Background knowledge of the Cusheon watershed

A review for public meeting of Salt Spring Island Watershed Authority
September 28, 2015
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This report starts at the end; I will fill in the background after that.

The Management Plan of 2007

The plan was triggered by the Cusheon Lake Stewardship Committee as the result of periodic algal blooms and a drinking-water ban because of cyanobacteria (CWMPSC 2007).

The plan gave sources of phosphorus to Cusheon Lake as follows (slight effect of rounding)

Land runoff direct and via upstream lakes	63 kg	= 53.5%
Septic: shoreline residences & modular home park	27 kg	= 23%
Regeneration from sediment	25 kg	= 21.3%
Precipitation, fallout	2.6 kg	= 2.3%
Total	117 kg per year	

The septic component was estimated from best technical knowledge at the time. However, it might be much lower in view of recent findings by Dr. Don Hodgins around St. Mary Lake. If the shoreline residences contributed little, say 5 kg, then the same total loading would require that the estimate of land runoff increased to about 65.5% of the total.

The plan **recommended** that Cusheon Lake should be returned to its near-natural state (low mesotrophic) by eliminating 17 kg of phosphorus loading. The main remedies recommended were preservation and restoration of natural riparian vegetation, along with good practice for land use including reforestation.

Acknowledgements. Where did the data come from? Some from earlier studies by Ministry of Environment and others, but mostly from a year of intensive research by volunteers. These were Cusheon Lake residents Wayne Hewitt, Wiebke and Wilfried Ortlepp, and myself. Research funding of $2500 was provided by the Capital Regional District through Water Council, and by Islands Trust. The management plan with recommendations was developed over three years by a group of volunteers and government workers, with much solicitation of public opinion. Funding to publish the plan came from CRD, two societies and two individuals. Results of the Cusheon research findings are in five reports (Sprague 2005a, b, c, d and 2009).

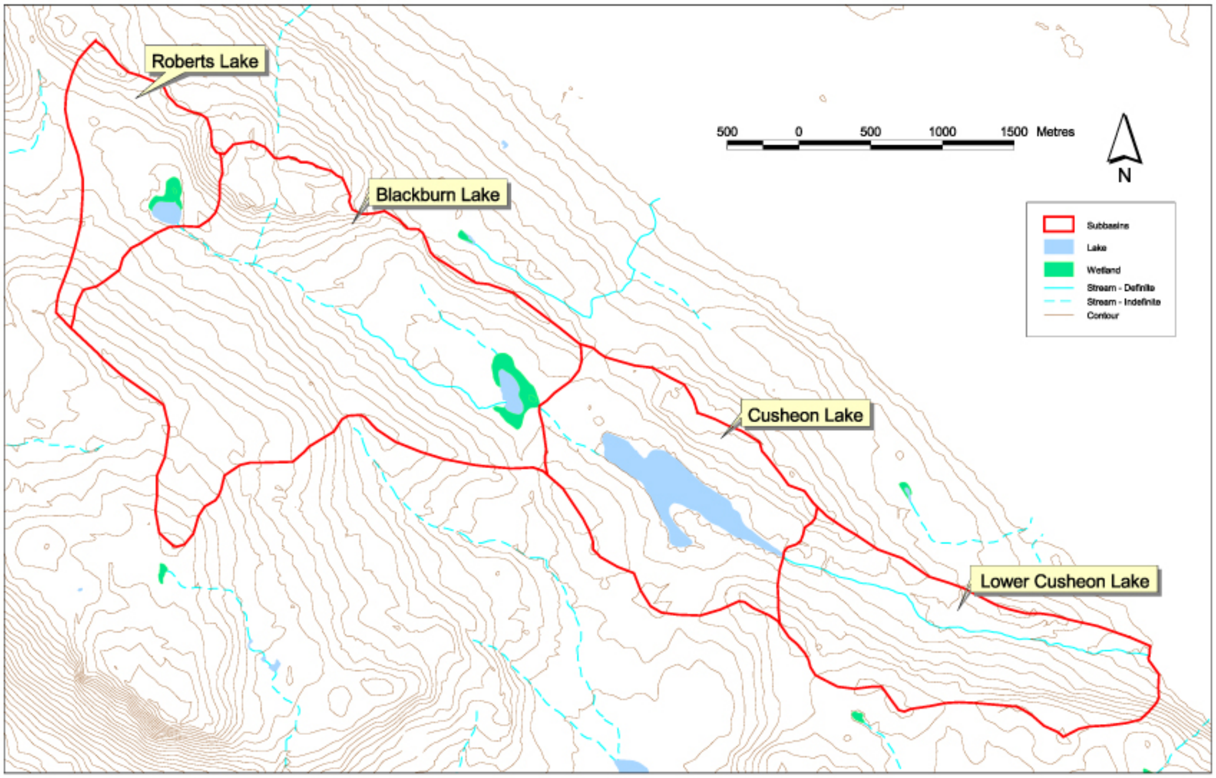

Figure 1. Drainage basins of the Cusheon system.

