting surges in flow. Flow measurements are shown by black points, and when there were values for adjacent days, the computer program joined then by straight lines.

Another possible site was at 134 Douglas Road, 2.1 km north of the centre of the culvert's drainage area. Careful records were kept here by Robert Aston (Aston 2006). These measurements are the most useful *historical* records for the upper Cusheon watershed (Sprague 2007c). Their afternoon timing made them less suitable for the present survey. Environment Canada's weather station beside Cusheon Lake ceased operation in 1999. Records are summarized in Table 2.

Yearly precipitation

The data from Old Scott Road (column 1 of Table 2) were used as the *daily pattern* of precipitation throughout the year, to help interpret the changing flows in Blackburn Creek. The record for Douglas Road (column 2) is used as the *amount* of precipitation during the year of study. As an estimate of typical rainfall near the Cusheon watershed, the average for the longest period at Douglas Road (29 years, column 3 of Table 2) is used. The 29-year average is 980 mm per year, the same as the average for 20 recent years (column 4). The value of 980 mm is considered the most representative and dependable estimate that is available for the Cusheon basin (Appendix 2). The year of study, with precipitation of almost 1140 mm, was much wetter than the usual year.

Table 2. Comparison of monthly precipitation at three sites on Salt Spring Island. Values in columns 1 and 2 are for 2004-05. Columns 3 to 5 are historic averages. Values in millimetres.

	(1) This study. Old Scott Road, one year, August 2004 to July 2005	Douglas Road (Aston 2006)				(6) Cusheon Lake Road, 22-year mean during 1977 - 1999 (Env. Canada 2006)
		(2) One year, August 2004 to July 2005	(3) 29-year mean, 1977 to 2005	(4) 22-year mean during 1977 - 1999	(5) 20-year mean, 1984 to 2003	
Aug.	45.0	76.5			25.4	28.2
Sept.	61.0	81.3			22.9	36.3
Oct.	94.2	99.6			94.5	91.1
Nov.	103	122.4			164.3	173.8
Dec.	133	184.7			164.3	162.8
Jan.	216	235.0			160.8	149.4
Feb.	36.3	46.5			101.3	121.8
Mar.	92.1	117.1			92.5	98
Apr.	66.6	66.3			60.5	69.3
May	31.7	46.0			44.5	49.1
June	33.5	41.9			29.2	36.2
July	20.7	22.6			19.8	21.4
Total	933.1	1139.7	979.6	983.3	980.0	1037.4

Table 2 shows that there is some variation from place to place on the island. However, the long-term average at Douglas Road (column 5) is only 5.5% lower than the average for the same 22 years at Cusheon Lake Road (column 6). The correlation coefficient between the two sets of data is 92.8% which is good. The Douglas Road site is as close to the basin of interest in this study, or closer, than are the Environment Canada weather sites on Cusheon Lake Road. The Douglas Road measurements appear to be much more reliable (Appendix 2).

Precipitation during the study

As mentioned, 2004-05 was a wet twelve months, 16% above the long-term average (Douglas Road records). Only six of the 29 years had higher totals. Precipitation started in August and continued with some regularity until early February, after which there was a fairly dry period until late March. There was another relatively dry period in late April and early May, then small amounts continued to fall until early July.

In 2004-05, the precipitation appeared to be appreciably higher in August, September, and January (Table 2, columns 1 and 2) than the long-term averages for those months (columns 5 and 6). Precipitation was appreciably lower than average in November and particularly so in February.

The large peak of precipitation and flow in January is of particular importance to this study (discussed in later sections). January was indeed very high in rainfall, with the Douglas Road site recording 235 mm. That is a surprising 46% higher than the long-term average for January at the same location (column 5 of Table 2), The historic individual monthly records for Douglas Road are not available, but comparing with the monthly records of Environment Canada, that value for 2005 is the fourth highest value for January in the 22 years of records (Environment Canada 2006).

Even more meaningful would be heavy precipitation over a few days, since that could cause high flows or flooding. In January of this study, there was continuing precipitation during a nine-day period (January 17 to 25) which was a time of very high flows in the creek. The rarity of the nine-day rainfall could be determined by inspecting historical daily rainfall records for previous winters. That has not been done at the time of writing because of the unavailability or questionable dependability of daily records for the sites of interest.

Evaporation from the lakes

Evaporation is estimated to lower the level of Cusheon lake by almost exactly one-third of a metre (33.4 cm) during the summer when there is no inflow, in an average year. The low point would come in September (Appendix 2).

The total evaporation from lakes during the whole year would reduce the total amount of water that flows out of the bottom of the system, in Cusheon Creek. The total yearly evaporation is estimated to average about 0.713 metres (71.3 cm). Thus, any given surface area of lake would receive almost one metre of rain and snow during the year, but it would evaporate about 70% of that. These estimates are derived from the work of Watson (2006) on St. Mary Lake. He based his calculations on work of Hamilton et al. (1998) and the rationale is shown in Appendix 2.

Natural flow of water in the Cusheon system

A simulation of creek flows can be calculated using estimates of evaporation and other variables. The logic can be followed line by line in Table 3. The calculations assume for the moment, that there is no human withdrawal of water. The simulation uses the estimate of evaporation given immediately above (0.713 m), the 20-year average rainfall of 0.98 m (Aston 2006), a runoff proportion of 0.484 from the land (Sprague 2007c), the land areas of Korteling (2006), and lake areas of the B.C. government (BC MSRM 2004).

From Table 3, the natural yearly flow of water through Blackburn culvert is estimated as 1,735,000 cubic metres, or an average of 55 litres per second. This theoretical value is somewhat higher than the estimated flow of 1,470,800 cubic metres, actually observed during 2004-05 (Appendix 1). Continuing the calculations through Blackburn Lake and Cusheon Lake, the natural outflow from that last lake is estimated as an average of 125.6 L/sec. in a typical year.

At the bottom of Table 3, the predicted Cusheon outflow is compared with the outflow measured by Barnett et al. (1993) for 1970 to 1992. Two adjustments are required. First, the rainfall was somewhat lower during Barnett's observations than it was during the rainfall period used here, according to records at Victoria collected by Environment Canada's weather office. The predicted outflow was accordingly adjusted 2.6% lower. Second, the prediction does not allow for the water removed from the system by human use. That human use might average 4.38 L/sec according to records of water supply districts and licences granted (Sprague 2007a). Subtracting that produces a predicted outflow from Cusheon Lake of about 118 L/sec, as an average for the year.

Table 3. Theoretical natural flows estimated for the Cusheon chain of lakes and creeks

		cubic metres per year
Roberts Lake drainage basin		
Land runoff: (116.5 ha x 10,000) x (0.980 m of rain x 0.48385) =		552,412
Directly onto lake = (3.44 x 10,000 x 0.980) =		33,712
Minus evaporation: lake area 34,400 x 0.713 m =		24,527
	Estimated annual natural outflow:	**561,596**
Drainage to Blackburn culvert		
From Roberts Lake:		561,596
Sub-basin land runoff: (247.5 ha x 10,000) x (0.980 m of rain x 0.48385) =		1,173,578
	Estimated annual natural through-flow:	**1,735,175**
Blackburn Lake drainage basin		
From Blackburn culvert:		1,735,175
Sub-basin land runoff: (260.2 ha x 10,000) x (0.980 m of rain x 0.48385) =		1,233,798
Directly onto lake = (3.08 x 10,000 x 0.980) =		30,184
Minus evaporation: lake area 30,800 x 0.713 m =		21,960
	Estimated annual natural outflow:	**2,977,196**
Cusheon Lake drainage basin		
From Blackburn Lake:		2,977,196
Land runoff: (193.1 ha x 10,000) x (0.980 m of rain x 0.48385) =		915,628
Directly onto lake = (26.9 x 10,000 x 0.980) =		263,620
Minus evaporation: lake area 269,000 x 0.713 m =		191,797
	Estimated annual natural outflow:	**3,964,647**
Estimated natural Cusheon outflow, converted to mean annual litres/second =		**125.6 L/sec.**
Observed mean annual outflow for 1970-1992 (Barnett et al. 1993) =		116.0 L/sec.
Adjust the estimated natural flow for different rainfalls. Records in Victoria indicate that precipitation averaged 2.6% lower in 1970-1992 (the period used by Barnett for observed flow) than in 1997-2005 (used above in table). Recalculating the table for lower rainfall yields a corrected estimate of natural outflow of 3,857,430 m3 / yr =		122.2 L/sec.
The flow observed by Barnett reflected withdrawals for human use. The possible removal for human use has been estimated as 138,124 m3/year or 4.38 L/sec (Sprague 2007a). Subtracting that from the corrected natural outflow given above =		**117.9 L/sec**
Discrepancy between estimated 117.9 and observed 116 L/sec =		**1.6 %**

Whether or not by coincidence, the prediction of 118 L/sec is only 1.6% higher than the value observed by Barnett et al., which is remarkably close agreement.

Phosphorus in precipitation
The phosphorus contained in rain and snowfall, and deposited on land and water surfaces, is estimated as 0.11 kg/ha • yr. Four estimates from the region have been averaged to provide this value which is used for modelling in this report (see Appendix 3).

4. MEASURED FLOW OF BLACKBURN CREEK AT THE CULVERT

It was important to estimate the daily volumes of flow in Blackburn Creek so that measurements of phosphorus *concentration* could be converted into phosphorus *loads*, i.e., the amount or mass of phosphorus that was being carried downstream in the creek. The concentration of phosphorus in the water was multiplied by flow, to calculate the daily load (see section 6 of this report). It is the absolute load of phosphorus which is important in assessing the enrichment of lakes. Methods of estimating flow are outlined here, along with the chief findings. Exact details are in Appendix 4.

Summary of methods
The overall technique was to measure the depth of water in the culvert, which had a diameter of 1.2 metres. That was used to estimate the cross-sectional area of water in the culvert. The cross-section was multiplied by the velocity through the culvert. A correction factor for drag was applied, and that yielded the volume of water passing through, in litres/second or cubic metres/day.

- Depth of water in the deepest part of the culvert was measured from the upstream end, on a scale attached to stick, which reached into the flat area of flow.

- In the early part of the study, the width of water in the culvert was measured instead of depth. Widths were converted to depths on the basis of trigonometry, checked by measurements in the culvert, then the estimation continued as below.

- The cross-sectional areas were calculated by trigonometry from the measurements of depth.

- The velocity was measured for 24 stages of flow, and a relationship was established between the velocity and the depth of water. The equation describing this was:
  Velocity, cm/sec = (114.355 x log of depth in cm) - 7.73591

- The cross-sectional area multiplied by velocities provided a raw estimate of volume of flow.

- A correction factor of 0.8 was applied for drag caused by contact with the culvert.

Heavy rain from January 17 to 23 caused fierce creek flows and a partial collapse of the downstream third of the culvert. Accordingly, from January 20 until the end of the study, only the upstream portion of the culvert was used for measurements, since it had not been seriously disturbed.

Interpolation of flows

The flow was estimated from field measurements on 146 days during the year. That represents 40% of the days, or an average of one estimate every 2.5 days. The estimates were focused on times of rising or changing flow (usually daily during times of major change). If significant rainfall was measured on a given morning, that was followed by a visit to the culvert and a direct measurement.

During quiescent periods of stable flow, or gradually declining flows, estimates were about weekly. Graphical interpolation was done to estimate flows on the intervening days. These interpolations were usually for the "descending limb" of the flow pattern following a freshet. Interpolations were patterned after the usual behaviour of the creek as seen by daily measurements during some periods, such as those for December shown in Figure 2. In other words, the shapes of *hydrographs* were imitated by the interpolations. For each month, a histogram of the daily rainfall was plotted on a graph, along with the observations of flow in the creek (similar to Figure 2). Interpolations were guided by the amount and timing of preceding rainfall.

The graphical interpolations are considered realistic although not exact. They were a definite improvement over several attempts using computer-based arithmetic simulations. Those attempts were abandoned (see Appendix 4). Measured values of flow can be identified in Appendix 1 because there is a value shown for depth of water in the culvert. The other estimates of flow in Appendix 1 are from interpolations. The general changes in creek flow may be seen in Figures 4a and b.

5. PHOSPHORUS CONCENTRATIONS

Kinds of phosphorus measured

***Total phosphorus* (TP)** was measured for each of the 130 samples taken throughout the year. This measurement includes all the water-borne phosphorus that reacts with the reagents of the chemical test. In general, it includes dissolved P and particulate P, described below.

***Total dissolved phosphorus* (TDP)** is included in the TP. It is directly dissolved in the water in one or other chemical form. Almost all TDP is easily available to algae and other plants, and reacts in the chemical measurement for phosphorus. The two measurements TP and TDP are considered the ideal ones for studies of P in streams (Brett et al. 2005). TDP was only measured in 22 samples in this study, because of financial limitations. In this report it is often referred to as "dissolved P".

In a creek, the TDP usually comes mostly from groundwater, i.e. from springs and similar sources. TDP tends to have a relatively constant input to the creek water during the year, and is not greatly affected by freshets. In this part of the Pacific coast, it tends to increase its concentration in creeks during the summer, as groundwater makes up an increasing proportion of the water in the creek (Brett et al. 2005).

***Particulate phosphorus* (PP)** is sorbed onto particles which are in the water, or is otherwise attached to the particles, or contained in them. This category was not directly estimated, but it is part of the measurement of total phosphorus. PP can be estimated approximately:

TP - TDP = PP, more or less
(Total phosphorus minus total dissolved phosphorus equals particulate phosphorus).

The particles could be of any origin, but would normally include organic fragments (e.g. pieces of leaf), suspended sediment or silt, or in times of surging flow in a creek, heavier particles approaching the size of sand grains. The chemical test will measure much of the phosphorus that is on or near the surface of the particles. It will not measure phosphorus that is contained within a solid particle, say a big particle of silt.

The particulate phosphorus is of special importance for Blackburn Creek because it probably dominated during the major runoff and flooding in January. Most of It was probably in tightly-bound forms that would not become available to algae and other organisms. This is further discussed in Appendix 6 and in section 6, below.

Sampling procedure

MB Laboratories Ltd. of Sidney, B.C. supplied clean 250-mL plastic (Nalgene) sample bottles and they were used throughout this study. Upon arrival at the culvert, the bottle was rinsed twice with a small amount of creek water, shaking the capped bottles vigorously after taking in the rinse water. The bottle was drained then filled, with the bottle nearly submerged and the mouth pointing upstream from the person collecting the sample. Care was taken not to stir up the bottom sediment or trap any debris in the bottle. However, when the water in the creek was muddy, suspended material was accepted as part of the sample. The bottle was pre-labelled. The sample was frozen within three hours. Later, a series of samples was carried to MB Laboratories by one of the volunteers, still frozen in a cooler.

After collecting the sample, the amount of water in the culvert was measured (see section 4). That was recorded along with date, time and sample number. Most samples were collected in mid- to late morning or in early afternoon.

Chemical analysis

Chemical analysis was done by MB Laboratories Ltd. of Sidney B.C., by ICP (inductively coupled plasma spectrometry) with a detection limit of 10 micrograms per litre (μg/L), or more usually by *Technicon*, with a reported sensitivity of 0.3 μg/L. Accuracy of analyses was reported and was very satisfactory.