Existing Information

Watershed sizes were determined by Brett Korteling of Islands trust in Victoria (Figure 1)
Sizes of lakes were those reported by the Ministry of Environment.
Rainfall data came from the precise records of Robert Aston (2006) at Douglas Road, 3 km north of Blackburn Lake (daily values and historical yearly average 980 cm).
Evaporation from lake surfaces was taken as 0.713 metres per year, from an estimate for St. Mary Lake by Bob Watson (2006) for North Salt Spring Watershed District.
Water runoff from land was taken as 48% of the annual precipitation, the robust average of eleven estimates by earlier workers
Outflow from Cusheon Lake had been measured for an earlier period. I used the above values for rainfall, runoff, and evaporation to calculate the flow cascading from the Roberts watershed down to the Cusheon outlet. The first run of calculations gave an outflow estimate within 2% of the earlier measured average, lending confidence to the adopted values.
Phosphorus in rainfall was obtained from the literature and by contacting experts.
Phosphorus concentrations in the lakes were those measured over the years by the Ministry of the Environment, plus our own sampling of Roberts Lake. They all averaged 16.3 to 16.7 ppb, indicating mesotrophic conditions. The pre-colonial average in Cusheon was 13.5 ppb according to analysis of fossils.

Estimating phosphorus runoff from the land.

The Cusheon watershed was not pristine. Only 13% was estimated to be in its natural state. There was logging and disturbance above Roberts Lake, a clearcut hillside by Blackburn Creek, siltation from road construction, and shoreline abuse on Cusheon Lake.

It was crucial to assess how much phosphorus (P) was washed from the land into the creeks and thence to the lakes. This was estimated by a mathematical model called the "Lakeshore Capacity Model", state-of-the-art and developed by Canadian limnologists for the Ontario cottage country.

Both Roberts and Blackburn lakes were excellent for making such an estimate because the shorelines had not been developed. They both provided ideal research setups. The only inputs of P to Roberts Lake would be rainfall (known), bottom sediment (estimated by the model), and land runoff (the unknown that was to be determined by the model). The only inputs to Blackburn would be the same three sources, plus the overflow from Roberts Lake.

In the example of the model (Figure 2), the first eight lines are for physical characteristics of the lake that are known or can be calculated (volume, surface, depth, etc). The only thing not known is the amount of P coming from the land. Like all models, if you know all the variables except one, you can estimate that one using the model. So by trial and error, various values were entered for land runoff until the model predicted the actual (observed) concentration in the

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V = Volume of lake =	140,000	cubic metres
Q = outlet discharge per year =	520,372	cubic metres
Ao = area of lake = 3.4 hectares =	34,400	square metres
Ad = area of watershed including lake = 119.9 hectares =	1,199,000	square metres
Ad2 = area of watershed without lake = 116.5 hectares =	1,164,600	square metres
r = runoff = Q/Ad = 520,372 / 1,199,000 =	0.43401	metres / year
qs = areal water load on lake = Q/Ao = 520,372 / 34,400=	15.127	metres / year
Tw = turnover time = V / Q = 140,000 / 520,372 =	0.2690	years
Rp = retention coefficient of P in lake = 7.2 / (7.2 + qs) =	0.32248	
JA = input of P by direct human activity = 2 x 2.2 x 0.6 x 0.26 x 0.33 kg =	0.227	kg / year
JN = input of P from sub-basin land = 116.5 x 0.09909 kg =	11.540	kg / year
JPr = input of P from precipitation to lake surface = 3.34 x 0.11 kg =	0.378	kg / year
Total input	**12.14**	**kg / year**
Loading = (JA + JN + JPr) / Ao = (Total input) / 34,400 =	0.3531	gm / m2 ˆ yr

Predicted P concentration in ice-free season = [Loading (1 – Rp)] / [0.956 x qs]
= [(0.3531) x (1 – 0.32274)] / [0.956 x 15.127] = 16.540 ug/L
= 16.5 ppb

Figure 2. Calculations to estimate the land runoff of phosphorus into Roberts Lake, using the Lakeshore Capacity model.

lake. The process was done for Roberts Lake, then for Blackburn Lake. The two estimates were 0.099 kg and 0.079 kg of P per year, from each hectare of land. The values are in reasonable agreement, so an average of 0.089 was adopted for the management plan.

Phosphorus runoff from the land could now be calculated for each lake and the total watershed, with the resulting load to Cusheon Lake.of 63 kg per year.

Predicting concentration of P in Cusheon Lake

All three lakes were included in a new Lakeshore Capacity model, to see if the phosphorus inputs that had been adopted, gave a realistic prediction of P concentration in Cusheon Lake. Sampling by the Ministry of Environment (MOE) had yielded an average value of 16.7 ppb.

Values had been adopted for P in *rainfall* and *land runoff*. The contribution of P from the *bottom sediment* was estimated from sampling data of MOE. (That direct estimate agreed with one that was obtained using the Lakeshore Capacity model.) The contribution from *septic input* of residences near the lake was estimated according to best knowledge at that time. That entailed listing the residences with distance from the lake, including the modular homes on Horel Road.

The first run of the three-lake model predicted an average concentration of 16.8 ppb of P in Cusheon Lake. Whether coincidence or good science, that matched almost exactly the actual average concentration of 16.7. Accordingly, the estimates of sources were adopted and provided the values used in the management plan.

Phosphorus carried by Blackburn Creek

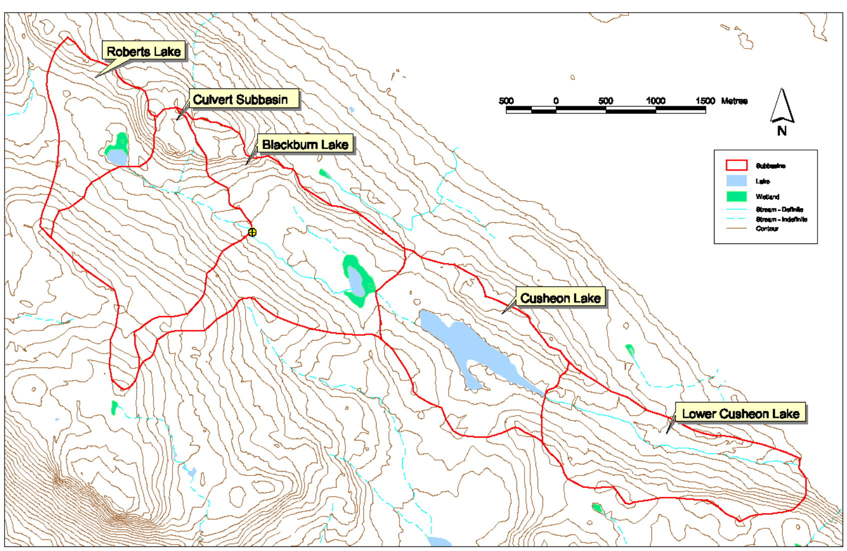

Figure 3. The drainage basin of Blackburn Creek for the sampling point at Blackburn Road. It is the area marked “Culvert sub-basin”, just below Roberts Lake.

By far the most research effort was one year of sampling Blackburn Creek, where it crosses Blackburn Road, well upstream of Blackburn Lake. That sampling point represents the runoff from Roberts Lake, plus an appreciable drainage basin (Figure 3)

The objective of the Blackburn survey was to estimate how much phosphorus was carried by the creek in a year. From that, the P runoff from the watershed land could be estimated. Results showed an extremely complex relationship among P content, recent rainfall, amount of water flow, and season of year. It was clear that any regular sampling schedule (e.g. every 10 days, monthly, etc.) would give an inadequate picture of the amount of P carried by the creek.

We measured P in Blackburn Creek (BB creek) 130 times during the water-year 2004-2005. That is more than once every three days but sampling was not on a regular schedule. Instead, we focussed sampling on periods of increased flow. We rushed to sample on each morning that followed a significant rainfall. Surges of flow were sampled daily, then every two or three days as flow tailed off. During steady or summer flow, sampling was weekly. The objective was to diagnose the high flushes of P, as well as the P during times of lower runoff.

Total phosphorus was always measured. That includes dissolved P and P that is within algal cells or attached to particles. Dissolved P was also measured, but less frequently because of financial constraints. Flow was always measured, and often between P samples. Flow multiplied by concentration yielded estimates of the amount or load of P.

Big changes were documented in the creek and its P concentration. As we all know, the flow increases after significant rainfall and that was documented (Figure 4).