Precision of analyses proved to be excellent, as judged by twelve sets of "blind" replicates sent to the laboratory. The average coefficient of variation was only 4.2%, while the smallest and largest coefficients were 1.6% and 11.7%. This shows excellent analytical performance in unannounced trials (see Appendix 5). Analyses of the laboratory were also equivalent to analyses of replicate samples sent to the laboratory used by the B.C. Ministry of Environment, a comparison arranged through the courtesy of Deborah Epps, of the stewardship program of the ministry in Nanaimo. It is important that the present measurements should be comparable to government values, since the Ministry of Environment has made many more measurements than any other group.

Interpolation between measurements

There were 130 measurements of TP during the year, but a value for each day was desired in order to estimate the total load that Blackburn Creek carried in a year. That would represent the runoff of P from the drainage basin. From the samples, it appeared that the TP was to some extent a reflection of the creek flow, for any given time of year. (The relationship changed with the seasons, as discussed below.)

An example of the general correspondence of concentration and flow is seen in the measurements for December, which had frequent samples (Figure 3). The phosphorus peaked on the day when there was the first peak of flow. Phosphorus dropped rapidly on the day following a peak flow, then gradually declined towards a base concentration until the next surge of flow.

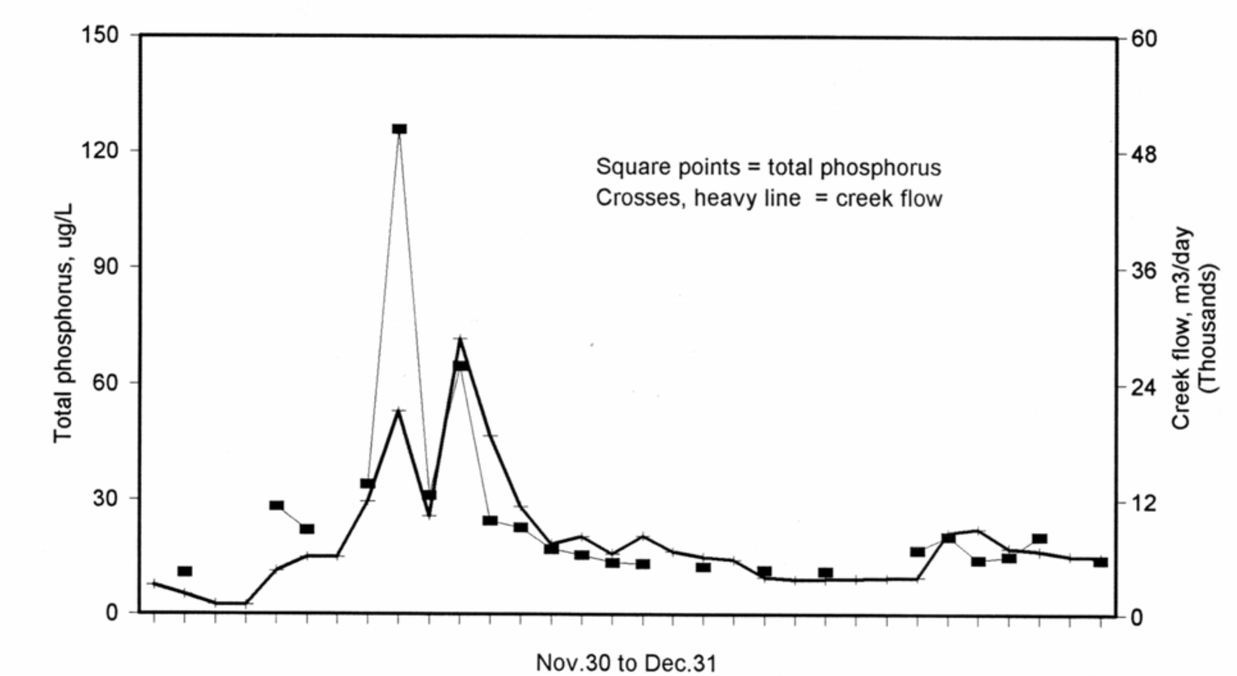

Figure 3. Measured values of creek flow and total phosphorus for December 2004. The phosphorus concentration was, to some extent, a reflection of flow. That assisted the process of interpolation, to estimate concentrations on days when it was not measured.

One phenomenon seen in the data for December (and other months, see below) was that the peak of P was much higher for the first surge of flow than for a subsequent surge. Thus it was important to sample for P on the days of high flow and peak flow, and we tried to do that.

Accordingly, graphical interpolation was used for phosphorus concentrations, in similar fashion to the interpolation that had been done for creek flow. Often this was for the declining phase after a peak, in what appeared to be a relatively straightforward procedure. In Appendix 1, there were measured values for most of the days for which a measurement of depth in the culvert is shown. Once estimated, the interpolated values were treated as real values for purposes of this study.

Phosphorus concentrations during the year; results and discussion

The pattern of TP during the year is a series of peaks and "declining limbs", roughly related to the pattern of flow (Figures 4a, b). When interpreting Figures 4a and 4b, it is important to note that phosphorus concentrations are shown on a straightforward arithmetic scale, while creek flows are shown on a logarithmic scale, with ten-fold jumps of flow from one marker line up to the next one.

Within the general pattern that shows rough parallels of flow and concentration, one of the most striking phenomena is that the early part of the study had much higher concentrations of TP for any given flow, than did the later part of the study.

Thus, Figures 4a and b, and Appendix 1, show a pattern of relatively high concentrations of TP from August to January. In August and September, very modest freshets of 300 to 400 m^3/day brought forth P concentrations in the range 40 to 100 μg/L. In October, it took higher flows of 1,000 to almost 4,000 m^3/day to result in peaks of 30 to 100 μg/L.

Even higher flows occurred in November but freshets of 11,000 m^3/day produced P concentrations of only 40 to 50μg/L, while flows in the vicinity of 1,000 to 4,000 m^3/day produced only 10 to 15 μg/L.

In December, some freshets peaked at very high flows in the range 20,000 to 30,000 m^3/day but the creek water carried only 60 to 130 μg/L. In the last part of December, there were high flows of 4,000 to 8,000 m^3/day, yet the water had phosphorus concentrations that were mostly only 10 to 15 μg/L.

In late winter and early spring, flows remained high but phosphorus did not. From February to April, flows were mostly 2,000 to 10,000 m^3/day, but the highest measured peaks of P were only 50 to 60 μg/L, and most concentrations were in the vicinity of 10 to 15 μg/L (Figure 4b, upper panel).

For the remainder of the spring and summer, flows started at about 2,000 m^3/day and declined to about 100 m^3/day by mid-July, higher than in the previous August-September, but they did not trigger P concentrations much above base levels, in the 10 to 20 μg/L range (Figure 4b, lower panel, and Appendix 1).

This phenomenon is quite well known. The high runoff of phosphorus occurs at the time of big freshets, but most particularly in the early part of the runoff season after a dry or low-flow period. In other parts of Canada, the giant surges of flow come in springtime, with the melting of the snow and rapid runoff. That is when much of the P is washed downstream, largely associated with erosion silt.

In small streams and creeks of the Gulf Islands and coastal British Columbia, the big surges of flow come with the rains in late autumn, winter, and early spring. In that period, the biggest peaks of phosphorus concentration come with the flow surges in the early half of the wet season, after the summer-autumn period of dry weather and low flow. This is documented in nearby creeks of Washington state, where there is a similar climate; Brett et al. (2005) estimated that “28.6% of annual TP load occurred during 5% of the days”.

The peaks of total phosphorus with freshets are also well known in other streams (Pacini and Gächter 1999). The phosphorus is associated with suspended sediment transport, i.e. erosion silt, and most of the nutrient is are transported in that particulate form, sorbed to soil particles (Peterjohn and Correll 1984)

January is somewhat of an exception to this general picture, and is discussed further below. The month brought wild flows of more than 50,000 m^3/day, and that was enough to bring the highest TP concentrations of the year, in the region of 150 to 180 μg/l, but thought to be mostly associated with very heavy particles.

The *arithmetic average* of all 365 daily concentrations of TP was 20.7 μg/L, and the lowest and highest actually measured were 8.5 and 126 μg/L, neglecting the anomalous high values of January. The Blackburn average was only about half of that found in daily samples from a creek in neighbouring Washington state (38.5 μg/L). That creek was in a mainly forested basin, with a small amount of development. However, its drainage basin was ten times as big as the complete Cusheon watershed, and appreciably more rain fell there (Brett et al. 2005).

The *geometric mean* of the 365 concentrations was 16.7 μg/L. This type of average is considered superior to the arithmetic mean for describing the “typical” concentration of a substance in a creek (Brett et al. 2005). The best description would normally be given by a flow-weighted mean (Johnson 1979). For the 365 values in Blackburn Creek, that would be 46.6 μg/L, a value that is heavily influenced by the giant peaks of flow in January, and by phosphorus that was probably bound to particles and of low availability (see below). Because of that influence, the value 46.6 is not a good description of the typical concentration in Blackburn Creek; it is well above almost all the concentrations during the year (Figure 4a, b). Substituting more reasonable values for the nine days of high flow in January (see below), the flow-weighted mean would be 36.2 μg/L.

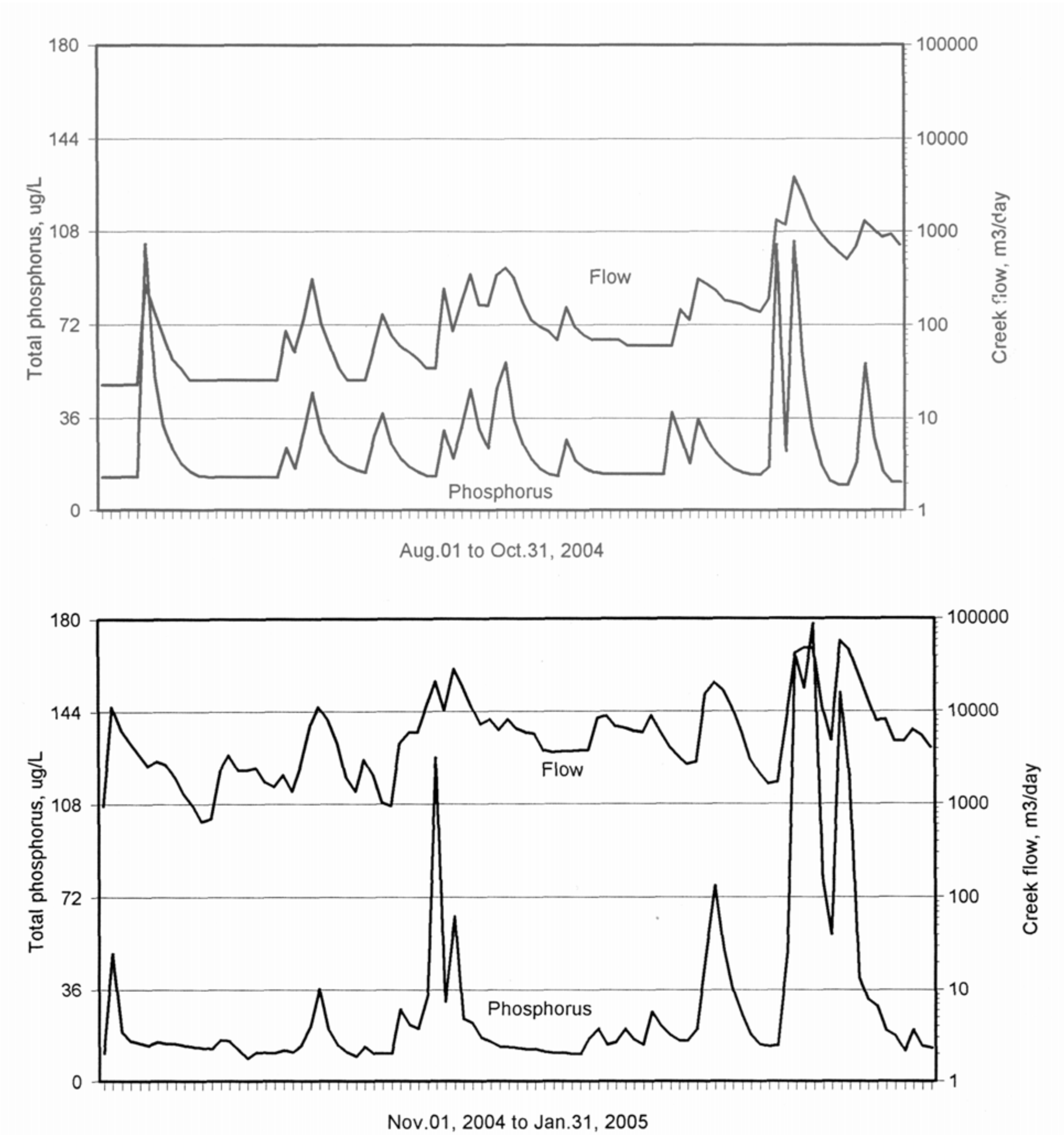

Figure 4a. **Estimated flows and total phosphorus concentrations in Blackburn Creek during the first two quarters of the study year.**

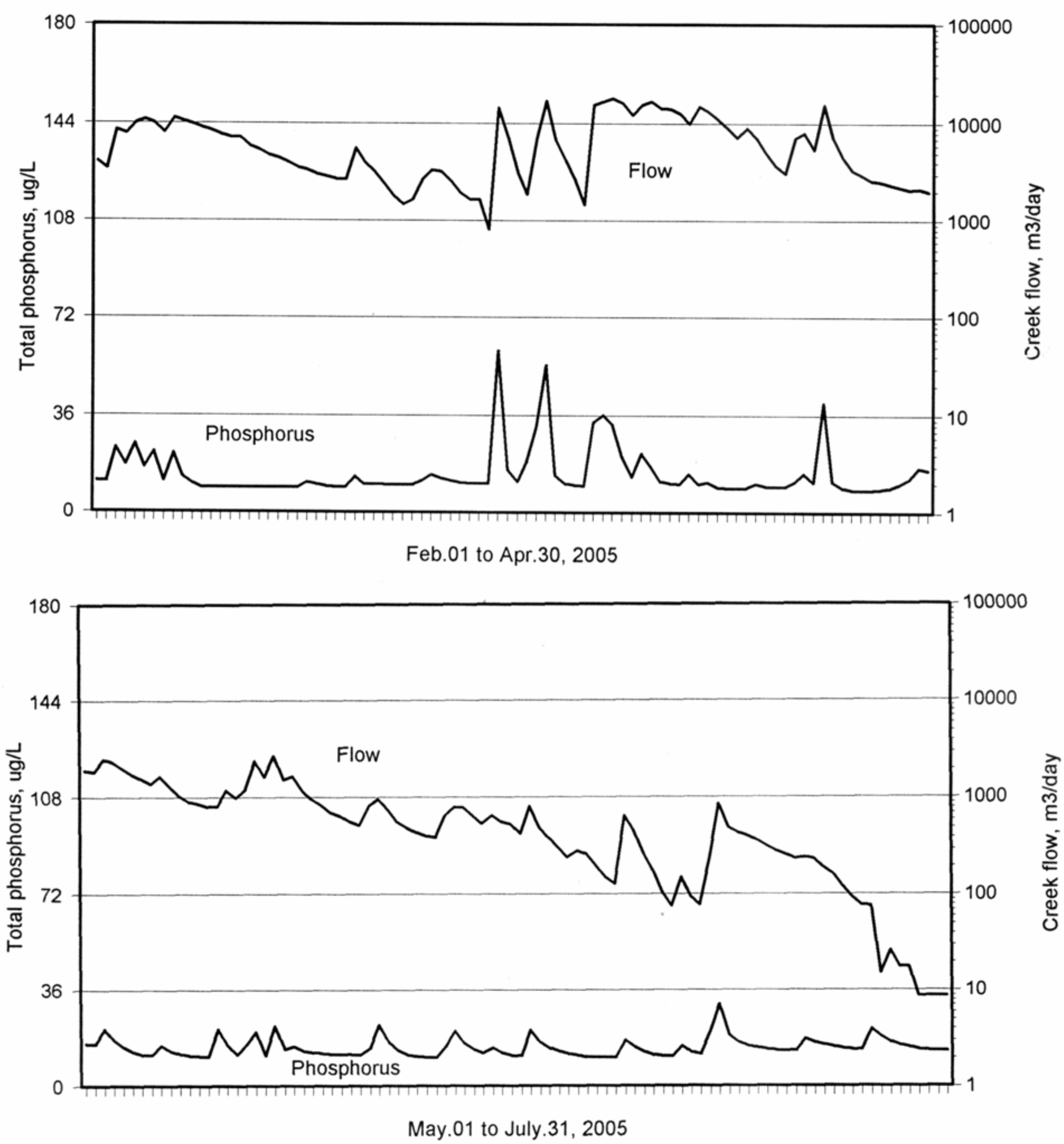

Figure 4b. Estimated flows and total phosphorus concentrations in Blackburn Creek during the last two quarters of the study year.