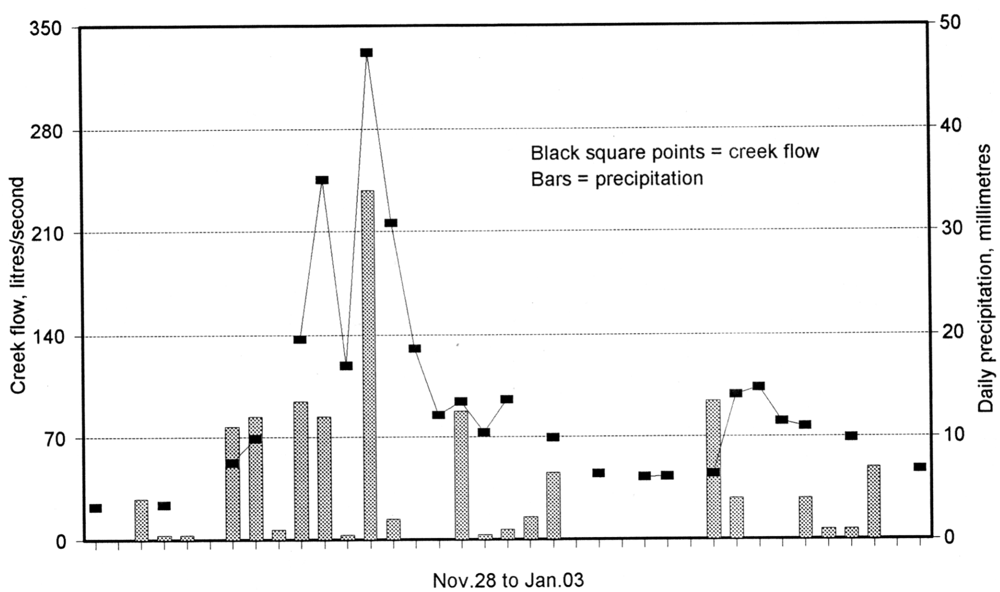

Figure 4. Increased flow in Blackburn Creek (black points) following rainfall events (bars).

As would be expected, P concentration varied with flow (Figure 5). With a big increase in flow after significant rainfall, the P concentration increased greatly. With small increases in flow, the P increase was also small. Notable on the left of Figure 5, the first peak of high flow generated much higher levels of P, than did a second peak of flow that followed close behind. Following the rainfall event, the flow and the P tailed off gradually.

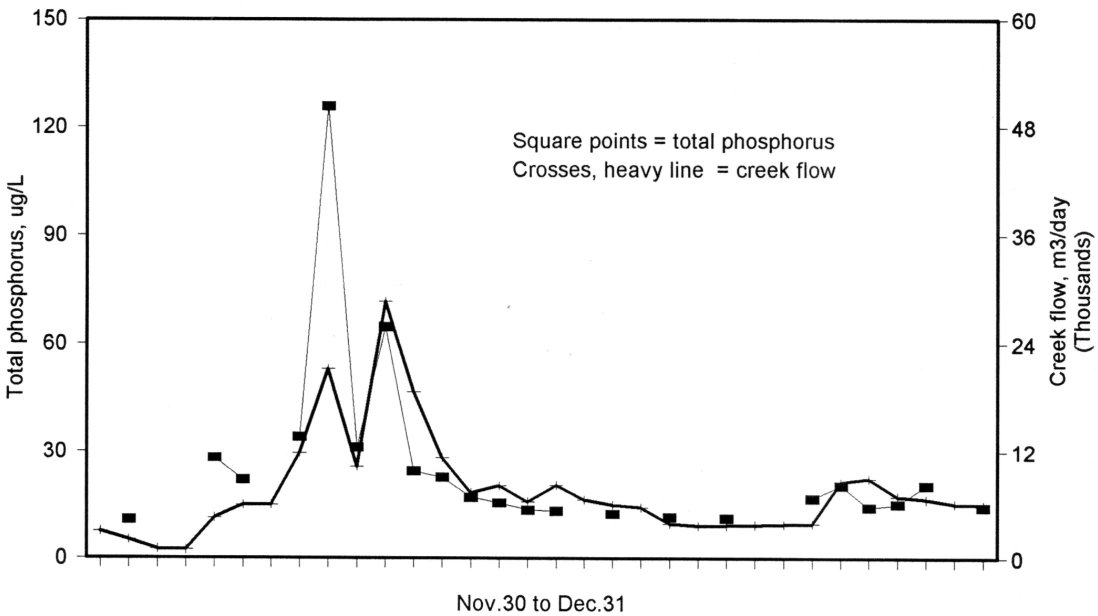

Figure 5. Increase in P content of Blackburn Creek (black points) with elevated flows following rainfall events (line).

Furthermore, there was a huge change in amount of P as related to flow, when the entire year was considered. As the water-year progressed from August through the winter and into the spring and following summer, the amount of P carried by any given flow decreased by an enormous amount. The following little table shows some examples picked from the year of observations on Blackburn Creek.

In August-September:	
P was 40 to 100 ppb at flows of:	300-400 m^3/day
In October:	
P of 30 to 100 ppb occurred at:	1,000-4,000 m^3/day
In November:	
P of 40 to 50 ppb was at about:	11,000 m^3/day
In December:	
P of 10 to 15 ppb occurred at:	4,000-8,000 m^3/day
and P of 60 to 130 ppb occurred at:	20,000 to 30,000 m^3/day

In other words, flows had to be something like 50 times higher in December, in order to produce a P content similar to that found at the start of the wet season. The divergence persisted for the rest of the water-year. Clearly, an adequate picture of phosphorus in the creeks requires judicious sampling over an extended period.

But changes were much more complicated that that. Figure 6 shows that the first runoff event in August of 2004, after the dry summer, had a very high concentration of dissolved phosphorus (about 100 ppb). After that it tailed off with subsequent rainfall events, and settled in a range of about 10 to 20 ppb during the rest of the year. That lower range probably represents water from springs which is thought to be mostly dissolved P. The peak in the first runoff, and elevations for a couple of months after that, might be from decomposed material washed in from the land by the early rains, perhaps including ashes of any burn piles subject to washing off.

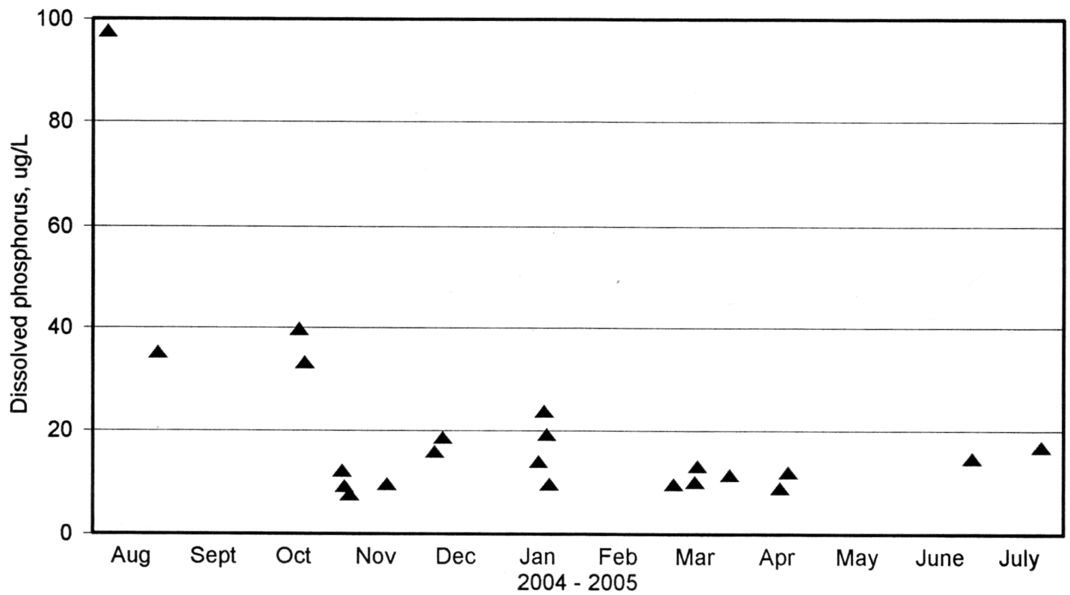

Figure 6. The change in concentration of dissolved phosphorus in Blackburn Creek during the water-year from August 2004 to July 2005. The upper left value at almost 100 ppm is for an unusual first rainfall on August 6.

The situation becomes even more complex when dissolved P as a proportion of total P, is related to flow in the creek. Figure 7 shows that almost all the P is dissolved at very low flows such as those that would prevail during summer. Presumably that represents largely water from springs. At higher flows from bigger and bigger rainfall events, the proportion of dissolved P drops off until at flood events, it is only about one-tenth of the total.

The year-long picture of creek discharge and concentration of total P is given by Figure 8. The general feature of higher P with higher discharge is seen. In general, the peaks of flow and phosphorus correspond. Note that the phosphorus is shown on an arithmetic scale, but the flow is on a logarithmic scale, so the units jump by factors of 10 on the right-hand scale.