Dissolved versus total phosphorus

Total dissolved phosphorus showed a relatively constant "base" concentration in the vicinity of 8 to 23 μg/L during most of the year (Figure 5). That was the case from November until the following July. During that time there had been a variety of high and low flows in the creek. The relatively low and steady concentration of dissolved P is in keeping with its presumed steady source in groundwater.

Earlier on, anomalies were apparent during freshets from August to October, with higher concentrations of TDP. During three small freshets from late August to late October, TDP was from 30 to 40 μg/L. During the very first freshet after the summer dry period (August 6), TDP was 98 μg/L, a very high concentration. TDP made up an astonishing 95% of the total phosphorus concentration of 103 μg/L on that day. That did not seem reasonable, and a request was made to the laboratory to check for a typing or recording error. They reported that the values were correct; the analyses had been done twice and the records were in order.

The high levels of dissolved P did not result from groundwater dominating during relatively dry weather. If that had been so, the same phenomenon would have shown up during the following July, but it did not.

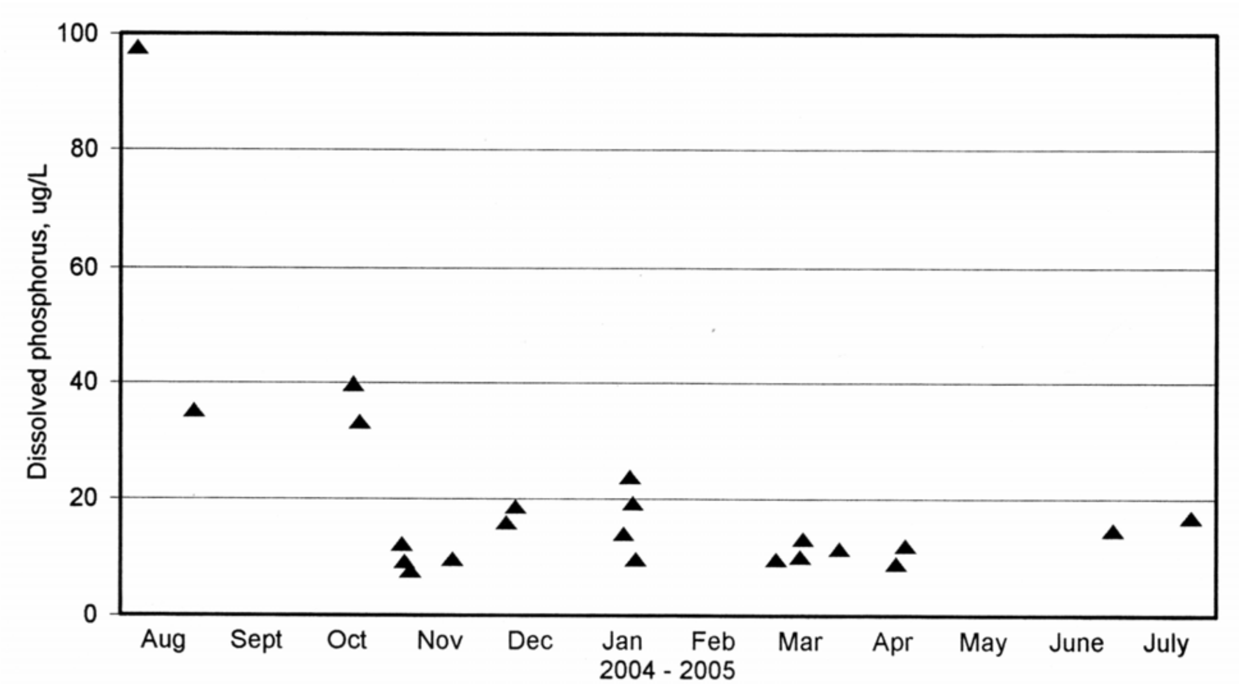

Figure 5. **Measured concentrations of total dissolved phosphorus in Blackburn Creek.** The very high value in the upper left corner represents the first modest rainfall and freshet in the creek after the dry period in summer.

Personnel at MB Labs suggested from past experience, that the initial peak of dissolved phosphorus might result from ash of burn-piles of "slash" (branches and brush) in logged or cleared areas. The ashes are rich in easily dissolved nutrients and lie on the ground at the burn site during the dry summer. The first appreciable rain can wash the minerals off into creeks. That could be an explanation for most or all of the surprising peak in dissolved phosphorus. Another source of this early runoff of dissolved P could be natural decomposition of vegetable matter during the summer, near the banks of creeks. The released or partially released phosphorus might be easily washed off into creeks by the first autumn rain. The modest freshet of August 6 was apparently not enough to cause appreciable erosion and a consequent rise in particulate phosphorus. It was enough, however, to wash off a major contribution of soluble phosphorus.

The same explanation could account for similar smaller elevations of TDP during the three other freshets in the early part of autumn (Figure 4a). By November, those concentrated sources of soluble phosphorus lying on the land had probably been washed clean, and TDP had dropped down to its base levels.

There does not seem to be a better explanation for the autumn anomalies of TDP.

Particulate phosphorus. Because the concentration of dissolved P was relatively steady all year (except early autumn), the high concentrations of phosphorus in winter were caused mostly by particulate phosphorus. That is seen in Figure 6. At low flows of 5,000 m^3/d and less, dissolved P averaged 76% of the total phosphorus (geometric mean 71%, range of individual values from 32% to 99%). The proportion dropped off steadily at higher flows. In the flood flows of mid-January, dissolved P was only 5 to 15% of the total phosphorus (three right-hand points in Figure 6). It should be noted that the vertical scale is logarithmic, that is, the ratio increases in ten-fold jumps.

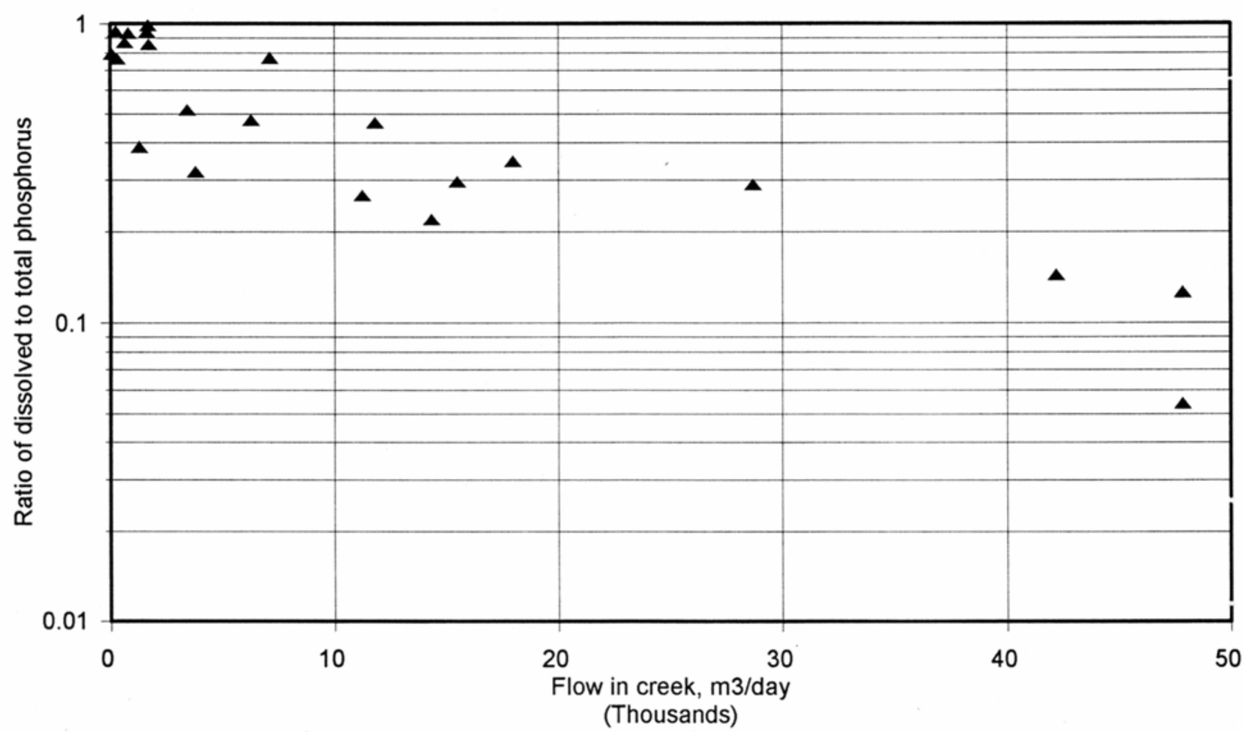

Figure 6. Declining proportion of dissolved phosphorus with increasing flow.

High flows brought increased erosion and more sediment in the water. The suspended P carried by that sediment became relatively more important. The linear relationship that best fitted the data of Figure 6 had a correlation coefficient 0.79, and is given by the following formula:

Logarithm (ratio, dissolved to total) = 1.863565 - [(1.92894* E-05) x (flow in m^3/day)]

As mentioned above, the peaks of TP with freshets are well known in streams, with much phosphorus transported in suspended sediment, i.e. erosion silt. Most of the transported nutrient is in the particulate form, sorbed to soil particles (Peterjohn and Correll 1984; Pacini and Gächter 1999; Brett et al. 2005).

6. PHOSPHORUS LOAD AT THE CULVERT

The yearly amount (*load* or *mass*) of phosphorus coming down Blackburn Creek can be obtained by simply adding the daily amounts listed in Appendix 1. Summing those data for the year, the total load of phosphorus passing through the culvert was 68.5 kg. That includes all forms of P measured by the chemical test, including forms that were tightly bound to large particles during the January flood.

The load of 68.5 kg is a valid estimate of total P for the 2004-05 period, but clearly the January surge of flow was an unusual event. Of the total amount during the year, 39.6 kg (58% of the total) came during that nine-day period of extreme flow in January. The entire remainder of the year only contributed 28.8 kg. The question about the biological availability of phosphorus measured during the January flood is discussed in Appendix 6, with a synopsis immediately below.

The January run-off event and unavailable phosphorus

For nine days (January 17 to 25) there were very high flows, all except one day having more than 10,000 m^3 passing through the culvert. There were two peaks, one almost 48,000 m^3 and the second 57,000 m^3 of water during the day. Flows during the nine days represented 20% of the year's flow, and the rainfall represented 15.5% of the year's precipitation.[1]

This storm run-off is judged here, to have been a once-in-a-decade event, according to several lines of evidence which are discussed in detail in Appendix 6. (a) There was a partial washout of Blackburn Road and collapse of the culvert (Appendix 4). (b) There was unusual flooding of main highways, shutting down road traffic across the lower part of Blackburn Creek, where a culvert was later replaced. (c) Judging by historical records (1970 - 1998) of flow in nearby Cusheon Creek, the peak flow in Blackburn Creek was three times as high as the average yearly maximum in Cusheon Creek (estimated by making an adjustment for the difference in sizes of drainage basins). (d) January precipitation in 2005 was 46% higher than the long-term average for January at the same location (see section 3 and Table 2).

The enormous flows in these nine days were, of course, scouring the stream-banks and carrying large particles downstream. Field notes at the time started with the word "Muddy", and the flow was described as "fierce!". Many or most of the large particles would probably have settled out quickly at the first quiescent place in the creek, or else in the marshy area of emergent vegetation along the edge of Blackburn Lake.

Deposition and layering of this sediment effectively removes it from making any contribution of nutrient to the water. As a second factor, although the P on the large particles is reactive to reagents in chemical tests, it may be "refractory", i.e. firmly fixed to the particles and largely unavailable to living organisms. These two factors are recognized in the scientific literature, as further documented in Appendix 6.

There is some indication from sampling at the time, that the large particles with their load of phosphorus were not simply passing through Blackburn Lake and reaching Cusheon Lake. A simplistic assessment is somewhat misleading, but it can be mentioned that during the period of flooding, samples from below Blackburn Lake where Blackburn Creek empties into Cusheon Lake, had only 16% of the phosphorus concentrations found above Blackburn Lake, at the Blackburn culvert (see Appendix 6).

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[1] The numbers for flow might be easier to understand if compared to other things. If the water could be carried like sand or gravel in big trucks, then a flow of 10,000 m^3 per day would represent about 1,100 big gravel trucks per day with loads of water. A flow of 50,000 would be 5,550 trucks, or almost four trucks per minute, delivering their full loads night and day.

The overall objective of this five-part study program is to assess how much phosphorus reaches Cusheon Lake and where it comes from. It appears the phosphorus attached to large particles, that was measured during the exceptionally wild flows over nine days in January, would result in only a relatively small contributions of available phosphorus to the downstream lakes. Most of it probably would not represent phosphorus that was of concern for Cusheon Lake. Accordingly, the measurements are retained (Appendix 1, Figure 4) as a portrayal of the situation in 2004-2005, but not as a judgement on the input of available phosphorus to the lake.

In particular, the measurements must not be taken to represent the average or "typical" yearly picture. Clearly the extreme flows would not occur in an average year. The sub-section immediately below attempts to present an estimate of a more likely typical year for phosphorus at the Blackburn culvert.

Estimating a typical annual load of phosphorus by adjusting for extreme runoff

The data in Appendix 1 are the actual measurements in the year of survey, 2004-05. However, for the purpose of representing a "typical" year, an arbitrary adjustment of the data was made. For the nine-day period of very high flows (January 17 to 25), data were removed from the tabulation. That included precipitation, creek flow, and phosphorus measurements. A substitution was made by repeating all the data from a nine-day period in December which represented the second most severe rainfall and flow during the year. In other words, that nine-day segment of data was used twice. The dates selected for repetition were those of the highest flows in December, from the 7th to the 15th.

When this was done, the hypothetical "typical" yearly loading became 35.15 kg. That value has been taken to represent a "typical" year of runoff.

Estimating a land runoff factor of phosphorus from measurements at the culvert.

The land draining to the culvert can be taken in two parts. The part draining to Roberts Lake is 116.5 hectares (Korteling 2006). The part downstream of Roberts Lake, but upstream of the culvert, is 247.5 ha. To estimate the runoff of P per hectare of watershed is not quite as simple as dividing the "typical" yearly loading of phosphorus by the total area of land. Part of the land runoff goes through Roberts Lake, and some of the P remains in that lake, rather than carrying on downstream to reach the culvert. It is necessary to adjust for this, using the procedures of Dillon-Rigler-Hutchinson (Dillon et al. 1986).