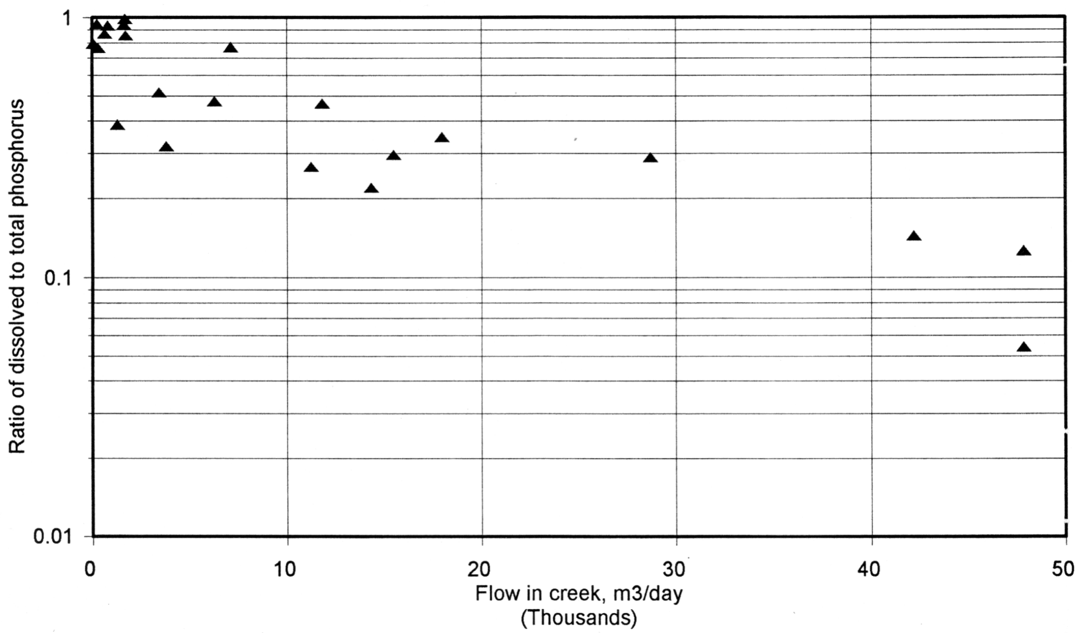

Figure 7. Proportion of dissolved phosphorus as part of total phosphorus, in Blackburn Creek for different amounts of flow.

One adjustment of the data was made. In mid-January there was a huge rainfall which generated at least 20-year flooding, possibly a 50-year event. (The storm resulted in air temperature at an all-time record for January.) Fulford-Ganges Road was closed at Blackburn Lake and other roads suffered washouts. The culvert at Blackburn Road was damaged and was later replaced. Peak flow was equivalent to four large truckfulls of water per minute. The water was running red-brown and was obviously scouring the creek-banks. Measurements further downstream indicated that most of the particulate P settled out in quiescent areas, was not a factor in loading of Cusheon Lake, and was probably unavailable to algae. Since our objective was to document an average or typical year, we replaced nine days of data with values from the second biggest flow of the year, which had occurred in December.

From these data, interpolations were made to provide estimates of phosphorus concentrations and flow of water for every day of the year. Thus the total load of P could be calculated for the year (35.2 kg). Since the P in the outflow of Roberts Lake was known (8.2 kg) as was the area of land draining to our sampling point, it was a simple calculation to calculate the runoff of P from the land. The answer was 0.106 kg of P every year, from a hectare of land. The answer was gratifyingly close to the previous modelling estimate of 0.089 kg/hectare. The slight difference could be almost fully explained by rainfall that was 16% higher than average (Aston 2008). The study at Blackburn Creek was taken as confirmation of the modelling estimate of 0.089 kg/hectare/