For Roberts Lake, it is estimated that 32% of phosphorus entering the lake stays in the lake, i.e. the lake's *retention coefficient* is 0.3225 (Sprague 2007a). Inputs other than the drainage basin of 116.5 hectares are small, and consist of the P in precipitation onto the surface of the lake (0.378 kg), and minor septic inputs from two nearby human habitations (0.227 kg) for an "other" sub-total of 0.605 kg (Sprague 2007a).

Given (a) the estimated loading of P at the culvert during a typical year, (b) the areas of the two sub-basins, and (c) the partial retention in Roberts Lake, the runoff of P per hectare can be estimated by algebra (calculations in Appendix 6). The estimate for a "typical" year is 0.106 kg of P from each hectare.

Evaluation of the runoff estimate. The estimate of 0.106 kg of phosphorus running off each hectare in a year does not seem unreasonable. It is only slightly higher than the standard value of 0.10 kg/ha which was established for "forest" on sedimentary drainage areas in Ontario. That estimate resulted from extensive research which produced a well-known set of procedures for evaluating lake enrichment ("the cottage-country model" of Dillon et al. 1986). The Ontario research estimated runoff of 0.2 kg/ha for "forest and pasture". The value estimated here is near the low end of the range given for Ontario, which might be reasonably appropriate for the upper Cusheon basins which are a mixture of forest and cleared areas, and where the soils might not be as rich as in southern Ontario.

The estimate of 0.106 kg/ha is close to the value of 0.089 kg/ha which was developed by modelling, as the estimate for land runoff of phosphorus (Sprague 2007a). The general agreement suggests that the value estimated from the one-year study at the culvert might have some validity.[2]

An estimated 0.106 kg/ha of phosphorus runoff might be somewhat high because it was a wet year. The year 2004-05 was apparently one with heavier than usual runoff, judging by the precipitation. In particular, January was very wet compared to the average. Even with the nine days of extreme flows of January replaced by less extreme data from December, the rainfall is still greater than average. With the adjustment, the yearly precipitation becomes 1094 mm, 11.7% higher than the long-term average, and the January total becomes 189.5 mm, about 18% higher than the 20-year average for January (Table 2).

Discussion of the runoff estimate.

- The estimate of 0.106 kg of total phosphorus running off from a hectare of land in the upper Cusheon watershed is considered to be a reasonable one. However, it is an approximation because many values used in the calculations were subjective estimates. (See below for discussion of deficiencies).
- The estimate might be somewhat higher than average because the study was done during a year that was wetter than usual.
- The estimate is in close agreement with a well-established value for runoff from forested land in eastern Canada.
- The estimate is also in general agreement with a value for land runoff to Cusheon Lake, developed independently by modelling.

Deficiencies of this study. The major anomaly in this study was a very large double peak of precipitation, flow, and phosphorus that came in middle to late January. The apparent phosphorus load during nine days of heavy flow made up 58% of the entire year's load. Those nine days of data are reported in this record of data, but they were arbitrarily removed from an estimate of a "typical" year. It seemed likely that the measured phosphorus was associated with heavy particles that would probably settle in the first quiescent area of water and be buried so that the P would not be available to biota. In addition, there is an indication from the literature that the phosphorus on large particles can be tightly bound, with little availability to organisms, although chemical procedures are strong enough to include it.

Accordingly, the data were adjusted in order to more closely simulate a "typical" year. The nine days of storm flow were replaced by repeating data from nine days of the second biggest flow event during the year, which had occurred about a month earlier. This manipulation of the data means that the estimate of 0.106 kg of P runoff per hectare does not represent the year of study, but is a subjective professional estimate for a near-typical year. The estimate might still be a little high, because as mentioned above, it still represented a rather wet year after the adjustment.

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2 An alternative approach was used to estimate inputs to Cusheon Lake by Sprague (2007a). Both upstream lakes, Roberts and Blackburn, have almost no human habitations along their shores, so almost all the phosphorus inputs are from land runoff. By trial and error, a value of land runoff was established, so that it predicted the observed P concentration in Roberts Lake (runoff = 0.099 kg/ha). The same was done for Blackburn Lake (runoff = 0.079 kg/ha). Cusheon Lake has extensive build-up around its shores, so the land runoff could not be estimated directly by the same technique. The land runoff in the sub-basin of Cusheon Lake was taken as the average of the runoffs estimated for the two upstream lakes. That average is 0.089 kg/ha (calculated using additional significant digits).

Samples and flow measurements were complete on 130 days during the year, but were not taken daily. The interpolations to obtain daily values are thought to be reasonable but undoubtedly have errors. Errors might have been limited in scope because the interpretations were almost always for the declining phase of flow after a peak, when phosphorus levels tended to follow a gradual die-away pattern. Indeed it should be borne in mind that even daily measurements would have had deficiencies for assessing peaks and patterns, because changes in runoff events are sometimes very rapid.

If there were differences in the amounts of P running off the land in various parts of the basins, there was no way of ascertaining that from sampling at the culvert. For example, P runoff might be higher around Roberts Lake, which has been subjected to selective logging during the last few years. Undoubtedly the P runoff was lower in certain parts of the basins which had retained dense forest cover. The estimate represents an average for the mixed landscape in the upper Cusheon basin.

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We thank MB Laboratories Ltd. of Sidney B.C. for excellent work on the chemical analyses. Their reports were speedy and complete, and they gave the committee a generous reduction in analytical fees. The precision of their analyses proved to be excellent, as noted in the body of this report. Brett Korteling, GIS Coordinator for Islands Trust, Victoria, B.C., was most helpful in providing the map of drainage basins and the first authoritative estimates which we have had, for the surface areas of the basins.

We thank Deborah Epps, a biologist with the stewardship program of the Ministry of Environment, in Nanaimo, B.C., for analyzing duplicate samples, to tie in this work with her programs, and for providing all her data on water quality in the watershed. We are deeply indebted to Robert Aston of Salt Spring Island for his advice and data on precipitation, and thank him sincerely for help. We thank Dr. Rick Nordin (University of Victoria) for finding data on phosphorus in rainfall and for general advice. We much appreciate advice from Dr. Carol Kelly (Salt Spring Island) who detected an earlier error in modelling lakes, and Dr. Roxanne Vingarzan, atmospheric scientist with Environment Canada (Vancouver) who searched for information on chemistry of rainfall. Advice from hydrologists Warren Cooper (B.C. Ministry of Environment, Nanaimo, B.C.) and Charles Howard (Victoria) was also most helpful. Finally, we thank the other members of the Steering Committee for patience, so that these results could be incorporated into the final management plan.

REFERENCES

Aston, Robert 2006. Summary of 2005 Salt Spring weather. Gulf Islands Driftwood, 2006, Feb. 22 and March 01. Also personal communication, supplying data from Aston's record of 29 years of precipitation and temperature at Douglas Road, Salt Spring Island, B.C.

BC MSRM [B.C. Ministry of Sustainable Resource Management] 2006. Fisheries Inventory, Lake Survey. [Bathymetric maps of lakes in British Columbia] www.bcfisheries.gov.bc.ca/fishinv/lakesurvey [Accessed 2006.March.09]

Brett, M.T., S.E. Mueller and G.B Arhonditsis 2005. A daily time series analysis of stream water phosphorus concentrations along an urban to forest gradient. Environmental Management 35 (1): 56-71.

Cooper, Warren 2006. Personal communication. Hydrologist, B.C. Min. of Environment, Nanaimo, B.C.

CWMPSC [Cusheon Watershed Management Plan Steering Committee] 2007. Cusheon Watershed Management Plan. CWMPSC, Salt Spring Island, B.C. 81 p.

Dillon, P.J., and F.H. Rigler 1975. A simple method for predicting the capacity of a lake for development based on lake trophic study. J. Fish. Res. Board Can. 32: 1519-1531.

Dillon, P.J., K.H. Nicholls, W.A. Scheider, N.D. Yan, D.S. Jeffries, E. DeGrosbois, A. Nicholls, P.J. Scholer, and R.A. Reid 1986. Lakeshore capacity study. Trophic status component. Ontario Ministry of the Environment, Water Resources Branch, Aquatic Ecosystems Section. Report, May 1986. 89 p.

Drexel [Drexel University] 2005. The math forum @ Drexel. Drexel University, Philadelphia, Penna. http://mathforum.org/dr.math/faq/faq.circle.segment.html [Accessed 2005.March.07.]

Ellis, B.K. and J.A. Stanford 1988. Phosphorus bioavailability of fluvial sediments determined by algal assays. Hydrobiologica 160: 9-18.

Ellsworth, N. and C.D. Moodie 1964. Nutrient inputs in rainfall at nine sites in Washington state, 1962 and 1963. State of Washington, Agricultural Experimental Station. Interim Report on Project 1670. 9 p plus unnumbered tables and figures.

Environment Canada 2006. [Climate records, near Cusheon Lake and Sooke Lake.] www.climate.weatherofice.ec.ca/climateData/monthlydata_e. [Accessed 2006.March.06]

FAO [Food and Agriculture Organization of the United Nations] 1993. Field measurement of soil erosion and runoff. FAO Soils Bulletin, TO 848/E. FAO, Rome.

Gilliom, R.J. 1980. Estimation of background loadings and concentrations of phosphorus for lakes in the Puget Sound region, Washington. U.S. Dept. of Interior, Geological Survey, Open File Report of 80-328. 37 p. [Cited through Truscott 1981.]

Hatch, L.K, J.E. Reuter and G.R. Goldman 1999. Relative importance of stream-borne particulate and dissolved phosphorus fractions to Lake Tahoe phytoplankton. Canad. J. Fisheries and Aquatic Sciences 56: 2331-2339.

Hodge, W.S. 1995. Groundwater conditions on Saltspring Island. B.C. Min. Environment, Lands and Parks, Water Management Div., Hydrology Branch, Groundwater Section. Unnumbered report, 74 p.

Howard, Charles, P.Eng. 2006. Personal communication. Victoria, B.C. [Verbal advice from this long-time and well-known hydrologist.]

Johnson, A.H. 1979. Estimating solute transport in streams from grab samples. Water Resources Research 15: 1224-1228.

Korteling, B. 2006. [Outline maps of drainage basins of lakes in the Cusheon watershed, and calculations of the basin areas.] Provided to Cusheon Watershed Management Plan Steering Committee, March 2006. B. Korteling, G.I.S. Coordinator, Islands Trust, Victoria, B.C. Electronic file.

Nordin, R. 2006. Personal communication. [Phosphorus measured in precipitation at the Sooke reservoir] Dr. Rick Nordin, Senior Research Scientist, Environmental Management of Drinking Water, Dept. of Biology, Univ. of Victoria, Victoria, B.C.

Nordin, R.N., C.J.P. McKean, J.H. Wiens 1983. St. Mary Lake water quality: 1979-1981. Prov. of British Columbia, Ministry of Environment, Victoria, B.C. 120 p. [File: 64.080302]

Pacini, N. and R. Gächter 1999. Speciation of riverine particulate phosphorus during rain events. Biogeochemistry 47: 87-109.

Peterjohn, W.T. and D.L. Correll 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. Ecology 65: 1466-1475.

Sprague, J.B. 2007a. Apparent sources of phosphorus affecting Cusheon Lake, Salt Spring Island, B.C. Sprague Associates Ltd., 474 Old Scott Road, Salt Spring Island, B.C. Background report for the Cusheon Watershed Management Plan and Steering Committee, Salt Spring Island, B.C. , iv + 55 p.

Sprague, J.B. 2007c. Nine lakes on Salt Spring Island, B.C.: size, watershed, inflow, precipitation, runoff and evaporation. Sprague Associates Ltd., 474 Old Scott Road, Salt Spring Island, B.C. Background report for the Cusheon Watershed Management Plan and Steering Committee, Salt Spring Island, B.C., 19 p.

Sprague, J.B. 2007d. Phosphorus carried by small culverts into Cusheon Lake, Salt Spring Island, B.C.. Sprague Associates Ltd., 474 Old Scott Road, Salt Spring Island, B.C. Background report for the Cusheon Watershed Management Plan and Steering Committee, Salt Spring Island, B.C., 14 p.

Sprague, J.B. 2007e. Phosphorus content of certain creeks and lakes in the Cusheon Lake basin, Salt Spring Island, B.C. Sprague Associates Ltd., 474 Old Scott Road, Salt Spring Island. Background report for the Cusheon Watershed Management Plan and Steering Committee, Salt Spring Island, B.C., 18 p.

Truscott, S.J. 1981. Quantitative models for integrated land use and lake quality planning: applications in the Brannen and St. Mary Lakes watersheds, B.C. Master's thesis, Faculty of Interdisciplinary Studies, Simon Fraser Univ., Burnaby, B.C. 92 p.

University of Washington 2005. Stream discharge and channel measurements. University of Washington, College of Forest Resources, Seattle, Wash. Laboratory instructions for course FE 425/525, 4 p. http://www.cfr.washington.edu/classes.fe.425/labs/stramlab05.doc [Accessed 2006.March.03]

Vingarzan, R. 2006. Personal communication. Dr. Roxanne Vingarzan, Atmospheric Processes Scientist, Environment Canada, Vancouver, B.C.

Vingarzan, R., W. Belzer and R. Thomson 2003. Nutrient levels in the atmosphere of the Elk Creek Watershed, Chilliwack, BC (1999-2000). Environment Canada, Aquatic and Atmospheric Sciences Division, Vancouver, B.C. Tech. Rept # EC/GB-02-038. 74 p.

Watson, R.H. 2006. Water supply assessment. Draft report in preparation for the North Salt Spring Waterworks District, Salt Spring Island, B.C. 25 p.

Zeman, L.J. and O. Slaymaker 1978. Mass balance model for calculation of ionic input loads in atmospheric fallout and discharge from a mountainous basin. Hydrological Sciences Bull. 23: 103-117. [Cited through Truscott 1981.]

Appendix 1. Data for survey of phosphorus in Blackburn Creek at Blackburn Road.
Explanatory notes at bottom and in text.

Month and day	Time	Precipitation, mm				Flow (= discharge)			Total phosphorus		Dissolved P	
		Old Scott Road	Total month OSR	Aston	Total month, Aston	Culvert Depth cm	Calculated and interpolated		Daily mean ug / L	grams per day	ug/L	Ratio TDP to TP
							L/sec	m3/day				
Aug 1							0.3	22.9	13.0	0.30		
2							0.3	22.9	13.0	0.30		
3		T					0.3	22.9	13.0	0.30		
4				1.3			0.3	22.9	13.0	0.30		
5						1.5	0.3	22.9	13.0	0.30		
6	15.00	7.0		23.1		3.1	3.1	264.9	103.0	27.29	97.7	94.9%
7							1.6	138.2	52.6	7.27		
8							0.9	77.8	33.2	2.58		
9							0.5	43.2	24.0	1.04		
10							0.4	34.6	18.3	0.63		
11							0.3	25.9	15.2	0.39		
12							0.3	25.9	13.5	0.35		
13							0.3	25.9	13.2	0.34		
14							0.3	25.9	12.9	0.33		
15							0.3	25.9	12.9	0.33		
16							0.3	25.9	12.9	0.33		
17							0.3	25.9	12.9	0.33		
18							0.3	25.9	12.9	0.33		
19							0.3	25.9	12.9	0.33		
20							0.3	25.9	12.9	0.33		
21				17.8			0.3	25.9	12.9	0.33		
22	13.00	11.0		1.0			1.0	86.4	24.3	2.10		
23							0.6	51.8	16.4	0.85		
24		3.0		9.1			1.3	112.3	30.1	3.38		
25	11.30	18.5		21.8		3.3	3.5	305.5	45.9	14.02	35.2	76.7%
26	11.00	5.5		2.3		2.2	1.2	102.9	30.5	3.14		
27							0.7	60.5	23.1	1.40		
28							0.4	34.6	19.2	0.66		
29							0.3	25.9	17.1	0.44		
30							0.3	25.9	15.7	0.41		
31			45.0		76.5		0.3	25.9	14.8	0.38		
Sept 1	7.00	1.0		4.3			0.7	57.9	28.8	1.67		
2		2.0					1.5	129.6	37.9	4.91		

Month and day	Time	Precipitation, mm				Flow (= discharge)			Total phosphorus		Dissolved P	
		Old Scott Road	Total month OSR	Aston	Total month, Aston	Culvert Depth cm	Calculated and interpolated L/sec	Calculated and interpolated m3/day	Daily mean ug / L	grams per day	ug/L	Ratio TDP to TP
3							0.9	77.8	25.6	1.99		
4							0.7	60.5	20.2	1.22		
5							0.6	51.8	17.0	0.88		
6							0.5	43.2	15.0	0.65		
7							0.4	34.6	13.6	0.47		
8				4.6			0.4	34.6	13.3	0.46		
9		4.0					2.8	241.9	31.1	7.52		
10				1.3			1.0	86.4	20.4	1.76		
11	11.30	21.5		21.3		2.6	2.0	173.6	32.3	5.61		
12							4.0	345.6	47.4	16.38		
13		2.5		15.7			1.9	164.2	31.9	5.24		
14	16.00	4.5		0.5		2.6	1.8	159.3	24.4	3.89		
15	10.30	12.0		17.8		3.4	4.0	342.5	47.6	16.31		
16				1.3			4.6	397.4	57.6	22.89		
17	10.30	7.5				3.3	3.7	317.5	36.0	11.43		
18		2.0		6.6			2.0	172.8	25.8	4.46		
19		1.5		4.8			1.3	112.3	19.9	2.24		
20							1.1	95.0	16.2	1.54		
21							1.0	86.4	14.1	1.22		
22				2.8			0.8	69.1	13.4	0.93		
23		2.5		0.3			1.8	155.5	27.8	4.32		
24							1.1	95.0	19.4	1.84		
25							0.9	77.8	16.6	1.29		
26							0.8	69.1	15.0	1.04		
27							0.8	69.1	14.4	1.00		
28	14.00					2.0	0.8	70.7	14.3	1.01		
29							0.8	69.1	14.3	0.99		
30			61.0		81.3		0.7	60.5	14.3	0.86		
Oct 1							0.7	60.5	14.3	0.86		
2							0.7	60.5	14.3	0.86		
3							0.7	60.5	14.3	0.86		
4							0.7	60.5	14.3	0.86		
5	13.00			8.9		1.9	0.7	59.9	38.4	2.30		
6	11.00	10.2		1.8		2.5	1.7	146.0	28.9	4.21		
7		0.5					1.3	112.3	18.2	2.04		
8	14.45	8.0				3.3	3.5	305.5	35.5	10.85		
9		5.0		3.0			3.1	267.8	27.8	7.45		
10				0.5			2.7	233.3	22.4	5.23		
11				0.3			2.1	181.4	18.9	3.43		
12		0.3		0.5			2.0	172.8	16.3	2.82		

Month and day	Time	Precipitation, mm				Flow (= discharge)			Total phosphorus		Dissolved P	
		Old Scott Road	Total month OSR	Aston	Total month, Aston	Culvert Depth cm	Calculated and interpolated L/sec	Calculated and interpolated m3/day	Daily mean ug / L	grams per day	ug/L	Ratio TDP to TP
13							1.9	164.2	14.9	2.45		
14							1.7	146.9	14.0	2.06		
15							1.6	138.2	14.0	1.94		
16	11.30	0.3		0.5		2.7	2.2	190.7	17.1	3.26		
17	16.30	8.0		30.5		6.3	15.4	1328.5	103.0	136.83	39.8	38.6%
18	12.30	26.0		8.1		5.9	13.5	1165.9	23.1	26.93		
19	10.15	12.0		23.9		10.8	44.4	3833.1	104.0	398.64	33.3	32.0%
20	19.00	8.5				8.4	27.0	2335.5	55.0	128.45		
21	13.00					6.3	15.4	1328.5	31.7	42.11		
22		0.5					11.1	959.0	17.8	17.07		
23	18.00					4.8	8.7	752.0	11.8	8.87		
24				1.8			7.0	604.8	10.0	6.05		
25				8.6			5.8	501.1	10.0	5.01		
26		10.5		4.3			8.0	691.2	19.0	13.13		
27	18.00					6.3	15.1	1304.2	57.3	74.73		
28		T					12.1	1045.4	28.8	30.11		
29		0.5					10.0	864.0	15.3	13.22		
30	11.30	4.0		6.6		5.3	10.7	924.2	11.1	10.26		
31			94.2	0.3	99.6		8.2	708.5	11.0	7.79		
Nov 1		4.5		22.4			11.0	950.4	11.0	10.45		
2	8.30	38.0		23.6		19.2	130.2	11245.5	50.1	563.40	12.2	24.4%
3	9.00					14.0	73.0	6303.7	19.3	121.66	9.2	47.7%
4							54.0	4665.6	15.8	73.72		
5	8.30					10.2	40.1	3462.1	14.8	51.24	7.65	51.7%
6				4.6			30.0	2592.0	13.9	36.03		
7	9.30	10.5				9.4	33.9	2928.4	15.4	45.10		
8							31.0	2678.4	14.7	39.37		
9	12.00	1.0		0.5		7.6	22.6	1949.4	14.6	28.46		
10	11.30					6.3	15.1	1304.2	13.9	18.13		
11							11.0	950.4	13.4	12.74		
12							7.5	648.0	13.0	8.42		
13		1.0		2.0			8.0	691.2	12.7	8.78		
14	13.00	2.5		8.1		8.4	27.0	2335.5	16.2	37.84		
15	12.30	10.5				10.1	39.3	3397.4	15.8	53.68		
16	10.30			13.2		8.4	27.2	2351.6	12.1	28.45		
17	9.30	3.0				8.4	27.0	2335.5	9.0	21.04		
18	13.30	9.5		16.5		8.7	29.0	2501.9	11.3	28.27		
19	14.45	0.5				7.2	20.3	1751.0	11.2	19.61	9.59	85.6%
20							18.0	1555.2	10.9	16.95		
21	11.00					7.9	24.1	2082.9	12.1	25.20		

Month and day	Time	Precipitation, mm				Flow (= discharge)			Total phosphorus		Dissolved P	
		Old Scott Road	Total month OSR	Aston	Total month, Aston	Culvert Depth cm	Calculated and interpolated L/sec	Calculated and interpolated m3/day	Daily mean ug / L	grams per day	ug/L	Ratio TDP to TP
22		T		2.3			16.0	1382.4	11.3	15.62		
23		4.0		6.9			30.0	2592.0	13.9	36.03		
24	9.30	9.0		11.7		14.8	81.2	7013.5	21.8	152.89		
25		4.0		2.5			130.0	11232.0	36.2	406.60		
26	14.00					16.2	95.4	8238.6	20.5	168.89		
27		1.0					53.0	4579.2	14.0	64.11		
28	12.00					7.7	22.8	1966.3	11.4	22.32		
29				1.8			16.0	1382.4	9.6	13.27		
30		4.0	103.0	6.4	122.4		35.0	3024.0	13.5	40.82		
Dec 1	9.30	0.5		0.8		7.9	24.1	2082.9	10.8	22.50		
2		0.5		1.0			12.0	1036.8	10.8	11.20		
3							11.0	950.4	10.8	10.26		
4	11.00	11.0		24.1		11.8	52.8	4558.5	28.2	128.55		
5	11.00	12.0		4.3		13.6	69.2	5974.8	22.0	131.45		
6		1.0		10.4			69.0	5961.6	20.6	122.81		
7	11.30	13.5		15.2		19.8	137.1	11841.9	34.0	402.63	15.9	46.8%
8	11.30	12.0		21.8		27.5	245.3	21196.3	126.0	2670.74		
9	9.45	0.5		2.8		18.3	119.1	10290.1	31.2	321.05		
10	15.45	34.0		35.6		32.8	332.1	28690.9	64.7	1856.30	18.7	28.9%
11	12.00	2.0				25.5	215.7	18633.7	24.5	456.53		
12	12.00					19.3	130.6	11286.6	22.7	256.20		
13	14.00	T		2.5		15.2	84.8	7326.2	17.1	124.91		
14	13.30	12.5		10.4		16.1	94.3	8145.5	15.5	126.25		
15	13.00	0.5				14.0	73.2	6322.5	13.6	85.99		
16	13.00	1.0				16.2	95.4	8238.6	13.3	109.57		
17		2.2		3.8			76.0	6566.4	12.9	84.71		
18	16.00	6.5		7.6		13.6	69.3	5990.3	12.5	74.88		
19							66.0	5702.4	12.6	71.85		
20	12.00					10.8	44.9	3876.1	11.5	44.58		
21		T					42.0	3628.8	10.9	39.55		
22	11.30					10.6	42.7	3685.9	11.2	41.28		
23	16.00					10.6	43.0	3712.8	10.5	38.98		
24							44.0	3801.6	10.5	39.92		
25	13.00	13.5		19.3		10.8	44.9	3876.1	16.7	64.73		
26	14.00	4.0		12.4		16.5	98.6	8520.6	20.4	173.82		
27	15.00					17.0	103.6	8950.6	14.3	127.99		
28	13.30					14.8	80.3	6938.5	15.2	105.47		
29	16.00	4.0		6.9		14.4	76.7	6627.6	20.4	135.20		
30		1.0		5.6			71.0	6134.4	16.3	99.99		
31	16.30	1.0	133.2		184.7	13.6	69.0	5957.5	14.3	85.19		

Month and day	Time	Precipitation, mm				Flow (= discharge)			Total phosphorus		Dissolved P	
		Old Scott Road	Total month OSR	Aston	Total month, Aston	Culvert Depth cm	Calculated and interpolated L/sec	Calculated and interpolated m3/day	Daily mean ug / L	grams per day	ug/L	Ratio TDP to TP
Jan 1		7.0		7.1			104.0	8985.6	27.2	244.41		
2							70.0	6048.0	21.6	130.64		
3	11.00					11.2	47.6	4112.5	18.0	74.02		
4							38.0	3283.2	15.9	52.20		
5		T					31.0	2678.4	15.8	42.32		
6	16.30	1.0		2.8		9.3	33.2	2867.9	20.5	58.79		
7		12.0		29.7			180.0	15552.0	49.6	771.38		
8		15.5		24.9			233.0	20131.2	76.4	1538.02		
9							195.0	16848.0	51.5	867.67		
10							127.0	10972.8	36.2	397.22		
11							69.0	5961.6	26.0	155.00		
12	13.00					9.6	35.5	3064.3	18.2	55.77		
13							25.0	2160.0	14.5	31.32		
14							19.0	1641.6	13.7	22.49		
15	12.00					7.2	19.9	1717.7	14.1	24.22	14.0	99.3%
16		5.6		21.6			100.0	8640.0	50.8	438.91		
17	13.30	18.0		35.6		41.3	488.4	42193.9	166.0	7004.19	23.9	14.4%
18	14.00	26.0		17.8		44.6	553.8	47849.7	153.0	7321.00	19.3	12.6%
19	16.00	7.5		17.8		44.6	553.8	47849.7	178.0	8517.24	9.64	5.4%
20	13.00	15.0		9.9		18.8	125.1	10804.6	77.5	837.36		
21	16.00	1.5		1.5			56.0	4838.4	57.7	279.18		
22		47.0		41.1			664.6	57419.6	151.0	8670.36		
23	14.00	27.0		10.2			540.0	46656.0	119.0	5552.06		
24	15.00	0.5					285.0	24624.0	40.7	1002.20		
25	15.30						163.0	14083.2	32.1	452.07		
26	14.45			2.0		15.0	91.5	7905.6	29.5	233.22		
27	16.00	2.0				16.0	93.0	8038.2	19.7	158.35		
28	16.30					12.1	55.4	4785.1	17.7	84.70		
29	13.15	1.0				12.1	55.4	4785.1	12.0	57.42		
30	13.30	12.0		12.2		14.0	73.2	6326.7	20.1	127.17		
31	12.30	1.3	199.9	0.8	235.0	13.1	64.0	5533.9	13.8	76.37		
Feb 1	17.15					11.1	47.2	4081.6	13.0	53.06		
2	16.30					11.1	47.2	4081.6	11.9	48.57		
3	16.00					10.2	39.6	3425.3	11.6	39.73		
4	11.30	15.5		18.3		16.5	98.3	8491.3	24.1	204.64		
5		1.0					90.0	7776.0	17.9	139.19		
6	12.00	7.5		24.9		17.9	114.7	9909.2	25.5	252.68		
7	16.45	11.3		1.0		18.9	126.2	10901.5	16.9	184.24		
8	17.30					17.9	114.7	9909.2	22.6	223.95		
9	17.00					16.0	93.0	8038.2	11.9	95.65		

Month and day	Time	Precipitation, mm: Old Scott Road	Total month OSR	Aston	Total month, Aston	Flow (= discharge): Culvert Depth cm	Calculated and interpolated: L/sec	m3/day	Total phosphorus: Daily mean ug / L	grams per day	Dissolved P: ug/L	Ratio TDP to TP
10	13.45					19.2	129.7	11206.4	22.1	247.66		
11							122.0	10540.8	13.6	143.35		
12				1.5			113.0	9763.2	10.8	105.44		
13	17.00	1.0				17.0	104.2	8998.9	9.3	84.05		
14							97.0	8380.8	9.3	77.94		
15							89.0	7689.6	9.3	71.51		
16	13.30					15.0	82.7	7148.9	9.3	66.49		
17	10.30					15.0	82.7	7148.9	9.3	66.27		
18							67.0	5788.8	9.3	53.84		
19							61.0	5270.4	9.3	49.01		
20	13.00					12.0	54.5	4706.1	9.3	43.67		
21							50.5	4363.2	9.3	40.58		
22							46.0	3974.4	9.3	36.96		
23							41.0	3542.4	9.3	32.94		
24	11.30					10.0	38.4	3317.4	11.3	37.49		
25							35.0	3024.0	10.4	31.45		
26							33.0	2851.2	9.7	27.66		
27	16.00					9.0	31.3	2700.6	9.4	25.41		
28			36.3	0.8	46.5		30.5	2635.2	9.4	24.77		
Mar 1		6.0		9.1			64.0	5529.6	13.5	74.65		
2	0.00	1.0		1.3		11.0	46.1	3986.6	10.4	41.46		
3		T					37.0	3196.8	10.4	33.25		
4							28.0	2419.2	10.4	25.16		
5							21.0	1814.4	10.3	18.69		
6							17.0	1468.8	10.3	15.13		
7	15.30	1.0		1.3		7.0	18.9	1632.9	10.3	16.82	9.74	94.6%
8	14.00			0.5		9.0	31.3	2700.6	12.0	32.41		
9	13.00	3.0		2.0		10.0	38.4	3317.4	14.2	47.11		
10		T					37.0	3196.8	12.9	41.24		
11							29.5	2548.8	12.0	30.59		
12							22.5	1944.0	11.3	21.97		
13							19.0	1641.6	10.9	17.89		
14	15.30					7.0	18.9	1632.9	10.8	17.64		
15	12.00			3.6		5.0	9.3	804.6	10.8	8.69	10.1	93.5%
16	14.00	4.2		0.5		22.0	165.8	14321.7	59.6	853.57	13.1	22.0%
17	18.00	1.0		0.5		15.0	82.7	7148.9	16.0	114.03		
18		T		1.0			36.0	3110.4	11.7	36.39		
19	13.00	0.3		6.4		7.5	21.7	1878.3	19.0	35.69		
20	16.00	26.0		25.7		15.0	82.7	7148.9	31.8	227.34		
21		3.0		0.5			196.0	16934.4	54.3	919.54		