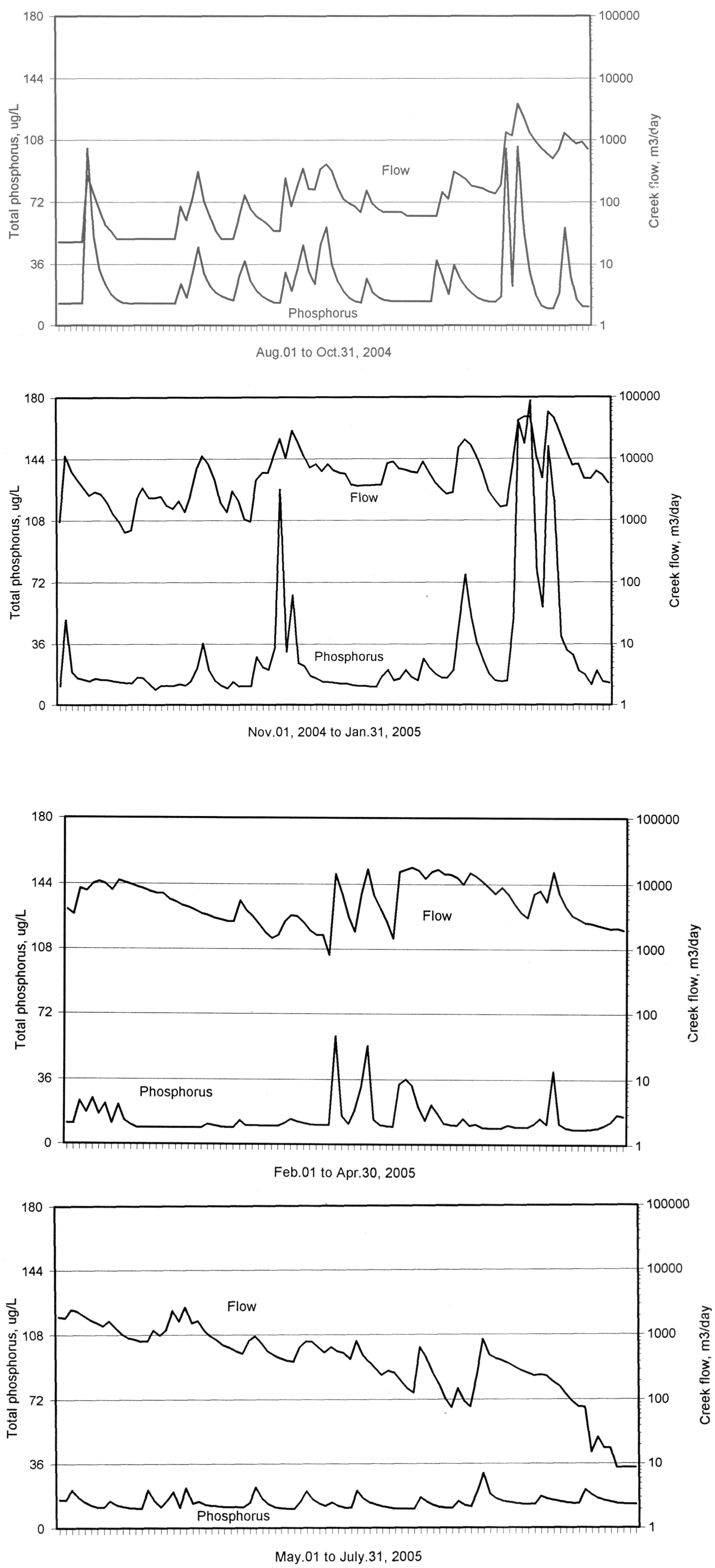

Figure 8. Flow in Blackburn Creek (upper line), and total phosphorus concentraion (lower line), for the water-year 2004-2005.

Sampling of creeks and lakes

We sampled a few other places at times of higher runoff following rainfall. These are shown by the circles in Figure 9. The three small creeks reaching Roberts Lake and two others in the Blackburn drainage were included and showed P runoff that was considered normal. Two points between Blackburn and Cusheon Lakes were sampled to appraise P input from the septic field for the group of modular homes. Six samples were taken in Roberts Lake when the lake was mixed, to establish its P content, since data were lacking.

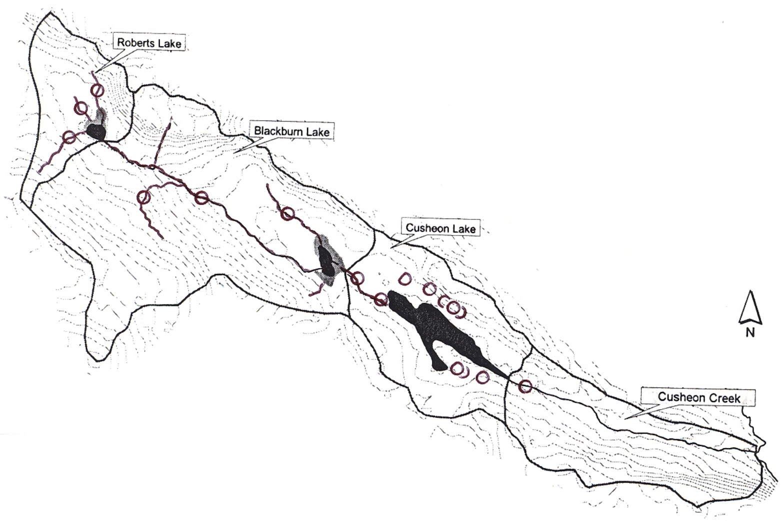

Figure 9. Sampling points at other creeks and culverts.

At eight culverts which guided runoff into Cusheon Lake, more intensive sampling was done during the year, at times when rainfall created appreciable runoff. These locations are shown more precisely in Figure 10.