Month and day	Time	Precipitation, mm: Old Scott Road	Precipitation, mm: Total month OSR	Precipitation, mm: Aston	Precipitation, mm: Total month, Aston	Flow (= discharge): Culvert Depth cm	Flow: Calculated and interpolated L/sec	Flow: Calculated and interpolated m3/day	Total phosphorus: Daily mean ug / L	Total phosphorus: grams per day	Dissolved P: ug/L	Dissolved P: Ratio TDP to TP
22	14.00					14.5	77.7	6713.4	13.9	93.32		
23							49.0	4233.6	10.9	46.15		
24							31.0	2678.4	10.3	27.59		
25							17.0	1468.8	10.0	14.69		
26	11.30	28.5		34.3		23.0	179.4	15496.7	33.5	519.14		
27	18.00	7.0		9.4		24.0	193.4	16706.1	36.1	603.09		
28	16.15	1.7		2.8		25.0	207.7	17949.0	32.9	590.52	11.4	34.7%
29	16.00	5.9		4.6		23.5	186.3	16097.2	20.9	336.43		
30	18.30	3.5		5.8		20.0	139.8	12078.8	13.5	163.06		
31	14.00	T	92.1	7.9	117.1	23.0	179.4	15496.7	22.2	344.03		
Apr 1	11.00	14.2		11.4		24.0	193.4	16706.1	17.3	289.02		
2	13.30	2.0		1.3		22.0	165.8	14321.7	11.8	169.00		
3		4.9		4.1			162.0	13996.8	11.1	155.36		
4	10.30					20.5	146.1	12625.8	10.7	135.10		
5	16.00			7.4		18.0	115.6	9986.1	14.5	144.80		
6	14.30	16.5				22.5	172.5	14904.8	10.7	159.48		
7	18.00	1.0		11.9		21.0	152.6	13182.0	11.4	150.28		
8	12.00	2.0		5.1		19.0	127.5	11013.2	9.6	105.84		
9							102.0	8812.8	9.2	81.08		
10				0.8			83.0	7171.2	9.1	65.26		
11	20.00	9.0		0.8		17.0	104.2	8998.9	9.4	84.72		
12	17.00	1.0		2.8		15.0	82.7	7148.9	10.8	77.21		
13		1.5		0.5			57.0	4924.8	10.0	49.25		
14							43.0	3715.2	9.7	36.04		
15				4.1			36.0	3110.4	9.7	30.17		
16	14.00	14.0		15.0		15.0	82.7	7148.9	11.5	82.21	8.89	77.3%
17		0.5		1.3			93.0	8035.2	14.7	118.12		
18							63.0	5443.2	11.4	62.05		
19	17.00					23.0	179.4	15496.7	40.5	627.62	12.0	29.6%
20	11.00					15.0	82.7	7148.9	11.6	82.93		
21							52.0	4492.8	9.5	42.50		
22	16.00					10.0	38.4	3317.4	8.7	28.70		
23							34.0	2937.6	8.5	24.91		
24		T					30.0	2592.0	8.5	21.98		
25							29.0	2505.6	8.8	22.07		
26							27.0	2332.8	9.4	22.00		
27							25.5	2203.2	10.7	23.57		
28							24.0	2073.6	12.7	26.33		
29	11.00					8.0	24.7	2138.2	16.8	35.92		
30		T	66.6		66.3		23.0	1987.2	16.1	31.99		

Month and day	Time	Precipitation, mm				Flow (= discharge)			Total phosphorus		Dissolved P	
		Old Scott Road	Total month OSR	Aston	Total month, Aston	Culvert Depth cm	Calculated and interpolated		Daily mean ug / L	grams per day	ug/L	Ratio TDP to TP
							L/sec	m3/day				
May 1							22.0	1900.8	15.8	30.03		
2		0.3		1.0			21.0	1814.4	15.6	28.30		
3		1.0					29.0	2505.6	21.3	53.37		
4							27.0	2332.8	17.1	39.89		
5		T					23.0	1987.2	14.5	28.81		
6							20.0	1728.0	12.8	22.12		
7							18.0	1555.2	11.8	18.35		
8							16.0	1382.4	11.5	15.90		
9		2.0		3.8			19.0	1641.6	15.1	24.79		
10							15.0	1296.0	13.1	16.98		
11							12.0	1036.8	11.9	12.34		
12							10.5	907.2	11.3	10.25		
13							10.0	864.0	11.1	9.59		
14	11.00	0.8		1.5		5.0	9.3	804.6	11.0	8.85		
15	12.15	9.0		6.9		5.0	9.3	804.6	21.1	16.98		
16	16.00	T		5.6		6.0	13.7	1187.3	15.2	18.05		
17	14.45	3.2		0.5		5.5	11.4	987.9	11.6	11.46		
18	13.30	8.0		9.4		6.0	13.7	1187.3	15.2	17.99		
19		1.5		3.6			27.5	2376.0	20.1	47.76		
20	12.00	3.2		5.1		7.0	18.9	1632.9	11.3	18.45		
21	11.30	T				9.0	31.3	2700.6	22.4	60.49		
22		0.7		2.8			17.5	1512.0	13.6	20.56		
23		1.0		0.5			19.0	1641.6	14.7	24.13		
24							13.5	1166.4	13.1	15.28		
25							11.0	950.4	12.5	11.88		
26							9.5	820.8	12.1	9.93		
27							8.0	691.2	11.8	8.16		
28	10.00					4.5	7.4	638.0	11.6	7.40		
29							6.5	561.6	11.6	6.51		
30							6.0	518.4	11.5	5.96		
31		1.0	31.6	5.3	46.0		9.5	820.8	14.0	11.49		
Jun 1		1.0					11.0	950.4	22.8	21.67		
2		1.5					8.5	734.4	16.0	11.75		
3							6.5	561.6	13.2	7.41		
4	12.00					4.0	5.7	488.6	11.5	5.62		
5							5.1	440.6	10.9	4.80		
6		T					4.7	406.1	10.7	4.35		
7							4.5	388.8	10.7	4.16		
8		3.0		3.8			7.4	639.4	14.7	9.40		
9		1.0		0.5			9.2	794.9	20.4	16.22		

Month and day	Time	Precipitation, mm Old Scott Road	Total month OSR	Aston	Total month, Aston	Flow (= discharge) Culvert Depth cm	Calculated and interpolated L/sec	m3/day	Total phosphorus Daily mean ug / L	grams per day	Dissolved P ug/L	Ratio TDP to TP
10							9.0	777.6	15.8	12.29		
11	11.30					4.5	7.4	638.0	13.7	8.74		
12		1.5		3.8			6.2	535.7	12.2	6.54		
13		1.8		3.0			7.5	648.0	14.1	9.14		
14							6.5	561.6	12.2	6.85		
15		1.0					6.1	527.0	11.3	5.96		
16							4.9	423.4	11.1	4.70		
17	14.30	8.5		14.0		5.0	9.3	804.6	20.8	16.74		
18	16.00	5.0				4.0	5.7	488.6	16.2	7.92		
19							4.5	388.8	14.1	5.48		
20							3.5	302.4	12.8	3.87		
21		T					2.8	241.9	11.9	2.88		
22		2.2		3.0			3.3	285.1	11.3	3.22		
23							3.0	259.2	10.7	2.77		
24							2.3	198.7	10.7	2.13		
25						2.5	1.7	149.8	10.7	1.60		
26							1.5	129.6	10.7	1.39		
27	21.30	6.0		13.7		4.5	7.4	638.0	16.9	10.78	14.7	87.0%
28		1.0					5.3	457.9	14.5	6.64		
29							3.1	267.8	12.6	3.37		
30		T	33.5		41.9		2.1	181.4	11.5	2.09		
Jul 1							1.2	103.7	11.0	1.14		
2						2.0	0.9	75.8	10.9	0.83		
3	17.30					2.5	1.7	149.8	14.8	2.22		
4							1.1	95.0	12.4	1.18		
5		T		6.9			0.9	77.8	11.6	0.90		
6	11.00	14.0		6.6		3.0	2.8	243.8	20.3	4.94		
7							9.8	846.7	30.5	25.82		
8	12.30	2.5		5.1		4.0	5.7	488.6	18.7	9.14		
9		2.5		1.0			5.0	432.0	16.2	7.00		
10		0.7					4.7	406.1	14.8	6.01		
11		0.4		1.0			4.2	362.9	14.0	5.08		
12				0.8			3.7	319.7	13.5	4.32		
13							3.3	285.1	13.2	3.76		
14							3.0	259.2	13.0	3.37		
15				1.3			2.7	233.3	12.9	3.01		
16	11.00	0.6				3.0	2.8	243.8	17.5	4.27		
17							2.7	233.3	16.2	3.78		
18							2.2	190.1	15.2	2.89		
19							1.9	164.2	14.5	2.38		

Month and day	Time	Precipitation, mm: Old Scott Road	Precipitation, mm: Total month OSR	Precipitation, mm: Aston	Precipitation, mm: Total month, Aston	Flow (= discharge): Culvert Depth cm	Flow: Calculated and interpolated L/sec	Flow: Calculated and interpolated m3/day	Total phosphorus: Daily mean ug / L	Total phosphorus: grams per day	Dissolved P: ug/L	Dissolved P: Ratio TDP to TP
20							1.4	121.0	13.9	1.68		
21							1.1	95.0	13.7	1.30		
22							0.9	77.8	13.4	1.04		
23	17.30					2.0	0.9	75.8	21.2	1.61	16.9	79.7%
24						1.4	0.2	15.0	18.3	0.27		
25							0.3	25.9	16.4	0.43		
26							0.2	17.3	15.1	0.26		
27							0.2	17.3	14.3	0.25		
28							0.1	8.6	13.7	0.12		
29							0.1	8.6	13.2	0.11		
30							0.1	8.6	13.0	0.11		
31			20.7		22.6		0.1	8.6	12.9	0.11		
			Yearly pptn = 917.0 mm		Yearly pptn = 1139.7 mm		Average = 46.6 L/sec Yearly total = 1,470,762 m3		Yearly total TP = 68.5 kg. Arithmetic mean of daily conc. of TP = 20.7 ug/L Flow-weighted average = kg/yr of TP divided by m3/yr of flow = 46.8 ug/L Average ratio of TDP/TP = 53.6%			

Notes.

* Estimates of flow were made on those days for which there is an entry in the column "Culvert depth". Other values for flow were graphic interpolations. On those same days, the water was sampled and phosphorus was measured. Exceptions, when flow was measured but not phosphorus, were on the following days: Sep 14, 21, 28, Oct 20, 21, 27, Nov. 10, Dec 23, Feb 10, 16, Mar 8, 9, 14, 19, May 14, Jun 25, and Jul 2, 24.
* August 5, Blackburn Crk had been running slightly but not between Blackburn and Cusheon Lakes.
* August 22, Flow estimate approximate, leakage from holes at end of pipe. No flow reached Blackburn Lake.
* August 25, validation of flow by measurement in creek = 2.7 L/sec.
* Sept 1, flow measured by collecting the volume discharged, 4L/6 sec =0.67 L/sec.
* Oct. 6, TP is average of 38.4 and 19.3
* Nov. 2, the TP is an average of 54.4 and 45.8 taken at 08.30 and 12.00 hours.
* Nov. 9 TP is average of 12.6, 15.5, 14.3, 14.8, 15.1 and 15.3
* Jan. 17-19, the flow of water was described as "muddy and fierce" and "muddy" until Jan. 23. Culvert was broken by Jan. 21, probably by Jan. 20.
* Jan. 23, flow estimate made in creek, 540 L/sec after applying drag factor 0.75
* Jan. 26, water noted as "fairly clear". Flow is mean of approximate depth in culvert (73.3), and approximate measurement in creek (107).
* Feb. 10, validation of flow by measurement in creek of 107 L/sec.
* May 21 , the TP is average of replicates 22.4, 24.9, 19.9

APPENDIX 2. PRECIPITATION, EVAPORATION, AND EFFECTS ON CREEK FLOW

Precipitation was measured daily during the year, to help interpret changes in creek flow, particularly between actual measurements of flow. To tie in this single year of measurement, historic values were obtained for other sites, as described below.

Methods for daily values during 2004-05

Daily measurements were made in an open area at 474 Old Scott Road, the residence of one of the volunteers (J.B.S.). This location is 5.1 km northeast of the centre of the basin that drains to the culvert. Measurements were made at approximately 8 a.m. each day, and the value was used as the data-point for that day. Thus the value for a given day includes precipitation that fell for the preceding 24 hours. That seems to be a suitable time of day, since there is probably a lag of some hours as runoff builds up during a rainfall event, then flows downstream to the culvert where we measured the flow later in the morning or in early afternoon.

Precipitation measurements were made with a commercial gauge designed for home use, with a square opening 4 cm on a side. The depth of snowfall was divided by 10 following standard meteorological practice including that of the Environment Canada weather service.

Other alternatives for measuring daily precipitation were considered less satisfactory. Because of travel plans of volunteers and other factors, it did not seem feasible to measure precipitation within the watershed. Environment Canada once had a weather station right beside Cusheon Lake but it ceased operation in 1999 so it is not useful as a daily record during the study. The records were from 1977 to 1999, taken at two successive locations on Cusheon Lake Road, 2.5 and 3.9 km easterly from the centre of the drainage area that concerns us here.

Another possible set of precipitation measurements were taken at 134 Douglas Road by Robert Aston. Measurements made by Aston were considered to be the most useful and appropriate *historical* records for the upper Cusheon watershed, in a report that compared the weather records from various locations on Salt Spring Island (Sprague 2007c). The Douglas Road location has meticulous measurements of weather for three decades (Aston 2006; see Table 2 in section 3 of the main text). The location is closest to the centre of the drainage area relevant to the culvert, being 2.1 km to the north.

However, the Douglas Road measurements were less suitable for the present survey. They were made at approximately 4 p.m. each day, and it appeared that the 8 a.m. measurements from Old Scott Road (described above) were better for correlating with creek flow on a given day, for the reasons which follow.

The Douglas Road measurements were made towards the end of the afternoon, after the usual time of sampling the creek (mid-morning to early afternoon). Any rain falling after the creek had been sampled would be credited to that day, but it would not have contributed to the flow measured earlier. The 8 a.m. measurements of rainfall at Old Scott Road should relate better to flow measurements made a few hours later. That appeared to be true when the day-by-day measurements of rainfall at the two locations were compared to the measurements of flow, using monthly graphs. The patterns of rain and snowfall at the two locations usually confirmed each other, although absolute amounts sometimes differed. However there were exceptions for occasional rainfall events, when Douglas Road showed the rainfall on the day before the record at Old Scott Road, and *ahead* of the freshet measured in the creek. In those cases, the rain (or snow) came during the day between 8 a.m. and 4 p.m., was measured at 4 p.m. at Douglas Road, and at 8 a.m. the following day for this study. Those particular 4 p.m. measurements plotted themselves the day before the apparent rise in flow, while the 8 a.m. measurements were on the same day as the freshet. Therefore, the morning measurement of precipitation appeared to be more suitable for the present purposes.

Accordingly, the 8 a.m. measurements from Old Scott Road were used in this study, for assisting in the interpretation of flow pattern. Although these measurements from Old Scott Road showed about 18% less precipitation (column 1 of Table 2) than at the Douglas Road location (column 2), the patterns were similar with the exceptions noted above, and the pattern is more important for interpreting flow changes than is the absolute amount of precipitation.

Average yearly precipitation

The long-term average at Cusheon Lake (column 6 of Table 2) is only 5.5% higher than the average for the same 22 years at Douglas Road (column 5). The correlation coefficient between the two sets of data is 92.8% which is good.

The obvious choice for historical data might seem to be the Environment Canada records which were obtained within the watershed. However, in view of the small difference between the two sets of data, it has been decided to use the Douglas Road data for historical yearly and monthly precipitation. The site is closer to the basin of interest in this study than are the weather sites on Cusheon Lake Road. The Environment Canada website that posts the Cusheon Lake Road data does not necessarily inspire full confidence. The totals for thirteen of the twenty-two years are marked as “Estimate”, including one marked “Incomplete”. Environment Canada apparently had problems recording data in some months of some years. It is not clear how the weather office manipulated the data to make the estimates. On the other hand, the Douglas Road values appear to be reliable and absolute. The author has seen the original records, the collecting equipment, and talked to Robert Aston about his procedures. The measurements seem precise and regular, and in fact the records indicate fastidious measurement and recording. Accordingly, the average for the longest period at Douglas Road (29 years, column 3 of Table 2) is used as an estimate of typical rainfall near the Cusheon watershed. The value is 980 mm per year, the same as the 22-year average (column 4).

Evaporation from the lakes

When modelling the flow of water through the Cusheon chain of lakes, evaporation of water from the lakes must be considered (along with runoff from the soil, see below). A small part of the water that flows into a lake, or falls on its surface, is removed from the system by evaporation. That must be allowed for (a) when considering lake levels, (b) when mathematically modelling the amounts of water that flow through the Cusheon chain of lakes, or (c) when otherwise evaluating flows.

Lake levels. If one is considering the levels of water in a lake, the evaporation is of no concern when water is flowing out of the lake. Any evaporation would simply reduce (slightly) the amount flowing out of the lake. But in some summer months, if there is no flow out of a lake, the evaporation is a factor in determining the lake level. Hodge (1995) showed that the most likely dry months are from June to October.

Evaporation has recently been estimated for St. Mary Lake on Salt Spring Island by Watson (2006). He worked from temperature records for the period 1976 to 2005. The estimates were based on relationships established from evaporation at Saanichton, on the Saanich peninsula near Salt Spring. The relationship was described by Hamilton et al. (1998) who made estimates of evaporation for 20 years of data up to 1996. Table A3.1 uses the evaporation estimates of Watson (2006), and the standard long-term record of precipitation from Aston (2006). The monthly precipitation records were not available for the whole period, so the 20-year period is used (from Table 2).

The right-hand column of Table A3.1 shows precipitation minus evaporation *(net precipitation)* for the five months June to October when the outflow is most likely to be dry. It is seen that a net loss of water through evaporation would be expected for an overlapping different period of five months, May to September. However, in May, Cusheon Lake is apparently still overflowing from its past supply of water (Hodge 1995).

Conversely, in October, the lake is not overflowing because it still has to build up after the summer lowering. So evaporation continues to affect lake level in October, even though there is more rainfall than evaporation. (It must be emphasized again that these are statements for long-term averages and will not necessarily apply to any given year.)

Table A3.1. **Estimate of net evaporation from lakes in the Cusheon chain.** Precipitation is a 20-year average provided by Aston (2006), and evaporation is a 30-year average estimated by Watson (2006). All values are in millimetres.

Month	Precipitation	Evaporation	Net value	Total negative
January	160.8	11.7	149.1	
February	101.3	18.0	83.3	
March	92.5	30.1	62.4	
April	60.5	48.9	11.6	
May	44.5	73.8	- 29.3	
June	29.2	97.3	- 68.1	- 297.7
July	19.8	118.7	-98.9	
August	25.4	120.7	- 95.3	
September	22.9	94.5	- 71.6	
October	94.5	58.3	36.2	
November	164.3	27.7	141.8	
December	164.3	13.1	151.3	
Total	980.0	712.8	322.4	

Accordingly, evaporation is calculated for June to October, the five months with probable lack of overflow. Summing for these months gives 297.7 mm of net evaporation, i.e., about 30 cm or 0.3 metres. Actually, the low point of lake levels would be expected in September, before October's positive net evaporation value. The sum of negative values to September would be 333.9 mm, or almost exactly one-third of a metre. We might expect Cusheon Lake to have its water level lowered by approximately one-third of a metre during the summer, in an average year.

Thus, evaporation is significant in the Cusheon watershed. It averages about 0.713 metres for the whole year (column 3 of Table A3.1). Any given surface area of lake would receive almost one metre of rain and snow during the year, but it would evaporate about 70% of that.

Evaporation and yearly flow in creeks

Different logic comes into play if one is concerned about how much water flows through the three-lake Cusheon system. For example, the total amount of water that flows out of Cusheon Lake would be reduced by the *total* amount of evaporation from all the lake surfaces during the whole year. (Evaporation from creek surfaces has been neglected here as it would be small.) It would not be merely a question of the net evaporation during the warm months. If the lake were overflowing (most months of the year), the amount flowing out would be reduced by the amount that was evaporating -- a slight effect but a real one. As calculated above, if the lake was not overflowing during the summer, evaporation would lower the lake level. It would take more water to fill it when autumn came, and hence there would be slightly less overflow.

The estimate of total evaporation is used in the mathematical simulation (model) of flow in the Cusheon chain (Table 3 in the main text). The model indicated that the natural flow of water through Blackburn culvert would be about 1,735,000 cubic metres per year. The outflow from Cusheon Lake was estimated as an average of 125.6 L/sec., adjusted to 118 L/sec. in a typical year, and allowing for human withdrawals.

APPENDIX 3. PHOSPHORUS IN PRECIPITATION

It is desirable to know the P content of rain and snow falling directly onto the surface of a lake. The information is needed elsewhere in this report, to model the inputs to Roberts Lake. There are only a few measurements of P in precipitation for this part of the Pacific coastal region.

One excellent study measured nutrients in the rain and air near Chilliwack B.C. (Vingarzan et al. 2003). The study found an average of 7.2 μg/L of P in precipitation during the year. For the average amount of precipitation in the Cusheon watershed (0.98 m), that provides an **estimate of 0.071 kg/year** of phosphorus onto each hectare of lake and land surface.

The senior author of the report, Dr. R. Vingarzan (2006), kindly searched for other published information. No other recent studies were found for coastal British Columbia. Her opinion on relevance of the Chilliwack value was that coastal precipitation would not have more phosphorus, but it was uncertain whether there would be less. The estimate from Chilliwack has been taken as a useful value.

Unpublished information from a state-of-the-art rain gauge at the Sooke reservoir near Victoria was provided by Dr. Richard Nordin of the water research group at University of Victoria. The total P in precipitation during 14 months was 0.136 kg/hectare • yr (Nordin 2006). Adjusting downwards to the Cusheon rainfall from the high amount of 1.659 m at Sooke Lake (Environment Canada 2006) yields another useful **estimate of 0.065 kg/ha of P in 12 months** for the Cusheon watershed.

In older work, an area north of Vancouver had 0.40 kg/ha • yr of dissolved and particulate P in its very heavy precipitation of 4.50 m/yr (Zeman and Slaymaker (1978). Adjusting downwards to the Cusheon precipitation yields an **estimate of 0.087 kg/ha • yr**.

Another older report for a coastal area of Washington state reports 0.13 kg/ha • yr of dissolved P in precipitation of 0.90 m (Ellsworth and Moodie 1964). Adjusting that slightly upwards for the precipitation at Cusheon provides an estimate of 0.142 kg/ha • yr. However, Gilliom (1980) concludes that the dissolved P would only be 60% of the total P in the samples of Ellsworth and Moodie, so the **estimate becomes 0.24 kg/ha • yr** of total phosphorus.

The four estimates have been averaged to provide a value of 0.1147 kg/ha • yr (rounded to 0.11 kg/ha • yr) for P in the precipitation in the Cusheon basin, and that is used in modelling for this report.

APPENDIX 4. MEASURED FLOW OF BLACKBURN CREEK AT THE CULVERT

The general approach and techniques are in the main text, section 4, with supporting details here.

Measuring depth or width at the culvert

The culvert had an inside diameter of 1.20 metres. The standard and most frequent measurement at the culvert was the depth of water in the deepest (central) part of the culvert's cross-section (Figure A4.1). A measuring scale was attached to a long stick, and the person making the measurement stood upstream of the culvert, on the bank of the creek so as not to interfere with the flow pattern. The stick was extended into the culvert, and the measurement made at about 1.5 to 2 metres downstream from the mouth of the culvert. At that point, the water level was generally flat and free from the initial small standing waves near the mouth of the culvert.

During the early period of the study, from August to mid-January, the width of the water surface in the culvert was measured instead of the depth. The width was the distance across the water surface from wall to wall of the culvert (Figure A4.1). That width was taken at about half a metre up inside the culvert from its downstream mouth, where the flowing surface was flat. The corresponding depth was obtained by standard trigonometric formulae, described below, and the relationship was checked by field measurements.

In mid-January, depth became the standard method of measurement, but until mid-February it was done by an undesirable technique. The investigator went 2 to 3 m into the upstream end of the culvert, then measured the depth upstream of himself, and that method required a correction (see below). Another potential source of variation was the four different people making measurements over the year.

Deliberate cross-checks were made among the various methods of measurement, and among the people. These checks were done at diverse stages of flow. In most cases the agreement was satisfactory. If not, a correction factor or correlation was established and applied to convert to the standard measurement of depth. Each relationship was fitted mathematically with a regression, all of which had good correlation coefficients (r-squared) of 92% or higher. If the regression indicated that a correction was desirable, it was applied in the preliminary stages of tabulation, using the formula of the regression. Thus, all measurements were converted to the standard one (depth). The details of these corrections are given below or else in background notes which are available from the author if required.

In particular, correction was made on those measurements which had been made by walking into the culvert. It became evident that the obstruction of the person's boots raised the water level in the culvert somewhat (about 3 cm for some commonly encountered flows). Therefore, a series of measurements were made at various stages of flow, to compare such depths "from inside" with the standard depth measured from outside with a stick. Linear regressions were calculated for the relationship of the measurements. The regression for correcting depths is given below, and had a good correlation coefficient (r-squared) of 0.95.

Standard depth = (0.969623 x depth measured from inside) - 2.43859.

Calculating cross-sectional area

The purpose of the depth estimates was to calculate the cross-section of water flowing through the culvert at any given time. The cross-section was obtained by standard trigonometric relationships (Drexel 2005). The formulae for the relationship are given below, and variables are shown in Figure A4.1. From the formulae, the depth could be calculated for any given width, and the cross-section of water in the culvert could be calculated from any depth. As a check, actual measured depths and widths were obtained simultaneously for various stages of flow, and the relationship agreed with that obtained by the mathematical formulae.

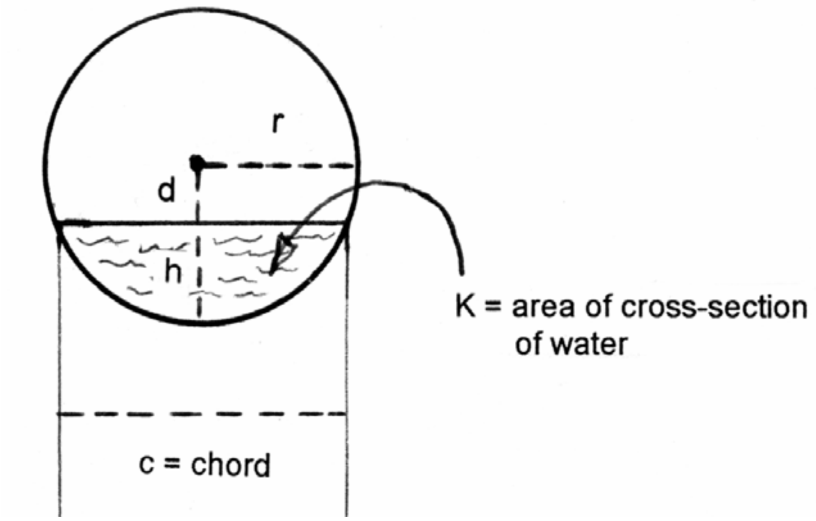

Figure A4.1. A sketch of the cross-section of the cylindrical culvert. The various symbols are shown, as used in formulae for calculating depths and cross-sections.

Symbols:

r = radius of the culvert cross-section = 60 cm
h = height measured for water in the middle of the culvert, in cm
d = distance vertically from water surface to the central point of the culvert cross-section. (Technically, called the apothem)
    d = (r - h)
theta = the central angle, in radians
    theta = 2 arc cos (d / r)
c = chord, that is, the width across the surface of the water in the culvert.
    c = 2r x sin (theta / 2)
K = the cross-sectional area of the water in the culvert
    K = r^2 [theta - sin (theta)] / 2

The values obtained for cross-sections by this formula agreed (of course) with values obtained from measuring areas in a scale drawing of the culvert cross-section.

In those cases where width of the water was measured (i.e. c, the chord), the height and cross-section of water could be obtained by the same set of relationships.

theta = 2 x arc sin [c / (2r)]
d = r x cos (theta / 2)
h = r - d
K = r^2 [theta - sin (theta)] / 2

Velocity for any given stage of flow

The velocity of the water through the culvert was measured by timing a flexible coloured float (red surveyor's tape) through the 9.75 metres of the culvert. Two people carried this out, one at each end of the culvert. One person dropped the float upstream, started a stopwatch when it entered the mouth of the culvert, and warned the second person that the float was coming. The downstream person gave a shout when the float reached the downstream edge, so that the upstream person could stop the timer.

This procedure was repeated several times on any given occasion, and the average time was used to calculate apparent velocity. This was done at a variety of high and moderate flows on 24 days. At low flows, the float tended to get sidelined and slowed down or even stranded. The slower velocities at low flows were therefore measured by the travel of a float at the upstream end of the culvert, over a 2-metre course from 1 metre inside the mouth of the culvert to 3 metres inside. That excluded any effect from the small standing waves near the mouth. This procedure allowed the investigator to watch that the float stayed in the centre of the channel, and to abort any measurements in which the float became stranded.

Using the average measurements of velocity at various stages of flow, a regression was calculated. This estimated velocity (the dependent variable) as a function of water depth in the culvert (the independent variable). The equation was:

Velocity, cm/sec = (114.355 x log of depth in cm) - 7.73591

A correction is necessary for such estimates of velocity. The measurements of velocity were made in the central, surface flow through the culvert. However, there is a drag on the velocity of water in contact with the walls of the culvert or near the walls. There are established formulae for estimating average velocity and there are established correction factors for various types of surfaces, including corrugated culverts ("Manning's coefficient"). A factor of 0.8 was used for correction of velocity in this study. That value is suggested by FAO (1993), and University of Washington (2005).

The factor 0.8 was applied to all 146 estimates of velocity and the resultant values were used in analysis.