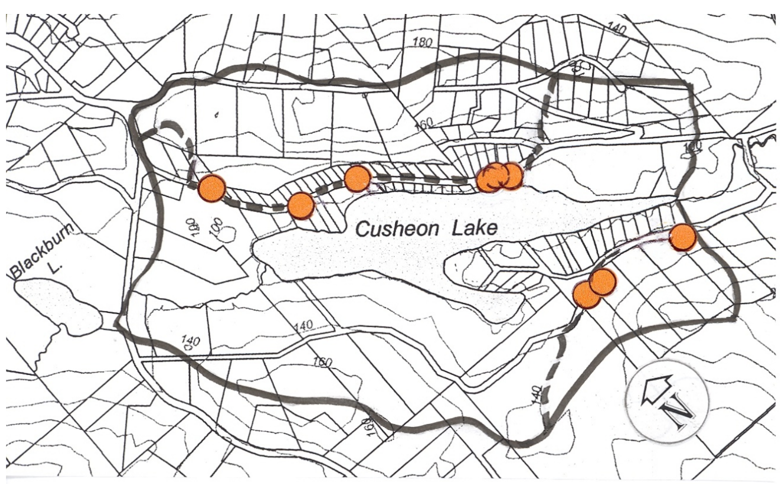

Figure 10. Location of eight culverts sampled after rainfall events. A ninth culvert on the right discharged downstream of Cusheon Lake and was not sampled.

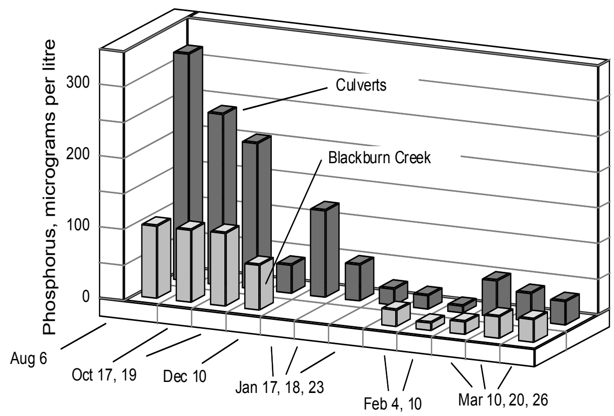

Figure 11. Overall phosphorus concentration in combined discharges from eight culverts draining into Cusheon Lake (black bars), compared to concentration in Blackburn Creek (grey bars)

We assessed P in the culverts during most of the significant runoff events. Figure 11 shows that early in the water year, the overall concentration of P in the culverts was considerably higher than in Blackburn Creek. Later, the culverts were similar in concentration to the creek. Presumably the early runoff from the residences and road allowance around Cusheon carried greater amounts because of the built-up nature of the land and human activities on that land.

Figure 12 shows that for the first runoff events in August and October, the *amount or load* of P in the culverts about equals that in the creek. Later, the culvert load was comparatively small. Totalling the nine events, the culverts carried only 15% of the load conveyed by the creek.

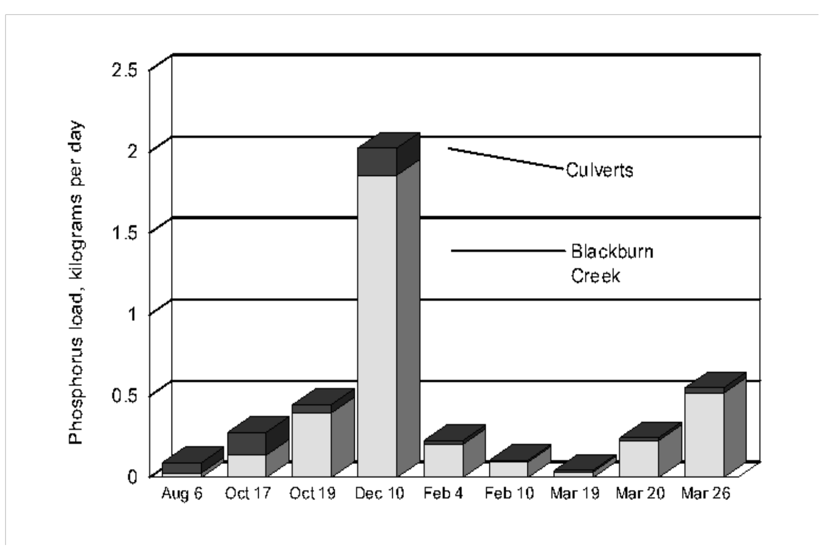

Figure 12. Weights of phosphorus carried into Cusheon Lake by eight culverts (black section) compared to the weights carried by Blackburn Creek on the same days.

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