Accordingly, estimating the flow from a measurement of depth was a simple process. The cross-sectional area and the corrected velocity were obtained from the regression. Multiplying the two values together yielded an estimate of volume of flow which could be expressed as L/sec or m^3/day.

Interpolation of flows

As mentioned, estimates of discharge were available for 146 days throughout the year, usually daily at times of changing flow or high flow. During periods of gradually decreasing flow, measurements were made at intervals of about one week. During those periods, interpolations between measured flows were made graphically, to obtain daily values. The technique was to fill in the blanks on a graph such as the one for December shown in the main text as Figure 3. Generally, a rise in flow followed any appreciable rainfall during the preceding 24 hours. Then if there was no further rainfall, the flow dropped off quickly at first, then more and more slowly as it tapered off into a stable flow or a slow steady decrease. The "descending limb" followed a pattern of logarithmic die-away.

The creek flow throughout the year is shown in Figures 4a and b of the main text. The measured and interpolated values are shown in Appendix 1.

Generalities on accuracy. The estimates of flow (and P runoff) can be taken as good approximations of the true values. Even if measurements were daily, changes in the creek would be faster. Increased streamflow might commence within an hour of the start of a rainfall event (Howard 2006). Thus it is unlikely that our measurements caught the exact peaks of flow during most freshets. Still, the important freshets during the wet season lasted for days (Figure 4a, b) and the sampling and measurements would reflect those major changes. Also, the opposite situation could prevail; a measurement of elevated flow could be made in the morning, then the flow and P concentration might drop off during the afternoon and evening.

Accordingly, our estimates of flow and phosphorus runoff are taken as realistic but not exact.

Failure of mathematical methods of fitting flows. An attempt was made to define some mathematical relationship or regression that could be applied objectively to the descending limb of a given freshet, in order to estimate the following daily flows. The attempt was made using fairly complete data for the declining flows over 18 days of no rainfall after the peak of a particular freshet. These were data collected from the same culvert in October of 2003. A linear regression of logarithm of flow on the logarithm of time proved to be a near-perfect simulation of the actual decline in flow. That regression had been constructed using only two measurements, the first one just after a freshet, and another one after an 18-day gap. The intervening six measurements were ignored in developing the mathematical model. The resulting regression simulated those actual measurements very well, with the predicted flows averaging only 0.5% higher than the actual measured flow. However, this particular regression and this general mathematical approach, did not prove to be applicable to other occasions. The regression failed to produce fits to the flows following other freshets that occurred during the 2004-5 study. Other types of semi-logarithmic or arithmetic relationships were found to be completely unsuitable for predicting the declining flows; they gave major over-estimates.

Advice was sought from two hydrologists. They confirmed that there was no standard method of filling in data between measurements, and no particular method could be recommended. It was clear that professionals in this field normally work with continuous measurements or very frequent ones. As would be expected from a specialist, they recommended much more intensive study of the hydrographs. There was some support for using a semi-logarithmic plot for simulating the descending limb of a freshet. Their advice was freely given and of general usefulness in the interpretations (Cooper 2006; Howard 2006).

Extreme flow and partial collapse of the culvert. There was a period of heavy rain and snow-melt from January 17 to 23, which caused high creek flows. The storm brought a 29-year record high temperature for January of 16.7 degrees (Aston 2006). The ensuing fierce flows of January 18 to 20 culminated in erosion of the downstream shoulder of Blackburn Road at the culvert, with sinking of the downstream side of the road, and a break and droop of the downstream third of the culvert (angle about 10 degrees). The shoulder and road were temporarily repaired a few days later. Accordingly, from January 20 until the end of the study, only the upstream portion of the culvert was used for measurements, since it had not been seriously disturbed. (After the end of this study, a new culvert was installed at the same location.)

Evidence is given in section 6 that the flooding associated with this rain and creek flow represented a once-in-a-decade event.

APPENDIX 5. PHOSPHORUS CONCENTRATIONS

Kinds of phosphorus and relevance to Blackburn Creek

The kinds of phosphorus measured are outlined in the main text at the beginning of section 5. The phosphorus in Blackburn Creek would have been present in a variety of chemical forms. The P would always be combined with some other chemical element or elements to form a chemical compound. (Elemental phosphorus would not be present because it is a violent oxidizer, and would quickly react with some material.) Some of the phosphorus in water can change fairly quickly from one form to another. If it changes to a dissolved phosphate, it becomes very bioavailable. An algal cell or some other organism would quickly snap up such available phosphate, which is always in short supply. The possibility that many forms of P could change to a readily available form such as phosphate is one reason for measuring the total phosphorus.

As stated, total phosphorus (TP) was measured in each of the samples over the year. The total dissolved phosphorus (TDP) was only measured in 22 of the samples, mostly because of funding limitations. Most analyses of TDP were at times of freshet in the creek, with a few of them at times of quiescent flow.

The chemical test for TP tends to include phosphorus that is fairly well bound to the bigger particles, and much of it might not be available to algae according to some studies (Ellis and Stanford 1988; Hatch et al. 1999). Apparently, the bioavailability of particulate phosphorus (PP) depends very much on the types of particles that are being considered, and the coarser, sand-like inorganic particles have the least bioavailable P. Despite this, the mathematical procedures for evaluating enrichment of a lake by phosphorus operate on TP; those procedures were intended to allow for the usual overall availability of the nutrient (Dillon and Rigler 1975).

Particulate phosphorus rises in concentration during freshets, because of the fine solids that are picked up and carried by the rushing water. This would include sediments that had previously settled out on the bottom of the creek, and particles of decomposing organic material. Most notably, in bigger freshets there could be silt from erosion of creek banks and also erosion runoff from the land, especially land that has lost some or all of its vegetation. The more violent the rainstorm and runoff, the more particulate matter is likely to be entrained, and so the particles are likely to be coarse ones. Thus, in bigger runoff events, it is likely that lower proportions of the TP would be bioavailable.

Chemical analysis

Chemical analysis was done by MB Laboratories Ltd. of Sidney B.C. Initially, samples were analyzed by ICP (inductively coupled plasma spectrometry) with a detection limit of 10 μg/L. For samples showing concentrations near that limit or below it, the analysis was repeated using a more sensitive process called *Technicon*, with a reported sensitivity of 0.3 μg/L. Early in the program, when it was clear that many samples in the batch would have relatively low concentrations, a switch was made and all samples were measured by Technicon.

Accuracy of analyses was controlled by a standard or reference solution which the laboratory ran with each batch of samples. Standard deviations were reported and were more than satisfactory.

More revealing is the precision of analyses, which proved to be excellent compared to the usual precision in chemical surveys of substances at very low concentrations. This was checked by sending twelve sets of “blind” replicates to the laboratory. These were two, three, or five samples filled from the same well-mixed container of creek water. The location for one of the samples was correctly identified in the list sent to the laboratory. The other sample or samples was/were given fictitious name(s) and placed in diverse sequence in the list of samples sent to the laboratory. (This was done during surveys of several creeks and lakes in the watershed (Sprague 2007d, e)).

The analyses of these blind duplicates and replicates were as follows (vertical sets):

13.5	14.3	17.3	18.6	19.9	27.5	32.5	35.9	51.6	60	65.6	127
14.0	14.8	17.7	19.1	22.4	28.8	33.3	36.1	52.8	64.1	68.8	150
	15.1	18.3	19.2	24.9			37.3	54.6			
	15.3										
	15.4										

The average coefficient of variation is 4.2% for the twelve sets of data. The smallest and largest coefficients are 1.6% and 11.7%. This shows excellent analytical performance in unannounced trials.

The B.C. Ministry of Environment has made many more measurements of P in surface waters than any other group, and that applies also to the Cusheon watershed. It is important that the present measurements should be comparable to those of the ministry. Through the sponsorship of Deborah Epps, of the stewardship program of the Ministry of Environment in Nanaimo, a comparison of measurements was made. A single sample from Roberts Lake in the Cusheon watershed was split into six replicate standard sample bottles. Three were sent to MB Labs within a regular shipment. The other three replicates were immediately sent in a cooler to Maxxam, the analytical laboratory used by the Ministry. All the samples were given assorted false names so that the laboratories would carry out "blind" analyses, without knowing of the replication. TP measurements by MB Labs were 18.6, 19.1 and 19.2 ppb, and by the Ministry lab: 21, 22 and 23 ppb.

The results are satisfactorily similar. The Ministry values average 16% higher than those from MB Labs. The two sets of values are not statistically different (t-test). We conclude that the phosphorus concentrations found in this study are equivalent to the findings in surveys by the Ministry.

APPENDIX 6. PHOSPHORUS LOAD AT THE CULVERT

The total load of phosphorus passing through the Blackburn culvert in a year was 68.5 kg. That is the sum of all the estimated daily loads given in Appendix 1.

The January run-off event

The nine days of January 17 to 25 represented very high flows in Blackburn Creek (Appendix 1, Figure 4a). It is argued here that the scouring flow of water carried very large particles of sediment downstream, and that phosphorus attached to those particles, or contained in them, was measured in the chemical tests, but most of it would probably not represent nutrient that was available to organisms in downstream lakes.

This storm run-off might have been a ten-year extreme, judging by effects on Salt Spring roads. The partial washout of Blackburn Road and collapse of the culvert are outlined in Appendix 4. Those are not every-year events. In addition there was unusual flooding of main highways to the point of stopping traffic where the lower part of Blackburn Creek crosses the Fulford-Ganges Road. The design of the culvert at that place was apparently inadequate for this unusual event and it was later replaced. There was similar flooding along other waterways of the island. This massive rainfall, snow-melt and flooding is considered here to represent a once-a-decade event. It had been nine years since there had been such major road flooding and erosion, resulting at that time from a record one-metre snowfall overnight, followed by melting.

We do not have satisfactory records of flows in a nearby creek, to place this event in a historic perspective. There are historic records for Cusheon Creek at the outlet of Cusheon Lake, but they ceased in 1998, so there are no data for 2005 to compare with past measurements. We do not know of any such flow records that are continuing to be made on Salt Spring Island. It is unfortunate that governments abandoned the Cusheon Creek measuring station, and many others, in recent decades.

The past records of flow in Cusheon Creek are available (www.wsc.ec.gc.ca/hydat/H2O/) but they are not in a daily form that allows an estimate of frequency for large peak flows. One comparison can be made, by pro-rating the Cusheon Creek and Blackburn culvert flows for the relative areas that they drain (see Table 1). If that is done, the average maximum flow in a year, at Cusheon Creek, is just one-third of the maximum observed at the Blackburn culvert in January of 2005. (The Blackburn peak of 665 litres per second on January 22 scales up to 1,540 L/sec on the basis of drainage areas. The average yearly maximum flow for 25 years of data in Cusheon Creek is 504 L/sec which is just about one-third of the Blackburn peak in 2005.)

A less satisfactory way to assess the January event is to compare the rainfall with historic records. Section 3 mentioned that in 2005, January precipitation was 46% higher than the long-term average for January at the same location (column 5 of Table 2). Comparing the January 2005 value to monthly records at the Environment Canada location, it is exceeded by only three January values in 22 years of records (Environment Canada 2006). A better comparison would tabulate 9-day totals for heavy rainfall over past years. That would require scrutiny of daily records over decades, and has not been done for this report.

An important aspect of this unusual event in January is that much of the phosphorus carried downstream was probably associated with large particles, and much of it was probably bound tightly enough that it had little availability for algae and other organisms. The main text (pages 23 to 25) indicates that with larger suspended particles, the phosphorus can be reactive in the chemical test but not bioavailable. There is no question that large particles were being carried by the creek, from field notes taken at that time.

Many or most of the large particles would probably have settled out quickly at the first place where the creek broadened and reduced its velocity. If not before, they would likely have settled in the marshy area of emergent vegetation at the edge of Blackburn Lake where the creek enters. There would have been a layering (burying) action to remove much of the silt from any contribution of nutrient to the water. The large particles "can become permanently lost to the lake sediments" according to Brett et al. (2005).

The situation is further explained by Brett et al. (loc. cit.) from their study of creeks in Washington state. They say that large particles

> "... will tend to settle out of the water column very rapidly, ... will have relatively low phosphorus content on a per mass basis, and will predominantly contain refractory nonextractable phosphorus (Pacini and Gächter 1999). For these reasons, one can probably ignore the eutrophication potential for phosphorus associated with large-sized particles. Conversely, small-sized particles like clays and silts will settle slowly ... and will have relatively high phosphorus content and more easily extracted phosphorus, especially if from agricultural catchments ...".

Brett et al. (loc. cit.) continue their explanation by citing other research supporting the above statements.

The present report is one of five, all parts of an overall study program which is focused on how much phosphorus reaches Cusheon Lake. *If* the large particles and their phosphorus were settling in quiescent areas where they became unavailable, the load at the Blackburn culvert would not represent phosphorus that was of concern for Cusheon Lake.

This point of view is supported to some extent by measurements made further downstream during the storm event. There were four measurements downstream of Blackburn Lake, below the point where the creek crosses the highway, and only 300 metres above its discharge into Cusheon Lake. Measurements were available there on four days during the event or just after it (January 17, 18, 23, and 26). The load of phosphorus at that point in the creek, near where it discharges to Cusheon Lake, totalled only 3.2 kg, compared to 20.1 kg at the Blackburn culvert. In that period, it appeared that only about 16% of the load at the culvert was passing through Blackburn Lake, on its way to Cusheon Lake (Sprague 2007e). It would be simplistic to interpret this as the complete story, but at least it indicates that the load was not passing rapidly through Blackburn Lake. (Blackburn Lake has a very rapid turnover, with 95% replacement of its water in about a month (Sprague 2007c).

A general conclusion is that the measured phosphorus load at the culvert during the wildest flow event of the year, the nine days in January, might result in only a relatively small contribution of available phosphorus to the downstream lakes. Certainly the event should not be taken as something that would occur every year.

In other words, the 2004-05 load of phosphorus passing the culvert is real, but is

(a) probably far too high as an estimate of lake enrichment, and
(b) is not representative of an average year.

***Using the measurement at the culvert to estimate a land runoff factor*.**
The approach is outlined in the main text. The algebraic calculations are shown here.

Let R be the amount that runs off in kg per hectare.

(a) Roberts output = (the runoff amount multiplied by the hectares, plus the minor additions) all multiplied by the amount not retained by the lake,
$= [\ (R \times 116.5) + 0.605\ ] \times (1 - 0.32248)$

(b) Culvert basin runoff = (the runoff amount multiplied by the hectares of the sub-basin)
$= (R \times 247.5)$

(a) + (b) must equal the load at the culvert = 35.15 kg of phosphorus.

$$\{ [(R \times 116.5 \text{ ha}) + 0.605 \text{ kg}] \times (1 - 0.32248) \} + (R \times 247.5 \text{ ha}) = 35.15 \text{ kg}$$

$$\{ (116.5 \text{ R ha} + 0.605 \text{ kg}) \times 0.67752 \} + 247.5 \text{ R ha} = 35.15 \text{ kg}$$

$$\{ 78.931 \text{ R ha} + 0.40990 \text{ kg} \} + 247.5 \text{ R ha} = 35.15 \text{ kg}$$

$$78.931 \text{ R ha} + 247.5 \text{ R ha} = 35.15 - 0.40990 \text{ kg}$$

$$326.431 \text{ R ha} = 34.74 \text{ kg}$$

$$R = 34.74 \text{ kg} / 326.431 \text{ ha} = 0.1064 \text{ kg/ha}$$

The phosphorus runoff is estimated as 0.106 kg from each hectare, in a year.
Rounding off, the runoff is taken as approximately 0.11 kg per hectare.